Regulating Conglomerates: Evidence from an Energy Conservation Program in China*

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Abstract

We study a prominent energy regulation affecting large Chinese manufacturers that are part of broader conglomerates. Using detailed firm-level data and difference-in-differences research designs, we show that regulated firms cut output and shifted some production to unregulated firms in the same conglomerate instead of improving their energy efficiency. To account for conglomerate and market spillovers, we interpret these results through the lens of an industry equilibrium model featuring conglomerate production. We quantify that a $160 social cost of carbon rationalizes the policy and that alternative polices that exploit public information on business networks can increase aggregate energy savings by 10%.
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Balancing economic growth with the negative side effects of industrialization—such as carbon emissions and pollution—is a central problem of governments in emerging economies. Nowhere is this problem more important or consequential than in China. As Figure 1 shows, energy regulation is of national and global importance given that the industrial energy use of China overshadowed that of other leading economies in the early years of the 21st century.

This paper studies the effects of a large program aimed at curbing the energy use of Chinese industrial firms. The regulation that we study—the "Top 1,000" program—targeted the largest energy-consuming firms in the most energy-intensive industries. The regulation was designed following examples of "voluntary agreement" programs in developed countries that relied on the belief that firms could significantly reduce their energy use by improving their energy efficiency. The implementation of the program was adjusted to Chinese institutions and constraints, with the result that in practice, lowering energy consumption became the main regulatory objective.

Understanding the effects of this regulation is central to broader questions of energy conservation. Firstly, this is because the firms regulated by this program accounted for 47% of total industrial energy use in China in 2004. Additionally, as in several developing countries, industrial firms in China are often part of much larger business networks.[1] The sheer size of the regulated firms and their broader networks of related firms imply that a complete assessment of the effects of the regulation needs to account for within-conglomerate and market-level spillovers. Finally, the perceived success of the regulation led the Chinese government to significantly expand the program in later years.

This paper characterizes the effectiveness of the Top 1,000 program by combining difference-in-differences research designs with an industry equilibrium model featuring conglomerate production. Our difference-in-differences estimations show that, relative to unregulated firms in energy-intensive industries, Top 1,000 firms significantly decreased their energy use after the regulation. Regulated firms achieved these reductions by lowering output; we find no impact on their energy efficiency. Using detailed data on business networks and a second difference-in-differences design, we then show that unregulated firms in the same conglomerate as regulated firms increased both output and energy use. This result uncovers an important margin of adjustment that allowed Chinese conglomerates to shift 40% of the output decline in regulated firms to unregulated affiliates. Finally, we provide evidence of market-level spillover effects by showing that unrelated and unregulated firms in more heavily regulated industries increased their output after the regulation. These results corroborate the notion that conglomerates were not able to fully shift production across related firms.

To quantify the aggregate and welfare effects of the policy, we specify and estimate an indus-

[1] Ramachandran, Manikandan and Pant (2013) describe the growing importance of conglomerates in India, China, and Latin America.

try equilibrium model of conglomerate production.[2] The model accounts for conglomerate and market spillovers, matches the estimated impacts of the policy, and clarifies the interpretation of difference-in-differences estimates in the presence of both types of spillovers. We show that the ability of conglomerates to shift production to related firms lowered the shadow cost of the regulation to Top 1,000 firms by 30%. We also evaluate the welfare effects of the program and quantify that the Top 1,000 program improves welfare when the social cost of carbon (SCC) exceeds \$160.[3] Finally, we use the model to simulate the effects of expanding the program to include more firms, to relying on size-dependent and universal energy taxes, and to using public information on conglomerate networks to design conglomerate-level regulations. We find that a conglomerate-level regulation could increase energy savings by 10% for the same welfare cost and would be rationalized by a SCC that is close to that of a universal energy tax.

We develop these results in three steps. As we discuss in Section 1, our first difference-in-differences strategy uses the fact that firms in similar industries that were regulated in later years are suitable controls for Top 1,000 firms. In Section 2, we use an event-study specification to show that regulated firms and unregulated firms had similar trends prior to the regulation. Relative to unregulated firms, Top 1,000 firms reduced their energy use by about 16% in response to the regulation. These estimates are robust to inclusion of industry-by-year and province-by-year fixed effects and of controls for firm characteristics. We also document that these firms saw a decline in output of about 20%, and we do not find meaningful or statistically significant changes in energy efficiency.

Our second set of analyses leverages detailed business registration data to map the conglomerate networks of regulated firms. If regulated firms were able to escape the regulation by shifting production to related parties, we would expect to see an increase in both the output and energy use of firms linked to regulated firms through ownership networks. We test this hypothesis in Section 3 by using a difference-in-differences strategy that compares unregulated but related firms to unregulated and unrelated firms.[4] These analyses show that after the reform, regulated conglomerates shifted production to affiliates that were not subject to the regulation. We estimate an increase in the output of related firms of about 12%; we also find increases in energy use but no effects on energy efficiency.[5] Importantly, we find increases in the economic activity

[2]The Top 1,000 program had the stated goal of reducing industrial energy use to lower emissions that contribute to global warming. While energy use reductions also lower local pollution, pollution reduction was not a stated goal of the program (Price, Wang and Yun, 2010). As a result, our welfare analyses focus on the program's objective to reduce aggregate energy use.

[3]We show that the SCC that rationalizes the policy is bounded between \$112 and \$197 across a broad range of model extensions, including heterogeneous levels of energy efficiency across firms, the possibility that firms respond to the regulation by improving their energy efficiency, and alternative parameters values.

[4]To ensure that these two groups of firms are similar, we use a matching procedure based on pre-regulation characteristics to find a suitable set of control firms.

[5]In Appendix C we show that the program did not significantly shift production to more polluted or populated areas. For this reason, our model and welfare analyses abstract from spatial implications of the policy.

of related firms only when their line of business coincides with the narrowly defined (4-digit) industry classification of the regulated firm. As a placebo test, we show that related firms in other industries did not see an increase in economic activity. Because related firms are smaller than regulated firms, we calculate that conglomerates were able to shift 40% of the output decline in regulated firms to related parties.

Conceptually, firms could respond to the Top 1,000 program in three ways: by increasing energy efficiency, by reducing output, or by shifting production to related parties. The fact that conglomerates adjusted their output allocation but did not improve their energy efficiency informs the cost of different margins of response to energy regulations. Our results are consistent with the notion that costly long-run investments would be required to improve the energy efficiency of regulated firms.[6] Additionally, the fact that regulated firms were not able to fully shift their production to related parties suggests there was no "low-hanging fruit" from a technological perspective (e.g., Allcott and Greenstone, 2012).[7] Consistent with the finding that conglomerates were not able to fully compensate their output loss by shifting production, we estimate market-level spillovers by showing that unregulated and unrelated firms in more heavily regulated industries increase their output as a result of the regulation. These results show that a complete assessment of the effects of the Top 1,000 program must take into account both within-conglomerate and market-level leakage.

In Section 4, we present an industry equilibrium model of conglomerate production that accounts for within-conglomerate spillovers to related firms as well as for market spillovers. We estimate the model in Section 5 by matching moments of the firm size distribution and patterns of within-conglomerate allocation of production prior to the regulation. We then use our reduced-form estimates as out-of-sample validations of the model. The fact that the model does a good job of matching the differences-in-differences estimates indicates that it correctly captures the quantitative importance of within-conglomerate and market-level spillovers.[8] The model further

[6]Since coal is the main energy source for regulated industries, meaningful improvements in energy efficiency would require adopting long-lived industrial machines that rely on electricity. Firms may have been reluctant to do so since coal is abundant and inexpensive in China and due to the government's uncertain commitment to energy saving policies. Zhao, Li, Wu and Qi (2016) discuss a case study of a Top 1,000 firm with old, energy inefficient capital. Even when this firm started the process of adopting new machinery in 2007, gains in energy efficiency did not materialized until 2011 due to construction and installation delays. In a model extension, we consider how long run improvements in energy efficiency impact the aggregate and welfare effects of the policy.

[7]Gillingham, Keyes and Palmer (2018) discuss a number of reasons why firms may under-invest in energy efficiency, including imperfect information, behavioral biases, and market failures. For instance, Anderson and Newell (2004) show that even when US firms obtain information from energy audits, managers expect fast payback periods when deciding to invest in projects that improve their energy efficiency. The ability of firms to escape the burden of the regulation by shifting production to related firms adds to the potential explanations for under-investment in energy efficiency.

[8]Additionally, we show in Section 6 that the model matches the effects of a within-conglomerate differences-in-differences estimation that compares regulated to unregulated firms in the same conglomerate. Since this design absorbs conglomerate and market level spillovers, this result shows the model correctly captures the reallocation of production within business groups.

decomposes our difference-in-differences estimates and shows that accounting for the effect of the program on unregulated firms lowers the effect on regulated firms from 20% to 14%. In contrast, the magnitude of spillovers to related firms increases from 12% to 19%. By combining reduced-form estimates with a structural industry equilibrium model, we are able to evaluate the effects of the Top 1,000 program taking into account spillover and equilibrium effects that are central features of prominent energy regulations.

Section 6 uses the model to quantify the aggregate and welfare effects of the Top 1,000 program. Accounting for market and conglomerate leakage, we calculate that the program reduced aggregate energy use by 4%, an annual decrease of about 48 million tce. A calibration of the social cost of energy-related emissions shows that the program raises welfare as long as the social cost of carbon exceeds $160 per ton of carbon. Using the model, we show that expanding the program by increasing the number of regulated firms or by tightening energy saving targets leads to similar trade-offs. A government facing administrative constraints would thus prefer to tighten the stringency of the regulation rather than increase the number of regulated firms.

The model allows us to compare the aggregate and welfare effects of incomplete regulations, such as the Top 1,000 program, to policies that would be preferable absent political or administrative constraints, such as a universal energy tax. First, we show that the government can increase aggregate energy savings by 10% for the same welfare cost by leveraging publicly available data on the ownership networks of regulated conglomerates. By targeting conglomerates instead of firms, such a regulation would avoid distorting the within-conglomerate allocation of production. Second, the model shows that a conglomerate-level regulation closely approximates the effects of a size-dependent energy tax that applies to all affiliates in conglomerates with Top 1,000 firms. Finally, we find that this size-dependent tax is only slightly inferior to a universal energy tax. These results highlight the promise of using information on the conglomerate networks of large Chinese manufacturers to improve the design of energy regulations.

Finally, in Section 7 we show that our model results are robust to using a wide range of alternative model specifications and parameter values. First, we extend the model to consider the possibility that firms responded to the regulating by improving their energy efficiency. Consistent with our empirical results, we find that firms faced significant costs of improving their energy efficiency. An optimistic calculation suggests that, over a longer horizon, the policy may be rationalized by an SCC of $112. Second, we extend the model to allow for preexisting differences in energy efficiency between regulated and unregulated firms. Assuming that Top 1,000 firms are 20% less energy efficient than all other firms yields an SCC of $133. Finally, we show that our estimates of the SCC that rationalizes the policy are not sensitive to alternative assumptions regarding parameter values and model specifications.

This paper contributes to our understanding of whether energy regulations and interventions

aimed at improving energy efficiency are effective in developing countries (e.g., Duflo, Greenstone, Pande and Ryan, 2013, 2018; Greenstone and Jack, 2015; Harrison, Hyman, Martin and Nataraj, 2015; Ryan, 2018; Ito and Zhang, 2020). In the Chinese context, the government's use of high-powered incentives that tie environmental performance to cadre promotion has been shown to provide a strong mechanism to enforce environmental policies (Kahn, Li and Zhao, 2015; Jia, 2017; He, Wang and Zhang, 2020). In their discussion of recent efforts to curb energy use in China, Auffhammer and Gong (2015) note that the Top 1,000 program along with its expanded version in later years are the "most significant national programs" focusing on energy efficiency and energy conservation. Official assessments of the program that compare over-time variation in energy use of regulated firms concluded that the program was effective, which motivated the expansion of the program. By using detailed firm-level data on treated and untreated firms, our analyses show that regulated firms achieved this decline in energy use by reducing output and not by improving energy efficiency. More importantly, by tracing the effects of the regulation along business ownership networks, our results provide a fundamental reassessment of the effectiveness of the Top 1,000 program.

The result that the Top 1,000 program impacted economic activity in regulated and unregulated firms contributes to the literature studying the economic costs of environmental regulations. In the US, researchers have documented significant effects of environmental regulations on emissions and economic activity (e.g., Greenstone, 2002; Greenstone, List and Syverson, 2012; Walker, 2013; Shapiro and Walker, 2018; Curtis, 2018). Colmer, Martin, Muûls and Wagner (2020) find that French firms that are subject to the European Union's emissions trading scheme do not experience significant declines in production and that their declines in energy do not spill over to unregulated firms. He, Wang and Zhang (2020) show that Chinese firms that face more stringent regulations experience significant decreases in productivity. Our paper contributes to our understanding of the economic cost of energy regulation in China, which consumes the lion's share of global industrial energy.

Researchers have also documented that regulations can have spillover effects along firm networks. For instance, Hanna (2010) finds that multinational firms respond to domestic environmental regulations by increasing their investment in foreign countries, and Gibson (2019) and Soliman (2020) find that firms may also shift economic activity to unregulated plants in counties that are subject to less stringent regulations. Conglomerate spillovers are particularly important in our setting since the Top 1,000 program targeted very large firms with elaborate ownership networks. Our detailed business registration data provide a unique view into how this regulation affected the production decisions of large Chinese conglomerates and how conglomerate spillovers impacted the effectiveness of the regulation. Our model leverages these spillovers to quantify the marginal cost of the regulation, using the fact that conglomerates incur a loss when they distort

the within-conglomerate allocation of production (see, e.g., Anderson and Sallee, 2011).

Our paper also takes into account the roles of leakage and market competition in environmental regulation. Research has shown that emissions leakage to unregulated firms can significantly alter the effects and design of environmental policies (e.g., Fowlie, 2009; Fischer and Fox, 2012; Bushnell, Chen and Zaragoza-Watkins, 2014; Baylis, Fullerton and Karney, 2014; Fowlie and Reguant, 2021). We abstract from strategic interactions between firms in a setting with monopolistic competition since we study manufacturing industries with a large number of firms that compete in national markets.[9] This paper quantifies the aggregate and welfare effects of the Top 1,000 program by combining microdata on the operations of Chinese industrial firms, transparent research designs that identify direct and spillover effects of a prominent energy regulation, and an industry equilibrium model that is consistent with the estimated effects of the program. The combination of these approaches accounts for market competition and leakage effects and shows that conglomerate spillovers are a distinct force that plays a quantitatively important role in the context of China and that feasible conglomerate-level regulations can improve the regulation of energy.

1 Policy Background and Data

This section describes the Top 1,000 energy savings program. We also describe the different datasets that we use to measure economic activity and energy use as well as our strategy to map the ownership networks of Chinese conglomerates.

1.1 The Top 1,000 Program

To save energy and reduce related carbon emissions, the Chinese government's 11th Five-Year Plan (11FYP) set an ambitious goal of reducing the country's energy intensity—defined as energy consumption per unit of GDP—by 20% between 2006 and 2011 (Price, Wang and Yun, 2010). Since the industrial sector accounts for 70% of total energy consumption, the government designed policies that focused on nine energy-intensive industries, which accounted for 80% of the country's industrial energy use. One of these key initiatives was the Top 1,000 Energy Saving Program, which targeted the firms with the highest energy consumption in the most energy-intensive industries.

The Top 1,000 program was first announced by the National Development and Reform Commission in April 2006, and the corresponding monitoring and assessment measures were released in 2007. The name "Top 1,000" refers to the $1,008$ industrial firms in the nine energy-intensive in-

[9]Studies of energy regulation with strategic interaction often focus on concentrated industries (see, e.g., Mansur, 2007; Ryan, 2012; Fowlie, Reguant and Ryan, 2016).

dustries with energy consumption above 180 thousand tce in 2004. The total energy consumption of these 1,008 super-firms was 670 million tce in 2004, accounting for 47% of China's industrial energy consumption and 33% of its total energy consumption. Importantly, since the policy was announced in 2006 and selected firms based on their retrospective 2004 energy consumption, it was not possible to manipulate the list of program participants. Moreover, the list of firms regulated by the program did not change during the five-year period. Table 1 reports the number of firms and their share of energy consumption in each of the regulated industries. Among Top 1,000 firms, those in the iron and steel, chemical, and electric power industries accounted for around 63% of the firms and 68% of the regulated energy consumption in 2005.

The Top 1,000 program was designed based on the belief that Chinese industries could significantly increase energy efficiency at a low cost (e.g., McKinsey & Co., 2009). The program was influenced by voluntary agreement programs in developed countries and had two stated goals: to significantly increase the energy efficiency of these super-firms and to save 100 million tce in energy consumption by 2011. Given the program's quick implementation, many aspects of voluntary agreement programs (such as providing technological expertise or financing energy efficiency improvements) played a relatively minor role (Price, Wang and Yun, 2010). In practice, firms were regulated based on energy use only and not on energy efficiency.

To implement the policy, the central government assigned a target reduction in energy use to each provincial government. In turn, local officials assigned individual energy use quotas to each of the Top 1,000 firms relative to their energy consumption in 2006. These firms were subject to annual energy audits carried out by a third party and also faced potential additional audits from the Ministry of Industry and Information Technology and the National Energy Administration. Leaders of provincial governments and state-owned enterprises were then evaluated on whether these energy saving targets were met. As a result, local government officials monitored and enforced the energy saving targets of Top 1,000 firms very closely.[10] We report the results of the government's annual assessments in Table A.1, which show a very high compliance rate. At the end of the 11FYP, the government estimated energy savings of 165.49 million tce, far beyond the original target of 100 million tons.[11]

Due to this perceived success under the 11FYP, the Top 1,000 program was expanded into the "Top 10,000" Energy Savings Program during the 12th Five-Year Plan (12FYP) in 2012. In

[10]Under the "one-vote veto" criteria, officials would not be considered for promotions or awards if the province or any of the local Top 1,000 firms did not achieve their targets. Similarly, the leaders of state-owned enterprises that did not meet the target did not receive annual bonuses. In interviews with executives of Top 1,000 firms, we confirmed that local officials had the power to stop production at regulated firms if the firm did not meet its energy target. In this way, the Chinese setting contrasts with other developing country settings where the design of incentives for energy auditors plays a key role (e.g., Duflo, Greenstone, Pande and Ryan, 2013, 2018).

[11]While government estimates of compliance may be subject to misreporting (Karplus, Shen and Zhang, 2020), our analyses rely on multiple measures of output and energy use from survey and administrative data that are unrelated to the government's evaluation of the program.

this case, "Top 10,000" refers to 16,078 energy-intensive firms with energy consumption above 10 thousand tce in 2010. These firms account for 60% of China's total energy consumption. As in the Top 1,000 program, firms among the Top 10,000 were required to improve their energy efficiency with a goal of saving a total of 250 million tce during the 12FYP. Our primary analysis focuses on Top 1,000 firms between 2001 and 2011. Since the industrial firms in the Top 10,000 (but not in the Top 1,000) were also energy intensive but were not regulated during the 11FYP, they serve as useful controls for our empirical analysis.[12]

1.2 Firm Data

Our empirical analyses combine several rich datasets that describe firm-level production and energy use. We obtain the list of firms in the Top 1,000 and Top 10,000 programs from the National Development and Reform Commission.[13] We then collect detailed information on firm energy consumption from 2001 to 2010 from China's Environmental Statistics Database (CESD) provided by China's Ministry of Environmental Protection. These data allow us to measure the effects of the regulation on the production and energy use of Top 1,000 and Top 10,000 firms. The CESD data are primarily collected by local environmental agencies and focus on polluting enterprises. These data are subject to audits by environmental protection agencies at both local and national levels and cover the vast majority of Top 1,000 firms and a subset of Top 10,000 firms. Because the CESD reports energy consumption only from primary sources (e.g., coal, oil, gas), our analyses of energy use and energy efficiency exclude firms in industries that rely mainly on electricity.[14] We also restrict the sample to those firms with complete yearly data on coal use. After these restrictions, our estimation sample comprises of 427 Top 1,000 firms, which we observe for an average of 8 years.[15]

We complement these data with two additional datasets. First, we use data on firm characteristics from the Annual Survey of Industrial Firms (ASIF) from the National Bureau of Statistics (2001–2009 and 2011).[16] This dataset provides detailed information on a firm's industry, ad-

[12] An important consideration is whether firms that were later part of the Top 10,000 expected that the Top 1,000 program would be expanded. This is unlikely to be the case since the details of the program were developed after the 12FYP by the National Development and Reform Commission, which did not announce the Top 10,000 program until 2012.

[13] Appendix A describes how we merge these lists with other firm-level datasets.

[14] In practice, we exclude industries where electricity consumption accounts for more than 30% of total energy consumption. As we show below, our results are robust to setting this threshold to between 20% and 50%, or to including firms in all industries.

[15] As we show below, our results are robust to how we construct the sample. We find similar results when we extend the sample by using administrative tax data to fill-in missing values for energy use, or when we restrict the sample to include firms that existed over the whole sample period.

[16] As is well known in the literature, data for the 2010 ASIF display a number of irregularities and are often excluded from statistical analyses. As we show below, our results are robust to using administrative tax data for 2009 and 2010.

dress, ownership, output, and financial information and covers all industrial firms with annual revenue above 5 million RMB (approximately 800,000 USD). These data are also valuable since they cover a large number of firms related to Top 1,000 firms, which allows us to estimate the spillover effects of the program. Second, we also use data from the Annual Tax Survey (ATS) for 2009 and 2010. One advantage of using multiple datasets is that we can cross-check our data to ensure our results are not driven by misreporting or other data quality issues. In Figure A.1, we show that firms report similar output and coal consumption in the CESD and tax data, which are collected independently and are not used to evaluate compliance with energy and environmental policies.

Panel A of Table 2 reports summary statistics for the Top 1,000 and Top 10,000 firms in our sample. Top 1,000 firms are larger, older, more likely to be state owned, and more export oriented than Top 10,000 firms. This table also shows that Top 1,000 firms are slightly less energy efficient (defined as the ratio of output to energy use) than Top 10,000 firms. However, this difference is driven mostly by industry differences, since Top 1,000 firms are more likely to be in energy-intensive heavy industries. As we show below, our empirical analyses are robust to controlling for these firm-level characteristics.

1.3 Mapping Conglomerate Networks

We identify firms' ownership networks using data from China's Administrative Registration Database (CARD). These data are collected by the State Administration of Industry and Commerce and list the registration information of all firms in China starting in 1980, including firm name, registration number, date of establishment, address, ownership, registered capital and related legal persons. Importantly, the data provide detailed shareholder information, which allows us to construct firm ownership networks at multiple levels.

We construct ownership networks using the four types of linkages displayed in Figure 2. First, we include wholly owned subsidiaries of regulated firms as related parties. Second, we include firms that are at least partially owned by regulated firms. We consider firms to be related if they are owned by a regulated firm by up to two levels of investment relations. Although in practice most related firms are fully owned, we require that the regulated firm own at least 25% of the related firm at each level of investment. Third, we include shareholders of regulated firms, and we allow up to two levels of shareholder links. Finally, we also include firms that are fully or partly owned by the shareholders of a regulated firm.[17] We exclude firms that are related only through the state-owned management committee.

Panel B of Table 2 shows that we can identify 46,178 related parties of Top 1,000 firms in

[17]We again allow two levels of investment, and we require ownership to be at least 25% at each level. Figure A.2 depicts all the possible links that we consider.

the CARD. Since a large number of related parties are service firms or small firms not recorded in the ASIF, we match 7,329 firms in the ASIF.[18] In our baseline regressions, we require related firms to be in the same 4-digit industry as a related Top 1,000 firm. Our main sample of related firms includes 2,466 industrial firms.[19] Since it is likely very hard to shift production to firms in other narrowly defined industries, we analyze firms within the same 2-digit industry but outside 4-digit industries in a placebo test. A potential concern with CARD data is that some of the related firms may not be engaged in production and may, in fact, be holding companies. By merging the CARD data with the ASIF and the CESD, we ensure that our results are driven by real economic activity in industrial firms.

Panel B of Table 2 also examines the robustness of our network definitions to alternative assumptions. Allowing for up to six levels of relations does not have a large effect on our sample of related firms in the same 4-digit industry. Decreasing the ownership requirements to 20% has a small effect on the number of related firms, and the number of related parties is similar when we increase the ownership ratio to 51%. These results suggest that within narrowly defined industries, firm ownership networks are very compact. Importantly, our measure of firm networks uses data from 2018, after the policy was implemented. Therefore, our business networks include any firms that may have been acquired by regulated conglomerates as a result of the regulation.[20] Moreover, it is important to note that regulated firms could not escape the regulation by splitting into smaller firms. Since local policymakers face regional energy use targets, they have strong incentives to ensure that any initially regulated firm meets its energy target. If firms split, the energy use targets would accompany the firms after any such separation.

The merged CARD and ASIF data reveal some interesting patterns. First, we find that Top 1,000 firms have an average of 2.45 related parties in narrowly defined industries. Second, since Top 1,000 firms are, in most cases, the largest firms in each industry, their related parties are smaller. On average, the output of related firms is 19.3% of the output of regulated firms. These facts imply that conglomerates may have had significant scope to substitute production across related firms.[21] However, it is also unlikely that related parties could fully make up for production declines in Top 1,000 firms. Third, firms within conglomerates have an interesting

[18] As we discuss below, accounting for spillover effects to firms that are smaller than the threshold required for inclusion in the ASIF does not meaningfully impact the total spillover effect of the policy.

[19] Omitting firms in unrelated industries is unlikely to affect our results since super-firms like Top 1,000 firms would not be able to shift production to service firms or very small firms.

[20] Using the ownership change information in the CARD, we estimate that between 2007 and 2018, less than 4% of related firms experienced significant ownership changes—defined as an ownership transfer of more than 25% to or from firms that are not in the same conglomerate.

[21] In Chen, Chen, Liu, Serrato and Xu (2021), we show that most related parties of regulated firms are located in the same province as the regulated firm. For this reason, we do not expect substitution of production across related parties to significantly affect the provincial distribution of energy use or related pollution. In Appendix C, we also show that the program did not significantly alter the allocation of production across cities with different levels of emissions and population density.

relative size distribution. To produce Panel A of Figure 3, we compute each firm's size relative to the largest firm in the group; we then plot the average relative size by firm rank. A striking fact of this graph is that the average relative size within a conglomerate declines sharply with firm rank: the second-largest firm in a conglomerate is only 29% as large as the largest firm, on average. Interestingly, the decline in relative firm size is almost geometric, a fact that we use in our structural model. Finally, Panel B of Figure 3 shows the relation between the output of the largest firm and the number of firms in a conglomerate. The fact that conglomerates with more firms also have larger leading firms suggests that the number of firms in a conglomerate might depend on technological efficiencies shared by all firms in a conglomerate.

2 Effects of the Policy on Regulated Firms

As detailed in Section 1, the Top 1,000 program mandated that firms reduce their energy use. To study the effects of the policy, we compare the activities of regulated firms relative to those of other large firms operating in energy-intensive industries. Specifically, we use firms that became regulated after 2011 as part of the Top 10,000 program as controls. Because related firms in the same conglomerate as a regulated Top 1,000 firm may be indirectly affected by the policy, we remove these firms from the set of control firms.

The identifying assumption of this difference-in-differences analysis is that absent the Top 1,000 regulation, the energy use and output of Top 10,000 firms would have trended similarly to those of Top 1,000 firms. To provide evidence that these firms had similar trends prior to the implementation of this regulation, we use firm data from the CESD to estimate an event-study analysis of the form:

$$Y_{ijkt} = \sum_{\tau \neq 2006}^{2010} \beta_\tau \times Treat_i \times Year_\tau + \alpha_i + \eta_{jt} + \delta_{kt} + \varepsilon_{ijkt}, \tag{1}$$

where Y_{ijkt} is a dependent variable for firm i in industry j, province k and year t. $Treat_i$ is a treatment group indicator that equals 1 for Top 1,000 firms and 0 for Top 10,000 firms. The coefficients β_τ from this specification represent differences in the dependent variable between Top 1,000 and Top 10,000 firms in each year. Given that the policy evaluation began in 2007, we identify the effects of the policy relative to performance before 2006. We include firm-level fixed effects α_i and year fixed effects in all regressions, and we show that our result are robust to inclusion of (2-digit) industry-by-year fixed effects η_{jt} and province-by-year fixed effects δ_{kt}. We cluster standard errors at the firm level.[22]

[22]While the setting of the Top 1,000 program may seem amenable to a regression discontinuity design, in practice, there are few treated and control firms at the energy use threshold, which makes such an approach unfeasible.

Figure 4 presents a visual implementation of our difference-in-differences estimation strategy. Panel A in Figure 4 displays the β_τ coefficients when the outcome variable is firm-level energy use (total coal consumption equivalent). This figure shows that prior to the implementation of the regulation, our treatment and control firms had similar trends. Additionally, this figure makes clear that the policy did indeed succeed in lowering the energy use of regulated firms relative to that of unregulated firms.[23] Panel B of this figure compares these year-by-year effects to the overall trend in energy consumption.[24] As this figure shows, the program successfully arrested the explosive growth in the energy use of regulated firms.

We quantify the effects of the policy by estimating difference-in-differences specifications of the form:

$$Y_{ijkt} = \beta Treat_i \times Post_t + X'_{it}\gamma + \alpha_i + \eta_{jt} + \delta_{kt} + \varepsilon_{ijkt}, \tag{2}$$

where $Post_t$ is an indicator that equals one after 2006. In addition to different fixed effects, some specifications control for firm characteristics X_{it}, which include indicators for state-owned firms and exporting firms, measures of profitability (e.g., return on assets), and firm age. Panel A of Table 3 shows that on average, the total energy consumption of regulated firms decreased by 12%–16%. These estimates are stable across specifications that include different levels of fixed effects and firm controls. To interpret the magnitude of this effect, recall that regulated firms consumed 670 million tce in 2004. Taking the coefficients in Table 3 at face value therefore imply annual reductions in energy use of close to 100 million tce, or about 20% of the total industrial energy use of the European Union.

To discern whether this reduction in energy use was driven by changes in economic activity or in energy efficiency, we now estimate the effects of the program on firm output (i.e., revenue). Panels C–D of Figure 4 show that after the reform, firm output in regulated firms also decreased significantly. Indeed, Panel B of Table 3 reports declines in output of between 10% and 23%, depending on the specification. Accounting for the declines in output implies that the policy had limited impacts on energy efficiency. Panels E–F of Figure 4 show that we cannot reject the null hypothesis that the policy had no impact on energy efficiency. Based on the specification with both industry- and province-by-year fixed effects of Panel C of Table 3, the 95% confidence interval rules out that the policy increased energy efficiency by more than 4%, which is significantly below the government's goal of improving energy efficiency by 20%. Contrary to the hypothesis that there was "low-hanging fruit" to be harvested in terms of energy efficiency,

[23] One potential concern is that our results may be contaminated by mean reversion. Because firms were regulated based on their 2004 energy use, one possibility is that regulated firms had idiosyncratically large levels of energy use in 2004 that reverted to lower levels in later years. As this and other similar graphs show, the outcomes for 2004 are not significantly different from those for 2001–2003, nor do we see large differences from the outcomes for 2005–2006.

[24] For visual clarity, Panels B, D, and F in Figure 4 follow Ohrn (2018) by plotting trends for the control group that have the same average level in the preperiod as the treated group.

our results show that over a period of five years, regulated firms were not able to significantly improve their energy efficiency.

We now explore the robustness of the effects of the Top 1,000 program on regulated firms. First, as we discuss in Section 1, these analyses exclude industries that rely primarily on electricity. Table A.3 shows that our results are robust to excluding more or fewer industries based on their electricity use and even to including all regulated industries regardless of their primary energy source. This table also shows that we obtain similar results when we use tax survey data on energy use to increase the number of firms in our sample. Second, our results are robust to the sample of firms in our regression and to the exclusion of new firms and those that exit during our sample period.[25] Third, one potential concern is that our results may be influenced by other, concurrent policies. Appendix B clarifies that this is not the case by showing that our estimates are independent of the effects of other pollution monitoring policies. As we show in Table A.6, these policies did not significantly impact the operations of Top 1,000 firms, and our results are robust to excluding firms that are part of these other programs. Finally, we explore the potential for heterogeneous effects across industries. Given the small number of regulated firms in each industry, we estimate heterogeneous effects across broad industry groups. Table A.7 shows similar effects of the program across different industry groups.[26]

The effects of the policy on regulated firms paint a picture of mixed success. On the one hand, the regulation succeeded in achieving a meaningful reduction in the energy use of energy-intensive firms. However, this reduction did not come about through a significant increase in energy efficiency, which—while not directly targeted—was one of the underlying intents of the policy. The next section studies whether conglomerates avoided the burden of the regulation by shifting economic activity to related parties.

3 Spillover Effects of the Policy through Ownership Networks

Regulated firms have strong incentives to shift production to related parties. By shifting production, conglomerates can partially offset declines in economic activity in regulated firms. Such shifting also allows conglomerates to comply with the letter of the regulation—if not with its

[25]Table A.4 shows that the effects of the program on regulated firms are robust to narrowing the sample to include only firms that existed before 2006 and after 2010. Table A.5 shows that our results are also robust to using an almost-balanced panel where we require that firms have no more than one missing year in the data. Note that due to the survey nature of the CESD data, our sample is substantially smaller in this case. Nonetheless, these results show that our estimates are not driven by firms entering the sample or ceasing operations.

[26]We also explore the effects of the program on other outcomes. In Table A.8 and Figure A.3, we show that regulated firms experienced a decline in the probability of investing after the regulation was enacted. Additionally, we test the Porter and van der Linde (1995) hypothesis by examining whether firms became more innovative after the regulation. Figure A.4 shows no increase in the filing of patents related to energy efficiency in regulated firms.

intent—without having to invest in potentially costly improvements to energy efficiency.

To measure the empirical importance of conglomerate spillovers, we use CARD data on the ownership networks of regulated firms to identify firms that may have indirectly expanded as a consequence of the Top 1,000 regulation. We then use matching methods to identify control firms that were (1) not part of the Top 1,000 program, (2) not related to a regulated firm, and (3) in the same industry and of similar size (measured in output) in the years prior to the regulation. Using these firms as controls, we then conduct event-study and difference-in-differences analyses using specifications similar to those in Equations (1) and (2).[27] In this setting, the $Treat_i$ variable is now an indicator of whether a firm is related to a Top 1,000 firm. As we discuss in Section 1, we focus our study of spillovers on related firms in the same 4-digit industry as the regulated firm. This restriction follows from the logic that only firms selling products similar to those of the regulated firms may be able to make up for the production decline in Top 1,000 firms.

Figure 5 plots the results of these event-study analyses using ASIF data. Panel A shows that prior to the regulation, related firms had output trends similar to those of unrelated firms. After the regulation, firms related to Top 1,000 firms saw significant increases in output that persisted for several years. The last column of Panel A of Table 4 shows that related firms expanded by 13%, on average, after the regulation. This table also shows that we obtain very similar results across specifications with different levels of fixed effects and with firm-level controls.

To gauge the magnitude of these spillover effects, it is important to account for the number of related parties of each regulated firm and for their relative size. On average, Top 1,000 firms have 2.45 related parties. However, since the average related firm is only 19.3% as large as its regulated counterpart, we calculate that conglomerates could only shift close to 41% of the output decline in regulated firms.[28] This result is informative for a couple of reasons. First, this result shows that conglomerates were not able to fully circumvent the regulation. Second, combined with the null effect of the program on the energy efficiency of regulated firms, this result shows that firms were unable or unwilling to increase their energy efficiency in production processes even if this meant losing profits to competitors.

[27]Specifically, we use one-to-one matching within 4-digit industries based on the Euclidean distance in output levels before the policy. To ensure that matches are comparable to related firms, we drop 5% of observations with the least comparable matches. As we show below, our results are robust to using alternative matching methods.

[28]Using the estimate on related firms from column (4) of Panel A of Table 4 of 12.7%, we calculate that the overall increase in related firms amounted to 6%($\approx 2.45 \times 19.3\% \times 12.7\%$) of the output of regulated firms. This increase is 41% of the comparable 14.5% decrease from column (4) of Panel B of Table 3. We consider the sensitivity of this estimate to the measurement of business networks in three ways. First, using estimates from the specifications in columns (3), we obtain an estimate of 27%. (*i.e.*, $27\% \approx 2.45 \times 19.3\% \times 11.8\%/20.4\%$). Second, supposing that regulated firms had an average of 3 related firms, spillovers would account for 51% of the output decline in regulated firms. Finally, we consider the role of related firms that are not in the ASIF. To obtain an upper bound of the importance of these firms, we assume that their output matches the size threshold of 5 million RMB for inclusion in the ASIF. Even in this case, the 3,081 related firms in the same 4-digit industry can at most account for 0.21% of the conglomerate's output. For this reason, our spillover calculation is largely unaffected by firms that are not in the ASIF.

The result that related firms display an increase in economic activity is robust to a number of checks. First, we show that we obtain similar results when we use the entropy balancing method of Hainmueller (2012) to find controls for related firms (see Figure A.6 and Tables A.9–A.10).[29] Second, we show that only those related firms operating in regulated firms' own narrowly defined industries—and that could thus possibly produce substitute output—increased their economic activity. Indeed, Panel B of Figure 5 and Panel B of Table 4 show no impact on the output of related firms operating outside the 4-digit industry of the regulated firm (but still in the same 2-digit industry). This placebo test rules out the possibility that firms related to large conglomerates saw increases in economic activity after 2007, say, in response to the financial crisis or other shocks or trends. Third, these results are robust to alternative definitions of ownership networks. Table A.11 shows similar spillover effects when we drop related firms with ownership changes between 2007 and 2018, when we restrict the sample by requiring 51% ownership at each link, and when we expand the sample to include 6 levels of relations and 20% ownership stakes. Fourth, these results are robust to dropping firms in power generation (see Table A.12 and Figure A.7). Finally, we assuage concerns that our results may be affected by data quality issues by showing similar effects when we rely on tax data to measure the output of related firms (see Figure A.8 and Table A.13).[30]

We now explore the potential for heterogeneous spillovers across related firms. Panel C of Table 4 shows that related firms in higher terciles of the size distribution display larger increases in output. This result suggests that larger related firms were more able to expand or, alternatively, that these firms had larger installed production capacity. As in our analysis of regulated firms, we explore potential heterogeneous effects across industries. Table A.15 shows no significant differences in how related firms in different industries responded to the program. Finally, we explore the possibility that the regulation shifted economic production and related emissions to more populated or more polluted areas. As we show in Appendix C, the spillover effects of the regulation do not disproportionately shift production to areas with higher population density or with higher preexisting levels of industrial emissions.

Having established that conglomerates shifted output across related parties, we now explore whether these firms also saw changes in energy use and energy efficiency. Panels C and D of Figure 5 report these results using data from the CESD. Panel C shows that related firms saw an increase in energy use after the regulation. Panel A of Table 5 shows that energy use in related firms increased by 30%–32% after the regulation. Note that the number of observations

[29]Our estimates of spillover effects are also not driven by the entry and exit of related firms. To find a suitable control, our matching analysis requires firms to have existed prior to 2006. Moreover, because we map business networks in 2018, our estimates include the effects on firms that joined regulated business groups after the program.

[30]We also find positive spillover effects on other measures of economic activity. Table A.14 shows estimates of positive spillover effects on sales, profits, capital and labor (see Figure A.9 for corresponding event studies).

in this panel is smaller than that in Panel A of Table 4. This is because related firms are overall smaller and only the larger related firms are included in the CESD. These larger effects are consistent with our results in Panel C of Table 4 showing larger spillover effects on larger related firms. While the available data include firms across all affected industries, caution is warranted in ascribing these increases in energy use to all related firms. Panel D of Figure 5 and Panel B of Table 5 show that these firms did not experience statistically significant changes in energy efficiency.

Overall, we find robust evidence that conglomerates shifted production across related parties. On average, this shifting behavior allowed conglomerates to recover about 40% of the output reduction in regulated firms. As we show in Section 6, the ability to shift production to related firms diminishes the aggregate energy savings and lowers the shadow cost of the regulation.

Market-level Spillovers

Since related parties could not make up the entire output loss of Top 1,000 firms, other firms in regulated industries may have been indirectly affected by the energy saving program due to reduced competition. To examine this indirect effect of the regulation, we estimate the following difference-in-differences specification:

$$Y_{ijt} = \beta spillover_j \times Post_t + X'_{it}\gamma + \alpha_i + \tau_t + \varepsilon_{ijt}, \tag{3}$$

where $spillover_j$ is the proportion of the total energy saving targets of Top 1,000 firms for industry j in total energy consumption of industry j in 2004. To interpret the coefficient β as the average spillover effect, we normalize the $spillover_j$ variable by the average exposure across regulated industries. Since the variation in the independent variable is at the industry-year level, we do not include industry-by-year fixed effects in this regression. We instead use firm fixed effects and year fixed effects only and we additionally control for overall output and energy use at the industry-year level.[31] Finally, to ensure that market-level spillovers are not contaminated by ownership-network spillovers, we exclude firms related to Top 1,000 firms from this specification.

Figure 6 shows that unregulated firms in industries with stricter regulation increased their output significantly after the policy was implemented. Table 6 shows that across all industries, the average market-level spillover led to a 7%–8% increase in the output of unregulated firms. The regressions in the first two columns of this table include both regulated and unregulated industries. We find similar increases when we include only firms in regulated industries. In this case, the identifying variation is driven solely by differences in regulation intensity across

[31] Note that the variation in $spillover_j$ is absorbed in our previous specifications that include industry-by-year fixed effects. By controlling for industry-level aggregates, the coefficient β in Equation 3 captures the impact of the regulation on the market share of unregulated firms.

industries.[32]

These results yield a couple of insights. First, the findings further confirm our previous estimates that related parties were not able to make up for the full output loss of Top 1,000 firms. Second, a full accounting of the spillover effects of the regulation needs to include both within-conglomerate spillovers and market-level spillovers. Third, a potential limitation of the difference-in-differences analyses is that their interpretation depends on the strength of conglomerate and market spillovers. The next section builds on these insights by proposing a model of conglomerate production. The model clarifies the interpretation of our reduced-form estimates in the presence of market and conglomerate spillovers, computes the aggregate effects of the Top 1,000 program, and allows us to consider the effects of alternative policies.

4 A Model of Conglomerates with Regulation

This section presents an industry equilibrium model of conglomerate production that is consistent with the cross-sectional data patterns and reduced-form responses to the policy of energy regulation. Appendix D provides detailed derivations of the model results.

4.1 Demand and Technology

Our industry equilibrium model draws the structure of product differentiation and monopolistic competition from Melitz (2003). We consider an individual sector with an exogenous aggregate expenditure R. The representative consumer has CES preferences over a continuum of varieties $\omega \in \Omega$:

$$U = \left[\int_{\omega \in \Omega} q(\omega)^{\rho} d\omega \right]^{1/\rho},$$

where $q(\omega)$ represents the consumption level of variety ω and $\sigma = 1/(1-\rho) > 1$ denotes the elasticity of substitution between varieties.[33]

Utility maximization by the representative consumer yields the following residual demand curve for each variety ω:

$$q(\omega) = RP^{\sigma-1} p(\omega)^{-\sigma},$$

where $P = [\int_{\omega \in \Omega} p(\omega)^{1-\sigma} d\omega]^{\frac{1}{1-\sigma}}$ is the aggregate price index.[34]

[32] As with our previous analyses, we confirm that our results are not driven by firm entry. Specifically, in Table A.16, we report similar estimates of market-level spillovers when we restrict the sample to firms in operation prior to 2006.

[33] Since the regulated firms produce raw and intermediate materials, one can view the representative consumer as a stand-in for the downstream industry.

[34] This market structure implicitly assumes that this industry is not characterized by dominant firms that may act strategically. This is a reasonable assumption in our setting since we study manufacturing industries that, even when narrowly defined, feature a large number of firms and that serve a national market.

We define a conglomerate in our model by the presence of a variety ω that can be manufactured by multiple affiliates.[35] Each conglomerate starts with a central producer—the model counterpart of a Top 1,000 firm. Conglomerates have heterogeneous production efficiencies ϕ, which are drawn from the distribution $G(\phi)$ with density $g(\phi)$.

Production at each affiliate i requires capital k_i, energy e_i, and variable inputs l_i. Energy and variable inputs are combined using Leontief technology $\tilde{l}_i = \min\{l_i, e_i\nu_i\}$, where ν_i is the affiliate's energy efficiency. The assumption that energy and variable inputs are perfect complements follows recent work in this area (e.g., van Biesebroeck, 2003; Fabrizio, Rose and Wolfram, 2007; Gao and Van Biesebroeck, 2014; Ryan, 2018).[36] Production at affiliate i is then $q_i = \phi_i \tilde{l}_i^{\alpha_l} k_i^{\alpha_k}$, which is subject to decreasing returns to scale, i.e., $\alpha = \alpha_k + \alpha_l < 1$. The decreasing-returns-to-scale assumption is consistent with the literature on span of control. Intuitively, conglomerates may operate more firms as a way to escape decreasing returns to scale and as a way to share production knowledge ϕ across firms. However, as we show in Panel A of Figure 3, conglomerates are not able to replicate the same scale across related firms. To match this fact, we assume that the productivity of the i^{th} affiliated firm is $\delta^{i-1}\phi$. This assumption can be interpreted as either a limit on the span of managerial control or as a measure of imperfect knowledge-sharing across firms. Finally, each manufacturing establishment incurs a fixed outlay of capital denoted by f. This assumption is motivated by the fact that conglomerates have a finite number of affiliates.

We consider the conglomerate's problem in two stages. Prior to the regulation, conglomerates observe their productivity ϕ and optimally choose the number of affiliated firms n and the amount of capital $\{k_i\}_{i=1}^n$ and variable inputs $\{l_i\}_{i=1}^n$ for each affiliate.[37] After the regulation, since capital is quasifixed, the conglomerate adjusts its variable inputs to maximize profits. We initially assume energy efficiency is constant and fixed (i.e., $\nu_i = 1$ for all firms) but consider costly investments to improve energy efficiency and heterogeneous efficiencies in Sections 7.1 and 7.2.

4.2 Profit Maximization

The conglomerate takes the prices of energy p_e, capital r, and the variable input bundle w as given. Given the Leontief technology, the conglomerate sets $l_i = e_i$ so that the cost of intermediate inputs is $w + p_e$. Holding the number of affiliates n constant, the conglomerate maximizes

$$\pi(\phi, n) = \max_{\{l_i\}_{i=1}^n, \{k_i\}_{i=1}^n} \left\{ R^{1-\rho} P^{\rho} \left[\sum_{i=1}^{n} \phi \delta^{i-1} k_i^{\alpha_k} l_i^{\alpha_l} \right]^{\rho} - (w + p_e) \sum_{i=1}^{n} l_i - r \sum_{i=1}^{n} k_i \right\}. \tag{4}$$

[35] This assumption implies that the outputs of related firms are perfect substitutes. We relax this assumption in Section 7.4, where we allow the outputs of related firms to be imperfect substitutes.

[36] Fabrizio, Rose and Wolfram (2007); Gao and Van Biesebroeck (2014) adopt this assumption from van Biesebroeck (2003) in the context of energy generation. Gao and Van Biesebroeck (2014) study the case of China. Ryan (2018) estimates a production function with energy using data from India and finds that energy and unskilled labor are close to being perfect complements.

[37] Conglomerates can choose $n = 0$, which we interpret as an exit decision.

For a firm i, the first-order conditions for l_i and k_i imply that $l_i = \frac{\alpha_l}{\alpha_k}\frac{r}{(w+p_e)}k_i$. Substituting this expression and comparing the first-order conditions for k_1 and k_i, we obtain the following result.

Proposition 1 (Within-Conglomerate Distribution)**.** *Absent regulation, the inputs and the output of producers in a conglomerate follow a decreasing geometric sequence given by*

$$\frac{q_i}{q_1} = \frac{k_i}{k_1} = \frac{l_i}{l_1} = \frac{e_i}{e_1} = \delta^{\frac{i-1}{1-\alpha}}. \tag{5}$$

The within-conglomerate distribution described in Proposition 1 is broadly consistent with the empirical pattern in Panel A of Figure 3, where the average output of the second-largest affiliate in a conglomerate is less than 30% of that of the largest one and where the output of other affiliated producers in the conglomerate decreases exponentially with their rank i. Equation 5 links this distribution to two model parameters. First, the size gap among affiliates is larger if within-group knowledge depreciation is more severe (lower δ). Second, if firms are closer to having constant-returns-to-scale production (α is closer to one), the conglomerate concentrates more activity in its top producer, which increases the dispersion of the within-group size distribution.

To consider the choice of total capital $K_n = \sum_i^n k_i$, define the conglomerate's total productivity $\phi\Delta_n = \phi[\sum_{i=1}^n (\delta^{i-1})^{\frac{1}{1-\alpha}}]^{1-\alpha}$ and the constant $C_\pi = (1-\alpha\rho)\left[\left(\frac{\rho\alpha_l}{w+p_e}\right)^{\alpha_l\rho}\left(\frac{\rho\alpha_k}{r}\right)^{\alpha_k\rho}\right]^{\frac{1}{1-\alpha\rho}}$. We reformulate Equation 4 using the results of Proposition 1 so the optimal choice of capital K_n solves

$$\pi(\phi, n) = \max_{K_n}\left\{\frac{R^{1-\rho}P^\rho C_\pi^{1-\alpha\rho}}{(1-\alpha\rho)^{1-\alpha\rho}}\left(\frac{\rho\alpha_k}{r}\right)^{-\alpha\rho}(\phi\Delta_n)^\rho K_n^{\alpha\rho} - r\left(\frac{\alpha}{\alpha_k}\right)K_n\right\}.$$

The optimal capital K_n and the firm profits for a conglomerate of size n are then

$$K_n = \frac{R^{\frac{1-\rho}{1-\alpha\rho}}P^{\frac{\rho}{1-\alpha\rho}}C_\pi}{(1-\alpha\rho)}\frac{\rho\alpha_k}{r}(\phi\Delta_n)^{\frac{\rho}{1-\alpha\rho}} \quad \text{and} \quad \pi(\phi, n) = R^{\frac{1-\rho}{1-\alpha\rho}}P^{\frac{\rho}{1-\alpha\rho}}C_\pi(\phi\Delta_n)^{\frac{\rho}{1-\alpha\rho}}.$$

Consider now the optimal number of affiliates. The conglomerate adds an affiliate if

$$\pi(\phi, n+1) - \pi(\phi, n) - fr = R^{\frac{1-\rho}{1-\alpha\rho}}P^{\frac{\rho}{1-\alpha\rho}}C_\pi \times \left[(\phi\Delta_{n+1})^{\frac{\rho}{1-\alpha\rho}} - (\phi\Delta_n)^{\frac{\rho}{1-\alpha\rho}}\right] - fr > 0. \tag{6}$$

Adding a new affiliate can improve the conglomerate's revenue and profit by lowering its overall marginal cost curve. On the other hand, the conglomerate incurs a fixed cost of fr when adding a new affiliate. While the marginal benefit of adding a new affiliate is increasing in ϕ, it is also decreasing in the number of existing affiliates n. Since the fixed cost is the same for all affiliates, Equation 6 guarantees the existence of a cutoff value ϕ_n, where conglomerates with efficiency $\phi > \phi_n$ operate at least n affiliated producers.

Proposition 2 (Optimal Conglomerate Size)**.** *Without regulation, the optimal number of firms in a conglomerate n is nondecreasing in its fundamental efficiency ϕ. For $n > 1$, a conglomerate*

chooses to have n affiliated producers when $\phi_n \leq \phi < \phi_{n+1}$, where

$$\phi_{n+1} = \frac{(fr)^{\frac{1-\rho\alpha}{\rho}}}{R^{\frac{1-\rho}{\rho}} P C_\pi^{\frac{1-\rho\alpha}{\rho}} \left(\Delta_{n+1}^{\frac{\rho}{1-\rho\alpha}} - \Delta_n^{\frac{\rho}{1-\rho\alpha}}\right)^{\frac{1-\rho\alpha}{\rho}}}. \tag{7}$$

Let $\pi(\phi) = \max_n \pi(\phi, n) - nfr$ be the profit for a conglomerate of efficiency ϕ at the optimal number of affiliates. The prediction from Proposition 2 is consistent with the observation in Panel B of Figure 3 that conglomerates with higher efficiency have, on average, a larger number of affiliated firms.

4.3 Equilibrium and Welfare

The unique equilibrium of the model is characterized by product-market clearing, the zero cut-off profit condition, and the free entry condition.

With M denoting the mass of active firms, the aggregate price index is given by

$$P = \left[\int_{\phi_1}^{\infty} p(\phi)^{1-\sigma} \frac{g(\phi)M}{1 - G(\phi_1)} d\phi\right]^{\frac{1}{1-\sigma}}. \tag{8}$$

Conglomerates operate whenever

$$\pi(\phi) \geq 0 \;\Rightarrow\; \phi \geq \phi_1 = \frac{(fr)^{\frac{1-\rho\alpha}{\rho}}}{R^{\frac{1-\rho}{\rho}} P C_\pi^{\frac{1-\rho\alpha}{\rho}}}. \tag{9}$$

Equation 9 shows that only firms with $\phi > \phi_1$ choose to participate in the market.[38]

To enter the market, an entrepreneur pays an entry cost rf_e. Upon entry, the efficiency of the conglomerate ϕ is realized. Since the conglomerate operates only if $\phi > \phi_1$, the free entry condition is given by

$$\int_{\phi_1}^{\infty} \pi(\phi) g(\phi) d\phi - rf_e = 0. \tag{10}$$

An equilibrium is given by the exit threshold ϕ_1 and the mass of active conglomerates M such that (1) conglomerates make optimal allocation and size decisions, (2) the product market clears, and (3) the zero profit and free entry conditions (Equations 9–10) are satisfied.

Welfare depends on consumption utility and on the utility costs of carbon emissions from energy use. The CES preferences of the representative consumer imply that indirect utility is given by $\frac{R}{P}$, where R is total expenditure. Utility is decreasing in total emissions βE, where E denotes aggregate energy use and β captures the carbon dioxide emitted per unit of energy. We assume that welfare takes the form

$$W = \left(\frac{R}{P}\right)^{1-\kappa} \left(\frac{1}{\beta E}\right)^{\kappa}, \tag{11}$$

[38] ϕ_1 is the minimum efficiency for a single-firm conglomerate, so that $\pi(\phi_1) = 0$.

where the parameter κ captures the social welfare losses from emissions.[39]

4.4 Effects of the Top 1,000 Program

We denote outcomes in the unregulated equilibrium with an asterisk to differentiate them from those in the regulated equilibrium. Since the Top 1,000 program targeted very large firms, we assume that only conglomerates with ϕ above an efficiency level $\tilde{\phi}$ are subject to the regulation. The regulation sets a proportional input quota for the largest firm in each conglomerate, which is the model counterpart of a Top 1,000 firm. Specifically, the energy use of regulated firms cannot exceed $\bar{e}_1(\phi) = \xi e_1^*(\phi)$, where $\xi < 1$ and e_1^* is the unregulated optimal energy use. At the time of the regulation, the conglomerate's capital allocations $\{k_i^*\}_{i=1}^n$ are quasifixed, but it can respond by adjusting its use of inputs $\{l_i, e_i\}_{i=1}^n$. Our model characterizes firm-level, conglomerate-level, and industry-wide effects of the program.

We first study how the regulation impacts firm-level production decisions. To do so, we substitute the result from Proposition 1 that $k_i = \delta^{\frac{i-1}{1-\alpha}} k_1$ into Equation 4, define $\phi^* = \phi(k_1^*)^{\alpha_k}$, and let λ be the Lagrange multiplier associated with the regulatory constraint.[40] The first-order conditions for l_i $(1 \leq i \leq n)$ are then

$$\frac{\partial \pi}{\partial l_i} = \underbrace{R^{1-\rho}P^{\rho}}_{\text{Market Demand}} \underbrace{\rho\left[\phi^* \sum_{i=1}^{n} \delta^{\frac{(i-1)(1-\alpha_l)}{1-\alpha}} l_i^{\alpha_l}\right]^{\rho-1}}_{\text{Residual Revenue}} \underbrace{\phi^* \delta^{\frac{(i-1)(1-\alpha_l)}{1-\alpha}} \alpha_l (l_i)^{\alpha_l - 1}}_{\text{Marginal Product}} = w + p_e + \underbrace{\lambda(\phi)\mathbb{I}[i=1]}_{\substack{\text{Shadow Cost} \\ \text{of Regulation}}}. \quad (12)$$

An important insight of this expression is that conglomerates internalize the marginal product of inputs across firms through the residual revenue term, which is common to all firms in the conglomerate. The impact of energy regulations on the residual revenue term is key to understanding the difference between within-conglomerate and market-level spillovers.

This equation shows that the regulation distorts the allocation of inputs within a conglomerate by adding a shadow cost $\lambda(\phi)$ to the input of the regulated firm. Because conglomerates with more affiliates can shift more production to related parties, conditional on being regulated, more efficient conglomerates (those with a higher ϕ) are subject to a smaller shadow cost $\lambda(\phi)$. Since only conglomerates with $\phi > \tilde{\phi}$ are part of the Top 1,000 program, the regulation also distorts input use across conglomerates.

The following proposition shows that the regulation leads conglomerates to allocate more inputs to the unregulated firms than in the case without the regulation.

[39] See Shapiro (2021) for a similar formulation of social welfare. Since we find that the regulation does not significantly shift the geographic distribution of energy use, our welfare measure does not account for the location of emissions (e.g., as in Shapiro, 2016).

[40] Note that $k_1^* = K_n^*(\Delta_n)^{\frac{-1}{1-\alpha}}$.

Proposition 3 (Within-Conglomerate Distribution under Regulation)**.** *Under the Top 1,000 regulation, the inputs and the output of producers follow the sequences given by*

$$\frac{e_j}{e_2} = \frac{l_j}{l_2} = \frac{q_j}{q_2} = \delta^{\frac{j-2}{1-\alpha}} \text{ for } j > 2,$$

$$\frac{e_i}{e_1} = \frac{l_i}{l_1} = \delta^{\frac{i-1}{1-\alpha}} \times \left[1 + \frac{\lambda(\phi)}{w + p_e}\right]^{\frac{1}{1-\alpha_l}} \text{ and } \frac{q_i}{q_1} = \delta^{\frac{i-1}{1-\alpha}} \times \left[1 + \frac{\lambda(\phi)}{w + p_e}\right]^{\frac{\alpha_l}{1-\alpha_l}} \text{ for } i > 1.$$

Even though conglomerates substitute production across firms, the regulation leads to an overall reduction in the conglomerate's output. The following proposition describes the conglomerate-level effects of the regulation on output and energy use.

Proposition 4 (Conglomerate-level Distortions from the Regulation)**.** *Under the Top 1,000 regulation, the energy use $e(\phi, n)$ and the output $q(\phi, n)$ of regulated conglomerates are given by*

$$\frac{e(\phi,n)}{e^*(\phi,n)} = \underbrace{\frac{\xi\left[1 + (\Delta_n^{\frac{1}{1-\alpha}} - 1)\left[1 + \frac{\lambda(\phi)}{w+p_e}\right]^{\frac{1}{1-\alpha_l}}\right]}{\Delta_n^{\frac{1}{1-\alpha}}}}_{=\xi_e(\phi)} \text{ and } \frac{q(\phi,n)}{q^*(\phi,n)} = \underbrace{\frac{\xi^{\alpha_l}\left[1 + (\Delta_n^{\frac{1}{1-\alpha}} - 1)\left[1 + \frac{\lambda(\phi)}{w+p_e}\right]^{\frac{\alpha_l}{1-\alpha_l}}\right]}{\Delta_n^{\frac{1}{1-\alpha}}}}_{=\xi_q(\phi)},$$

where $e^*(\phi, n)$ and $q^*(\phi, n)$ are the unregulated counterparts of energy use and output and where $\xi_e(\phi)$ and $\xi_q(\phi)$ describe the effective input and output wedges.

The term $\xi_e(\phi)$ captures the net effect on energy use by combining the reduction in energy use at the regulated firm (ξ) with the increase in related firms, which is governed by $\lambda(\phi)$. The denominator follows from the insight of Proposition 1 that in the unregulated case, the conglomerate-level input and output are $\Delta_n^{\frac{1}{1-\alpha}}$ times the input and output of the largest firm. The term $\xi_q(\phi)$ has a similar intuition, and it translates the effects of input changes on output through the exponent α_l.

We now characterize the equilibrium effects of the regulation.

Proposition 5 (Equilibrium under Regulation)**.** *The equilibrium price level under the Top 1,000 regulation solves the following system of nonlinear equations:*

$$\left(\frac{P}{P^*}\right)^{-\rho} = (1 - s_{\tilde{\phi}})\left(\frac{P}{P^*}\right)^{\frac{\alpha_l \rho^2}{1-\alpha_l \rho}} + s_{\tilde{\phi}} \mathbb{E}_e\left[\xi_q(\phi)^\rho \,\middle|\, \phi > \tilde{\phi}\right] \tag{13}$$

$$1 + \frac{\lambda(\phi)}{w + p_e} = (\xi)^{\alpha_l - 1}\left(\frac{P}{P^*}\right)^{\rho} \xi_q(\phi)^{\rho-1}, \tag{14}$$

where $s_{\tilde{\phi}}$ is the share of energy in regulated conglomerates prior to the regulation and $\mathbb{E}_e$ denotes the expectation with respect to the energy-use distribution from the unregulated equilibrium. Additionally, the aggregate change in energy use is given by

$$\frac{E}{E^*} = (1 - s_{\tilde{\phi}})\left(\frac{P}{P^*}\right)^{\frac{\rho}{1-\alpha_l \rho}} + s_{\tilde{\phi}} \mathbb{E}_e\left[\xi_e(\phi) \,\middle|\, \phi > \tilde{\phi}\right]. \tag{15}$$

Equation 13 shows that the equilibrium price depends on two forces. First, prices increase as regulated firms reduce their output by $\xi_q(\phi)$. Second, unregulated firms respond to this price increase by increasing their output. The relative importance of these forces depends on the share of energy in regulated conglomerates $s_{\tilde{\phi}}$.

Equation 14 describes the shadow cost of the regulation in terms of the equilibrium price effect $\frac{P}{P^*}$ and the conglomerate-level output wedge $\xi_q(\phi)$. This equation follows from the first-order conditions of both the regulated and unregulated cases and from the results of Proposition 3. Given $\frac{P}{P^*}$, Equation 14 and Proposition 4 define an implicit function for $\lambda(\phi)$. Interestingly, the shadow cost $\lambda(\phi)$ and the conglomerate-level wedge $\xi_q(\phi)$ are step functions of ϕ. While these functions depend on the number of affiliates in a conglomerate n, they are constant across conglomerates of the same size but with different values of ϕ.[41] Intuitively, this result is a consequence of the fact that the energy cap in the regulation is proportional to the firm's prior energy use, which itself depends on ϕ.

The equilibrium under the regulation is then determined by a single shadow cost for every value of n along with the equilibrium price $\frac{P}{P^*}$, which greatly facilitates the computation of the new equilibrium. Equation 15 then shows that the equilibrium effect on energy depends on the net change in conglomerate energy use $\xi_e(\phi)$ and the market leakage to unregulated firms.

These results characterize the welfare effects of the program since Equation 11 implies that

$$\frac{d\ln W}{1-\kappa} = -\ln\left(\frac{P}{P^*}\right) - \frac{\kappa}{1-\kappa}\ln\left(\frac{E}{E^*}\right). \tag{16}$$

Propositions 4 and 5 show that the equilibrium effects of the regulation on the industry-level price $\frac{P}{P^*}$ and on aggregate energy use $\frac{E}{E^*}$ are closely related to the conglomerate-level distortions ($\xi_q(\phi)$ and $\xi_e(\phi)$), which themselves depend on the shadow cost to regulated firms $\lambda(\phi)$. As we show in Section 6, these model quantities are closely related to our empirical estimates from Section 2–3. This framework also allows us to study the effects of alternative policies. For instance, a universal energy tax would have $s_{\tilde{\phi}} = 1$ and a constant ξ_q for all firms. In Section 6, we compare the Top 1,000 program to a universal energy tax, a size-dependent energy tax (i.e., $s_{\tilde{\phi}} < 1$), and alternative forms or regulations, including ones that mirror the Top 10,000 program.

5 Model Estimation

This section estimates the key parameters of the model to quantitatively match the data patterns for the period prior to the regulation. We validate our estimated model by showing that it matches the untargeted difference-in-differences estimates of the effects of the Top 1,000 program.

[41] As we show in Appendix D.2, this result follows by substituting $\xi_q(\phi)$ into the expression for $\lambda(\phi)$ in Proposition 5 and noting that this expression varies across firms depending on the term Δ_n only.

5.1 Parameterization and Estimation

We briefly describe the set of structural parameters of the model and how they are identified by the data. We start by setting the values of two parameters based on previous estimates. We follow the literature by calibrating the elasticity of substitution $\sigma = 4$ (Melitz and Redding, 2015, i.e., $\rho = 0.75$). We use the estimate of returns to scale of $\alpha = 0.9$ from Burnside, Eichenbaum and Rebelo (1995), who use energy data to proxy for utilized capital, and set $\alpha_l = 0.8$ to match the cost share of variable inputs in the data.[42] Finally, we parameterize the conglomerate efficiency distribution $G(\phi)$ with a log-normal distribution with mean zero and standard deviation σ_m.

The model is characterized by the three parameters that we estimate: $(\delta, \phi_1, \sigma_m)$, which include the within-conglomerate size depreciation δ, the conglomerate-level survival threshold ϕ_1, and the dispersion of the efficiency distribution σ_m. Given values of ϕ_1 and the market expenditure R, Equations 8 and 9 pin down f. The entry cost f_e is then determined by the conglomerate free-entry condition.[43]

We estimate the parameters $\theta = (\delta, \phi_1, \sigma_m)$ using the method of moments. For a candidate value of θ, we solve the model and compute the following moments: (1) the share of firms in three bins of firm revenue (5–20 million RMB, 20–100 million RMB, and greater than 100 million RMB); (2) the share of firm output in the same three bins; (3) the average output of the second, third, and fourth largest affiliates relative to the top firm in the conglomerate; and (4) the fraction of firms with revenue below 1 million RMB. Our data moments describe the equilibrium prior to the regulation using the ASIF and manufacturing census data for 2004. Intuitively, the parameter σ_m is pinned down by the moments (1) and (2) describing the firm size and firm output distribution. The parameter δ is determined by the within-conglomerate output distribution moments (3). The last moment (4) helps pin down ϕ_1. Our estimate of θ is given by

$$\hat{\theta} = \arg\min_{\theta \in \Theta} [m_d - m(\theta)]' W [m_d - m(\theta)],$$

where m_d are the data moments, $m(\theta)$ are the moments generated by the model, and W is the identity matrix.[44]

Table 7 reports the results of the estimation. We estimate that $\delta = 0.90$, which means that

[42] Conventional estimates of returns to scale range from 0.85 to 0.95, depending on aggregation and time period. In Section 7.3, we show that the aggregate and welfare effects of the program are robust to reestimating the model based on different values of ρ and α.

[43] To pin down f_e, first note that Equations 7 and 9 imply that $\phi_{n+1} = \phi_1 / \left(\Delta_{n+1}^{\frac{\rho}{1-\rho\alpha}} - \Delta_n^{\frac{\rho}{1-\rho\alpha}} \right)^{\frac{1-\rho\alpha}{\rho}}$ and that $\pi(\phi) = \left[\left(\frac{\Delta_n \phi}{\phi_1} \right)^{\frac{\rho}{1-\rho\alpha}} - n \right] rf$. The conglomerate free-entry condition is then $f_e = \int_{\phi_1} \left[\left(\frac{\Delta_n \phi}{\phi_1} \right)^{\frac{\rho}{1-\rho\alpha}} - n \right] fg(\phi) d\phi$, which is determined by our fixed and estimated parameters.

[44] We use the identity matrix since the sample size for the moments describing the size and output distribution is much larger than the sample size for the moments describing the relative size of firms within conglomerates. We calculate standard errors using a bootstrap covariance matrix of the moments that incorporates this information.

the productivity of the second largest firm in the conglomerate is close to 90% of that in the largest firm. Recall that Equation 5 shows that the output of affiliates depreciates in rank by the factor $\delta^{\frac{1}{1-\alpha}}$. This relation implies that the output of the second largest firm is close to 35% of the largest firm (cf., 29% in the data) and that of the third largest is close to 13% (cf. 20% in the data), which matches the pattern in Panel A of Figure 3. We also estimate that $\sigma_m = 1.24$ and $\phi_1 = 0.61$. To interpret these estimates, note that they imply a conglomerate entry cost of $f_e = 8.9$ million RMB (or about 1.1 million USD), which is reasonably commensurate with average profit in the economy. The per-firm operating fixed cost is determined by the average sales per conglomerate in the data, which implies that $f = 44,000$ RMB. Panel A of Figure 7 shows that our model does a good job of fitting both the observed firm-size distribution and the concentration of output prior to the regulation.

5.2 Model Response to the Top 1,000 Program

We need two additional parameters to implement the Top 1,000 program in our model. As discussed in Section 4, our version of the regulation targets conglomerates with efficiency level ϕ above $\tilde{\phi}$. We choose the threshold $\tilde{\phi}$ to match the share of total energy consumed by regulated firms within energy-intensive industries. Given our estimated parameters, the model implies a value of $\tilde{\phi} = 9.29$, which reproduces the fact that regulated firms account for 56% of total energy consumption in energy-intensive industries. Finally, we take the policy intensity ξ from the 11FYP, which targeted an energy reduction of 20%. For this reason, we set $\xi = 0.8$. Table 7 collects the model parameters.

We now use our estimated model to compute the effects of the Top 1,000 program. As in Section 4.4, we assume conglomerates take the number of affiliates and capital allocation as given. The new industry equilibrium ensures that (1) regulated conglomerates allocate variable inputs optimally (as in Equation 12), (2) unregulated firms increase output to respond to the increase in market prices, and (3) the product market clears (as in Equation 8).

Panel B of Figure 7 compares our difference-in-differences estimates to simulated model analogues. The model does a remarkable job of matching the estimated effects on firm output. This is true for regulated firms, related firms, and market-level spillovers. The model prediction of the change in input use of regulated firms is within the 95% confidence interval of our empirical estimate, but the model has a hard time fitting the effect on the energy use of related firms. This may reflect the fact that, as we discuss in Section 3, this estimate is based on a smaller sample of larger firms and may not be representative of the overall response. However, the model does a good job of matching the effects of the program on the energy efficiency of both regulated and related firms. Overall, these results show that our model can reproduce the effects of the regulation on the output of regulated, related, and unrelated firms, which is remarkable since

these are all out-of-sample predictions of the model.

5.3 Using the Model to Interpret Difference-in-Differences Estimates

An important force in the model is that unregulated firms are impacted by the regulation through the market spillover. This force contributes to the effects of the program on the equilibrium price and aggregate energy use. We now use our model to understand how this market spillover impacts our difference-in-differences estimates.

To see how the regulation in our model connects to our difference-in-differences analysis, note that we can write conglomerate j's revenue from affiliate i as follows:

$$\ln \text{Revenue}_{ij} = \underbrace{\ln(\text{Production Share}_{ij})}_{\text{Allocation Effect}} + \underbrace{\rho \ln\left(\sum_{i \in j} q_{ij}\right)}_{\text{Residual Revenue}} + \underbrace{\ln(R^{1-\rho}P^{\rho})}_{\text{Market Demand}}, \tag{17}$$

where $\text{Production Share}_{ij} = q_{ij} / \sum_{i \in j} q_{ij}$.[45] Equation 17 clarifies the three ways in which the Top 1,000 program impacts the revenue of regulated firms. First, when firm i is regulated, the conglomerate is forced to reallocate inputs to other firms, which lowers the production share in regulated firms. Panel A of Table 8 reports that in our model, the share of production in regulated firms within a conglomerate decreases by 12.9%. Second, since the marginal cost goes up at the conglomerate level, the market share of the conglomerate's variety decreases, which lowers the group's residual revenue. Table 8 shows that regulated conglomerates see their residual revenue decrease by 3.7%. Finally, the Top 1,000 program impacts the industry-level price P. This price increase has a countervailing effect on the revenue of the regulated firm and lessens the overall decline by 2.6%. Combining these three forces, our model implies that regulated firms decreased their output by 14%.

Equation 17 also characterizes the impact of the regulation on the control firms in our difference-in-differences analyses. Since these firms are not regulated or related to Top 1,000 firms, the regulation does not impact the within-conglomerate allocation of production. Control firms see an increase in their residual and firm-level revenue as the market reallocates demand. Table 8 shows that the residual revenue of control firms increases by 3.9%. As in the case of regulated firms, unregulated firms also benefit from the equilibrium impact on market demand.

This discussion clarifies that our difference-in-differences estimates differ from the total effect on Top 1,000 firms along two margins. First, the difference-in-differences estimator captures both the within- and across-conglomerate reallocation of production. This leads to an overestimate of the effect of the program on regulated firms of 3.9%. Second, since the market effect cancels out,

[45] Equation 17 follows by multiplying conglomerate j's inverse residual demand by affiliate i's production.

the difference-in-differences estimator does not capture the countervailing effect on the industry-level price, which further overestimates the effect of the program by 2.6%.[46]

Similarly, our model allows us to decompose the estimates of the spillover effects of the regulation through ownership networks. Panel B of Table 8 shows that related firms share the residual revenue and market effect terms but have a positive allocation effect as their share of production within the conglomerate increases. The total effect on related firms is an output increase of 19.3%. The effects on control firms is the same as that in Panel A. By ignoring the positive market effect and subtracting the residual revenue effect on control firms, the difference-in-differences estimator understates the spillover effect on related firms by 6.5%.

In addition to clarifying the interpretation of our reduced-form estimates, our model also motivates an alternative approach that does not depend on the residual revenue or market effects. Specifically, consider a within-conglomerate difference-in-differences estimator where treated firms are the regulated Top 1,000 firms and the control firms are unregulated firms in the same conglomerate. Because Equation 17 shows that the residual revenue and market effect are common to a given conglomerate, this estimator captures only the allocation effects of the program. Figure 8 implements this within-conglomerate difference-in-differences approach. This figure plots the results from an event-study specification similar to Equation 1 but where we additionally include conglomerate-by-year fixed effects. Consistent with our previous results, we find a significant decline in the output of Top 1,000 firms relative to that of other firms in their same conglomerates. Table 9 reports estimates of these relative declines of between -31.5% and -36.7%. As with our previous reduced-form effects, Panel B of Figure 7 shows that the model matches this within-conglomerate effect very well. Moreover, Panel C of Table 8 confirms that this effect is a combination of the allocation effects on regulated and related firms.

These insights highlight the importance of interpreting quasirandom estimates through the lens of a model that accounts for within- and across-conglomerate reallocation of production as well as equilibrium impacts on industry-level prices.

6 Policy Analysis

This section uses our estimated model to capture the effects of the Top 1,000 program by quantifying the shadow cost to regulated firms, the aggregate effects on prices and energy use, and the implied welfare trade-off of the program. We then consider the effects of alternative policies including program expansions (e.g., the Top 10,000 program) and the possibility that the government can use information on business networks to improve energy regulation.

[46]Note that the first channel arises from the impact of the regulation on the control firms. The second channel is an aggregate effect that is not identified by a difference-in-differences research design.

6.1 Effects of the Top 1,000 Program

Given that the shadow cost is the fundamental building block of our model outcomes, we first quantify this cost of the policy.

6.1.1 Shadow Cost of the Policy

To compute the shadow cost of the policy, we solve for the regulated equilibrium as in Proposition 5. Panel A of Figure 9 plots the implied shadow cost as a function of efficiency ϕ. The blue line plots the shadow cost of our computed Top 1,000 program. This shadow cost is zero for firms with $\phi < \tilde{\phi}$ and jumps to an average of 8.7% for regulated firms. Since the shadow cost has the same scale as the cost of variable inputs, we can interpret this value as an equivalent tax on variable inputs. While 8.7% might seem like a small number, recall that inputs constitute a large tax base, especially relative to profits.[47]

A somewhat surprising feature of Panel A of Figure 9 is that the shadow cost appears to be constant with respect to conglomerate productivity ϕ. Panel B of Figure 9 zooms in to show the different shadow costs for regulated firms (i.e., $\phi > \tilde{\phi}$). As we discuss in Section 4, the shadow cost is constant for conglomerates with the same number of related firms. This result follows from the fact that the regulation is based on previous energy use, which is proportional to firm productivity. When ϕ crosses the thresholds that define conglomerate size (Proposition 2), we see that the shadow cost drops as conglomerates with more affiliates are more able to escape the burden of the regulation. However, the differences in shadow costs are very small in comparison to the overall difference between regulated and unregulated conglomerates. This small impact is driven by the decay in within-conglomerate size, which implies that the marginal (n^{th}) affiliate may not be able to supplant a large fraction of the combined activity of all the other affiliates (1 through $n-1$) in the conglomerate.

We now validate the magnitude of the shadow cost using an additional implication of the model. Recall the insight from Proposition 3 that the shadow cost is related to the within-conglomerate output distribution after the regulation. Based on this insight, we can write the output difference between the Top 1,000 firm and related firms as follows:

$$\begin{aligned} \ln \text{Revenue}_{\text{Top1000},jt} - \ln \text{Revenue}_{\text{Related},jt} &= \ln\left(q_{\text{Top1000},j}\right) - \ln\left(\sum_{i \neq \text{Top1000},j} q_{ij}\right) \\ &= -\frac{\alpha_l}{1-\alpha_l} \ln\left[1 + \frac{\lambda(\phi)}{w + p_e}\right] - \ln\left(\Delta_n^{\frac{1}{1-\alpha}} - 1\right). \end{aligned}$$

By definition, $\lambda(\phi) = 0$ prior to the regulation, and Δ_n is constant over time. Therefore, taking a time difference of this expression shows that the within-conglomerate difference-in-differences

[47] Indeed, in models with constant marginal cost and with a similar value of σ, inputs are $(\sigma - 1) = 3-$times as large as profits. An equivalent profit tax would then be 26.1%.

estimation identifies the term $-\frac{\alpha_l}{1-\alpha_l}\ln\left[1+\frac{\lambda(\phi)}{w+p_e}\right]$. Using the estimate in the first column of Table 9 of -34.3% and our value of $\alpha_l = 0.80$, we estimate a shadow cost of 8.95%.[48] Given that the shadow cost plays an important role in our quantification exercises of the aggregate effects of the program, it is reassuring that our estimated magnitude is consistent with the reduced-form pattern of within-conglomerate reallocation of production.

Our model allows us to consider how different mechanisms impact the shadow cost of the program. The top line of Panel A of Figure 9 shows that shutting down the market and conglomerate spillovers would increase the shadow cost to 15.6%. That is, the equilibrium price increase and the ability to shift production to related firms lowered this mechanical effect by almost 50%. The model also allows us to isolate how the ability of conglomerates to shift production to related firms lowered the shadow cost of the regulation. The second line from the top in Panel A of Figure 9 plots the shadow cost under the assumption that market prices adjust but that regulated firms are not able to shift production to related parties. In this case, the shadow cost of the regulation would be 11.2% of input costs, which is about 30% larger than the level in the baseline case.[49] These calculations showcase the importance of accounting for both market and conglomerate spillovers in the measurement of the shadow cost of the regulation.

6.1.2 Aggregate and Welfare Effects of the Program

The analysis so far has focused on the distortionary aspects of the regulation. We now evaluate the aggregate and welfare effects of the policy by considering the social welfare function of a government concerned with both decreases in energy-use-related emissions and the impact of distortions to production on consumption.[50]

We compute the aggregate effects of the program by solving the equilibrium conditions in Proposition 5. Panel A of Figure 10 plots the effects of the Top 1,000 program in the space of price increase and energy reduction. The red diamond in this figure shows that the Top 1,000 program led to a price increase of about 3.5% and an aggregate energy use reduction of close to 4%. Equation 15 helps us understand how we obtain a 4% aggregate reduction in energy use. First, we find that—including within-conglomerate reallocation—regulated conglomerates reduced their energy use by $1-\mathbb{E}_e\left[\xi_e(\phi)\,\middle|\,\phi > \tilde{\phi}\right] = 5.8\%$. Second, the unregulated conglomerates increased their energy use by close to 6.5%. Finally, we obtain the aggregate 4% decline by using

[48] This calculation follows from $1+\frac{\lambda(\phi)}{w+p_e} = \exp\{-\beta\frac{1-\alpha_l}{\alpha_l}\} = \exp\{0.343\frac{1-0.8}{.8}\} = 1.0895$. In principle, we identify the average value of this quantity across firms. However, as we show in Figure 9, there is little variation in $\lambda(\phi)$.

[49] This counterfactual assumes that, similar to unregulated firms, the production of related firms responds to equilibrium price increases. Restricting production in related firms to pre-regulation levels further increases the shadow cost to 14%.

[50] To match the short-run nature of our empirical analysis, we focus our discussion on the short-run effects of the policy, ignoring the entry of new conglomerates. Later changes to regulations and the overall environment also complicate the simulation of long-run impacts.

the fact that the share of energy in regulated conglomerates is $s_{\tilde{\phi}} = 86\%$.[51] Thus, even though we find in Section 2 that Top 1,000 firms reduced their energy use by close to 100 million tce, the annual aggregate reduction—including conglomerate and market leakage—was closer to 48 million tce.[52]

While reducing energy use improves welfare by lowering related carbon emissions, the overall effects of the program on welfare also depend on how the program impacts consumption. According to Equation 16, welfare increases when the aggregate price-to-energy use elasticity $\left(\text{i.e., } \frac{-\ln\left(\frac{P}{P^*}\right)}{\ln\left(\frac{E}{E^*}\right)}\right)$ is smaller than $\frac{\kappa}{1-\kappa}$. Given our aggregate estimates of the effects of the Top 1,000 program, we find that the program raises welfare as long as $\frac{\kappa}{1-\kappa} < \frac{3.5}{4} = 0.875$. That is, the Top 1,000 program raises welfare as long as the government is willing to accept a 0.875% price increase for every 1% reduction in energy use.

To obtain a more concrete interpretation of this condition, we calibrate κ by building on the Cobb-Douglas intuition that exponents are related to expenditure shares. This intuition implies that we can approximate κ as follows:

$$\kappa = \frac{\text{Social Cost of Carbon} \times \text{Carbon Emissions}}{\text{Aggregate Income} \times 0.8}.$$

The adjustment factor 0.8 comes from the fact that the Chinese government declared in the 11FYP that relative to its policy goals, the government was underspending on reducing emissions by 20%. We implement this equation with 2006 data on overall emissions in China (6.38 billion tons of carbon) and national income (2.752 trillion USD). We can then compute a value of κ that corresponds to an estimate of the social cost of carbon (SCC). In the US, the Biden administration has recently proposed using an SCC of $51 (IWG, 2021), although researchers have recently argued for a higher value of $125 (Carleton and Greenstone, 2021). In contrast, Germany has proposed an SCC value of $218.

Figure 10 implements this calibration by plotting black indifference curves where κ varies according to different values of the SCC. That is, for a given SCC value, these lines plot combinations of price and energy use changes that yield the same effect on welfare. The red diamond in this figure shows that the Top 1,000 program lies on the indifference curve that corresponds to an SCC of $160. This implies that this policy is desirable from a welfare perspective only if policymakers use relatively higher values of the SCC.

[51] The energy increase for unregulated firms is given by $\left(\frac{P}{P^*}\right)^{\frac{\rho}{1-\alpha_l\rho}} = (1.035)^{\frac{0.75}{1-0.8*0.75}} \approx 1.065$. Recall that regulated firms account for 56% of energy use; accounting for related firms in the same conglomerate raises this fraction to 86%. The aggregate effect is then $-4\% = \ln(1.06 * 0.14 + 0.942 * 0.86)$.

[52] In Appendix D.2.3, we connect the model solution to our reduced-form estimates by showing that we can solve an approximate version of the equilibrium using the value of λ that is implied by the within-conglomerate difference-in-differences results.

6.2 Alternative Policies

We now use the model to consider alternative policies. We first explore different ways in which the Top 1,000 program could be expanded or contracted. This exercise is motivated by the fact that the Chinese government expanded the program to include more than 14,000 firms in the Top 10,000 program in 2012. We then explore the effects of alternative regulations and energy taxes to examine the degree to which the government can improve the regulation of energy.

We explore two ways to change the scope of the Top 1,000 program. First, we consider the effect of varying the regulation threshold $\tilde{\phi}$, which changes the number of firms affected by the program. The blue dots in Panel A of Figure 10 show the effects of changing the size threshold, $\tilde{\phi}$. The first blue dot (left of the red diamond) considers the effect of decreasing the number of regulated firms to cover only 50% of the energy use in the regulated industry (relative to the current 56%). The second blue dot lowers $\tilde{\phi}$ so that the regulation instead covers 60% of the industry's energy use. As would be expected, we find larger energy decreases when the program covers a larger fraction of overall energy use. However, Figure 10 shows that expanding or contracting the number of firms in the program does not alter the fundamental trade-off that the government faces between price increases and reductions in energy use.

An alternative way to change the scope of the Top 1,000 program is to increase or decrease the energy use quota ξ. The maroon squares in Panel A of Figure 10 plot the effects of policies where $1-\xi$ varies in 5% increments between 5% and 30%. Larger values of $1-\xi$ lead to both larger price increases and larger energy reductions. Taking both changes into account, we find that the implied SCC increases with the required energy reduction and equals \$165 when $1-\xi = 30\%$. This result is valuable since the government may be concerned about the administrative costs of regulating a larger number of firms. Since increasing ξ and lowering $\tilde{\phi}$ have similar welfare effects, it may therefore be desirable to place stricter energy use limits on fewer firms if the government lacks the capacity or the funds to conduct additional energy audits.

We now consider the effects of an alternative policy that targets the energy use of all firms in a given conglomerate.[53] The orange crosses in Panel B of Figure 10 plot the effects of this type of regulation for different values of ξ. These policies have the benefit that they do not distort the within-conglomerate distribution of production. Panel A of Figure 9 shows that regulating conglomerates has a lower shadow cost of 4.9% (instead of 8.7%). Such a policy is preferable to the Top 1,000 program from a welfare perspective since it can achieve larger energy use reductions for a given price increase. As we show in Panel B of Figure 10, this type of regulation can yield a 4.36% reduction in aggregate energy use for the same price increase as the Top 1,000

[53] We derive equilibrium conditions under these alternative regulations in Appendix E. To make this case comparable, we model the effects of a regulation that limits the conglomerate-level use of energy to the levels of the Top 1,000 program. That is, we set ξ to values corresponding to $\xi_e(\phi)$ in the Top 1,000 program.

program. This is a 10% increase from the energy reduction of the Top 1,000 program, which corresponds to additional energy savings of 5 million tce. This policy improves welfare as long as the SCC$\geq$ \$152. While this program would involve monitoring additional firms, the number of firms related to Top 1,000 firms is less than 20% of the number of firms in the Top 10,000 program. These results show that the government can improve the regulation of energy by using publicly available data on business networks to target conglomerates and that doing so would be more effective than regulating additional unrelated firms, as with the Top 10,000 program.

Finally, we consider the effects of energy taxes. We first model the effects of a tax that affects only firms in conglomerates with Top 1,000 firms (i.e., with $\phi > \tilde{\phi}$). Panel A of Figure 9 shows that we would obtain the same energy reduction as that under the Top 1,000 program by taxing inputs at 4.9%.[54] The green circles in Panel B of Figure 10 show that the effects of this energy tax are very close to those of the conglomerate-level regulation.[55] We further consider the effects of a universal energy tax such that $s_{\tilde{\phi}} = 100\%$ instead of 86%. Panel B of Figure 10 shows that while a universal energy tax yields a slight improvement over the size-dependent tax (SCC= \$151), both the size-dependent tax and the conglomerate-level regulations imply very similar welfare trade-offs.

The preferred policy solution for most economists on the regulation of carbon emissions related to energy use is a universal carbon tax. In practice, this policy may not be feasible given legal, administrative, or political constraints. The results in this section inform the efficacy and design of a prominent real-world policy that regulates quantities and has incomplete coverage. We find that the government can achieve similar aggregate effects by either expanding the program through stricter regulations for current firms or increasing the number of firms in the program. While the former has narrower coverage and generates larger inequities between regulated and unregulated firms, the latter may require an increase in administration costs. We also find that the government can improve the regulation of energy by targeting the ownership networks of regulated firms. This policy increases aggregate energy savings by 10% without increasing welfare costs. Moreover, this policy can be implemented with publicly available data, has a lower administrative cost than the Top 10,000 program, and implies a welfare trade-off close to that under a universal energy tax.

[54] As with the Top 1,000 regulation, the shadow cost of the conglomerate-level regulation decreases slightly as the number of related firms increases. In contrast, the shadow cost of the size-dependent energy tax is constant for all firms affected by it. Since energy costs are close to 15% of variable input costs for Top 1,000 firms, the equivalent energy tax would be closer to 32.7%($\approx \frac{4.9\%}{15\%}$).

[55] It is worth noting that our quantification lacks two features that often motivate the use of taxes over regulation. First, in our calculations, the revenue from the tax is not rebated to consumers; this calculation ignores potential "double dividend" effects. Second, firms in our setting have homogeneous abatement costs; in a setting with heterogeneous abatement costs, a tax would additionally reallocate production to "cleaner" firms.

7 Extensions and Robustness

This section explores four extensions of our model. First, we consider the possibility of firms responding to the regulation by investing in energy efficiency. Second, we consider how preexisting differences in energy efficiency across firms may alter the overall energy savings from the program. Third, we study the robustness of our welfare calculations to alternative parameterizations of the model. Finally, we extend our model to allow imperfect substitution between products produced by firms in a given conglomerate.

7.1 Endogenous Energy Efficiency

Our baseline analysis assumes that in the short run, firms do not make any investments to improve their energy efficiency. This assumption is consistent with our empirical results in Sections 2–3. Following the intent of the Top 1,000 program, we now extend our model to allow firms to respond by adjusting their energy efficiency. Appendix G.1 provides additional details of this model extension.

We assume that the conglomerate can improve energy efficiency at firm i, ν_i, by spending $l_i c(\nu_i)$, where $c'(\nu_i) > 0$ and $c''(\nu_i) \geq 0$. We can then restate the regulated conglomerate's problem as

$$\pi(\phi, n) = \max_{\{l_i\}_{i=1}^n, \{\nu_i\}_{i=1}^n} \left\{ R^{1-\rho} P^\rho \left[\phi^* \sum_{i=1}^n \delta^{\frac{(i-1)(1-\alpha_l)}{1-\alpha}} l_i^{\alpha_l} \right]^\rho - \sum_{i=1}^n l_i \left(w + \frac{p_e}{\nu_i} + c(\nu_i) \right) \right\},$$

where we omit the cost of fixed capital. Absent the regulation, the conglomerate sets $c'(\nu^*)\nu^{*2} = p_e$ for all firms. This result implies that Propositions 1–2 continue to describe the equilibrium prior to the regulation. To simplify the exposition, we assume that $c(\nu) = \frac{\nu^\gamma}{1+\gamma}$, where $\gamma \geq 1$. This implies that the effective price of energy inclusive of investments in energy efficiency is $\frac{p_e}{\nu^*} + c(\nu^*) = c'(\nu^*)\nu^* + c(\nu^*) = (\nu^*)^\gamma$.

Consider now the effects of the regulation. First, note that the Top 1,000 regulation does not impact the choice of ν_i for unregulated firms. We then use these results and the fact that $\nu_i = \frac{l_i}{e_i}$ to restate the conglomerate problem as

$$\pi(\phi, n) = \max_{\{l_i\}_{i=1}^n} \left\{ R^{1-\rho} P^\rho \left[\phi^* \sum_{i=1}^n \delta^{\frac{(i-1)(1-\alpha_l)}{1-\alpha}} l_i^{\alpha_l} \right]^\rho - (w + (\nu^*)^\gamma) \sum_{i=1}^n l_i - l_1 \left[\frac{1}{1+\gamma} \left(\frac{l_1}{\xi e_1^*} \right)^\gamma - (\nu^*)^\gamma \right] \right\},$$

where we substitute the regulatory constraint into the cost of energy efficiency and where we abstract away from the cost of the regulated energy, $p_e \xi e_1^*$, since it is a constant.

The conglomerate's first-order conditions for l_i $(1 \leq i \leq n)$, i.e., $\frac{\partial \pi}{\partial l_i}$, are then

$$\underbrace{R^{1-\rho}P^{\rho}}_{\text{Market Demand}} \underbrace{\rho\left[\phi^* \sum_{i=1}^{n} \delta^{\frac{(i-1)(1-\alpha_l)}{1-\alpha}} l_i^{\alpha_l}\right]^{\rho-1}}_{\text{Residual Revenue}} \underbrace{\phi^* \delta^{\frac{(i-1)(1-\alpha_l)}{1-\alpha}} \alpha_l (l_i)^{\alpha_l - 1}}_{\text{Marginal Product}} = w + (\nu^*)^{\gamma} + \underbrace{\left[\left(\frac{l_1}{\xi e_1^*}\right)^{\gamma} - (\nu^*)^{\gamma}\right]}_{\substack{\text{Shadow Cost} \\ \text{of Regulation}}} \mathbb{I}[i = 1].$$

Interestingly, this extension of the model yields very similar results to those in Equation 12. For the case of unregulated firms (i.e, l_i for $i > 1$), we simply substitute p_e with the effective price of energy: $(\nu^*)^{\gamma}$. The first-order condition for the regulated firm implies that the shadow cost of the regulation is given by

$$\frac{\lambda(\phi)}{w + (\nu^*)^{\gamma}} = s_e \left[\left(\frac{\nu_1}{\nu^*}\right)^{\gamma} - 1\right],$$

where s_e is the share of variable input costs accounted for by energy and where energy efficiency at the Top 1,000 firm improves by $\frac{\nu_1}{\nu^*}$ relative to that in the unregulated case.[56] The results of Proposition 3 continue to hold using this definition of the shadow cost of the regulation, which captures the incremental cost of improving energy efficiency in the regulated firm.

This framework allows us to infer how costly it would have been for regulated firms to have improved their energy efficiency. We implement this calculation using our estimated model parameters. Our estimated model fundamentals remain valid since Propositions 1–2 continue to describe the unregulated equilibrium and since we estimated the model with data from prior to the regulation. To implement this model extension, we set $s_e = 15\%$ based on our data and calibrate γ based on the estimated effects of the program on the energy efficiency of regulated firms. Since we estimate statistically insignificant effects of program on the revenue-to-energy ratio of regulated firms, we calibrate γ using the upper bound of the 95% confidence interval.[57] In Appendix G.1, we show that when $\gamma = 7.4$, the improvement in the revenue-to-energy ratio of Top 1,000 firms in our model equals 11.6%, which matches the 95% confidence interval of column (1) in Panel C of Table 3.[58] The ability to improve the energy efficiency of the regulated firm lowers the shadow cost of the regulation, as it loosens the energy use restriction on the Top 1,000 firm. In this case, the shadow cost is 6.5% instead of the 8.7% in our baseline scenario.

This model extension also allows to quantify the aggregate effects of the policy under different assumptions of the costs of improving energy efficiency. Panel A of Figure 11 plots the aggregate

[56]The functional form assumption for $c(\nu)$ only simplifies the derivation. Absent this assumption, one can replace p_e in Equation 12 with the effective cost of energy $\nu^* c'(\nu^*) + c(\nu^*)$. Similarly, the shadow cost would be $\lambda(\phi) = [\nu_1 c'(\nu_1) + c(\nu_1)] - (\nu^* c'(\nu^*) + c(\nu^*))$.

[57]We also show in the appendix that the Top 1,000 program did not lead to improvements in the variable costs-to-energy ratio. Figure A.10 and Table A.18 show a null effect on this measure of energy efficiency for regulated firms, and Figure A.11 and Table A.19 find the same result for related firms.

[58]Alternatively, our model implies a value of $\gamma = 12.8$ if we target the 99% confidence interval of column (4) of Panel C of Table 3.

effects of the regulation for different values of γ. This model nests our baseline model under the assumption that $\gamma \to \infty$. In this case, firms do not improve their energy efficiency, which is consistent with our empirical results. When the cost of improving energy efficiency decreases (lower values of γ), the Top 1,000 program achieves greater energy reductions and results in smaller price increases. Both of these forces imply that the SCC that rationalizes the program also increases with γ. For our calibrated value of $\gamma = 7.4$, the Top 1,000 program reduces aggregate energy use by 5.6% for a price increase of 2.8%. This calculation also yields a bound on the SCC since as we show in Panel B of Figure 11, the program raises welfare for this value of γ as long as the SCC$\geq$ \$112.[59]

We can also use our model to calculate the value of γ that would have allowed regulated firms to improve their revenue-to-energy ratio by 20%. We find that firms would have met this energy efficiency improvement target if $\gamma = 0.55$. In this case, the shadow cost of the regulation would have been 1.6%. This scenario represents the "low-hanging fruit" perspective according to which small investments can lead to large gains in energy efficiency. While our results show that firms did not expect to recoup the costs of improving energy efficiency over a five-year period, it is possible that firms may find ways to improve their energy efficiency over the long run.[60]

7.2 Heterogeneous Energy Efficiency

The previous section showed that allowing endogenous investments in energy efficiency does not significantly alter our results. We now explore the possibility that—even prior to the Top 1,000 program—regulated, related, and unrelated firms operated under heterogeneous energy efficiencies.

One possibility is that the government targeted Top 1,000 firms because they were particularly energy inefficient. Similarly, the production increase in unrelated firms may have smaller effects on overall energy use if these firms are more energy efficient. In both of these cases, the regulation may be more effective to the extent that it shifts production to more energy-efficient firms. Alternatively, the Top 1,000 program may lead to smaller reductions in energy use if Top 1,000 firms are more energy efficient than other firms.

Appendix G.2 generalizes our analysis to allow the energy efficiency of related firms to differ from that of Top 1,000 firms by a factor of ν_R. Differences in energy efficiency would alter the pattern of production within a conglomerate even prior to the regulation. This is because energy efficiency influences the unit cost of related firms. Differences in energy efficiency would then

[59]The result that the conglomerate-level regulation would increase energy savings by 10% for the same welfare cost is robust to allowing firms to improve their energy efficiency.

[60]The fact that conglomerates were able to shift production to related affiliates lowered the incentive for regulated firms to invest in energy efficiency. Using our baseline calibration of $\gamma = 7.4$, we calculate that regulated firms would have increased their revenue-to-energy ratio by 13.8% if they had not been able to shift production to related firms.

influence the allocation of production within the conglomerate. We can additionally assume that other unrelated firms have an energy efficiency that differs from that of Top 1,000 firms by a factor of ν_O. These differences impact both the response of related and other firms to the regulation and overall energy use. To explore the sensitivity of our results to differences in energy efficiency, we solve the model under different values of ν_R and ν_O. We allow for ν_O and ν_R to be up to 20% lower (which would exacerbate energy leakage) or to be 20% greater than that of the Top 1,000 firms (leading to negative leakage, e.g., Baylis, Fullerton and Karney, 2014).[61]

Panel B of Figure 11 shows the effect of heterogeneous energy efficiency on our welfare calculations. We first assume that firms related to Top 1,000 firms are 20% less energy efficient, i.e. $\nu_R = 0.80$. This case implies a larger welfare loss due to a larger price increase as well as smaller energy savings. Under this assumption, the SCC that rationalizes the program increases to \$191. Further assuming that other firms are also 20% less energy efficient, i.e. $\nu_O = 0.80$, also increases prices, decreases energy savings, and is rationalized by an SCC of \$197. These calculations show that the within-conglomerate energy leakage is an important contributor to the overall energy effects of the program. If we alternatively assume that Top 1,000 firms are particularly energy inefficient, i.e. $\nu_R = \nu_O = 1.2$, the program can be rationalized with SCC values as low as \$133. To the best of our knowledge, Top 1,000 firms are not relatively inefficient in comparison to their related firms. Nonetheless, this calculation provides an interesting bound for the welfare effects of the program.

7.3 Robustness to Alternative Parameters

The structural model in Section 4 used calibrated values for the decreasing-returns-to-scale parameter α and for ρ, which determines the elasticity of substitution $\sigma = \frac{1}{1-\rho}$. This section discusses how our results are affected by changing the values of these parameters. To do so, we first vary the values of these parameters. We then reestimate the structural parameters following the same procedure as in Section 4. Finally, we solve for the regulated equilibrium that is implied by every pair of values of α and ρ.[62]

Panel C of Figure 11 shows how varying these parameters affects the estimated aggregate effects of the Top 1,000 program and the implied SCC. The red diamond plots the effects of the program under our baseline parameterization that sets $\alpha = 0.90$ and $\rho = 0.75$. Consider first

[61] Unfortunately, there is no comprehensive survey data covering a large sample of manufacturing firms that allows us to precisely measure differences in the energy efficiency of regulated, related, and competing firms in the market. Using the CESD, we observe in Panel A of Table 2, Top 1,000 firms are 10% less energy efficient than Top 10,000 firms. Based on this statistic, the 20% deviations we explore below allow for considerable differences in energy efficiency. Additionally, we report in Figure A.12 the SCC that rationalizes the policy when energy efficiencies differ by up to 50%.

[62] The value of α_l is determined by the value of α and the cost share of variable inputs. Additionally, we solve for a new regulation threshold $\tilde{\phi}$ to match the share of energy in regulated firms. Table A.17 reports the estimated model parameters across different specifications.

the effects of fixing $\alpha = 0.90$ and setting ρ at either 0.70 (so that $\sigma = 3.33$) or at 0.90 (so that $\sigma = 10$). These two cases are denoted in Panel C of Figure 11 by the green circles, which show that the aggregate effects of the policy are barely altered by changing σ. This result is driven by the fact that when σ is larger, the distributions of firm size and output imply a smaller variance of firm productivity ϕ. Thus, even though we would expect a larger market spillover for a larger value of σ, this effect is offset by the decrease in the dispersion in firm productivity.

Consider now the effect of fixing $\rho = 0.75$ and setting α to either 0.85 or 0.95. These two cases are denoted in Panel C of Figure 11 by the blue triangles. In this case, we find that lower values of α lead to both larger energy use reductions and larger price increases. The intuition for this result is that when production faces more decreasing returns to scale, conglomerates are less able to substitute production across related firms. Similarly, unregulated firms are less able to respond to the price increase by increasing their own production. Both of these forces lead to larger energy use reductions and price increases.

Across these cases, the reduction in aggregate energy use ranges between 2.9% ($\alpha = 0.95$) and 4.9% ($\alpha = 0.85$). In terms of the total reduction in energy use, these values imply annual aggregate energy savings of between 37 and 57 million tce. Since the parameter α governs the extent of energy leakage to related and unregulated firms, it is reasonable that uncertainty in this parameter should generate uncertainty in the aggregate energy use reduction. Interestingly, the change in the aggregate price covaries with the reduction in energy use. As a result, the ratio of the price change to the energy change varies very little. We denote this in the graph by plotting gray lines that correspond to the implied values of the SCC for each case. These lines show that across all these different parameterizations, the implied SCC that rationalizes the policy varies only between \$154 and \$165.

Overall, the values of α and ρ do not significantly affect our quantitative assessment of the fundamental trade-off faced by the government.

7.4 Imperfect Substitution within Conglomerates

The previous section shows that the welfare effects of the Top 1,000 program are robust to the use of a range of values for the parameters ρ and α. This section explores the robustness of our results to allowing the outputs of firms within a conglomerate to be imperfect substitutes. We now assume that conglomerates produce a composite good $q(\omega) = \left(\sum_i q(\omega, i)^{\rho_c}\right)^{1/\rho_c}$, where $0 < \rho < \rho_c < 1$. This assumption implies that consumers have a larger elasticity of substitution between products of firms in a given conglomerate than across goods produced by different conglomerates, i.e., $\frac{1}{1-\rho} < \frac{1}{1-\rho_c}$. As we show in Appendix G.3, many of the results of our baseline model extend to this case after slight modifications.[63] For instance, we redefine the total productivity of a

[63]Indeed, we obtain our baseline when $\rho_c = 1$. Table A.17 reports the estimated model under this extension.

conglomerate as $\phi\Delta_n^C$, where $\Delta_n^C = \left[\sum_{i=1}^{n} \delta^{\frac{(i-1)\rho_c}{1-\alpha\rho_c}}\right]^{\frac{1-\alpha\rho_c}{\rho_c}}$.

To operationalize this extension, we first reestimate the model assuming that $\rho_c = 0.90$. To gain intuition into how this extension impacts our model parameters, note that the share of the conglomerate's revenue from the i^{th} affiliate is now $\left(\frac{\delta^{i-1}}{\Delta_n^C}\right)^{\frac{\rho_c}{1-\alpha\rho_c}}$. Since $\rho_c < 1$, the within-conglomerate distribution of output in Panel A of Figure 3 implies a lower value of δ. Intuitively, since firms related to Top 1,000 firms are now less productive, the firm faces a greater productivity loss when shifting output to related firms. As a result, we estimate that $\delta = 0.80$ when we reestimate the model, which implies a larger shadow cost of the regulation of about 11%.

The black square in Panel C of Figure 11 plots the aggregate effects of the program under the assumption that $\rho_c = 0.90$. Two features of the model lead to larger decreases in energy use. First, the imperfect substitution of output within the conglomerate limits the extent to which regulated conglomerates can shift production to related firms. Second, the lower value of δ limits the extent of these spillovers. Both of these forces limit within-conglomerate leakage of energy use. However, these forces also lead to a larger price increase, which exacerbates market leakage by shifting production to unrelated firms. On the whole, we find larger price effects and energy savings. As the black square in Panel C of Figure 11 shows, these effects imply an SCC that is quite close to our baseline estimate.

8 Conclusion

This paper studies the effects of a prominent energy conservation program in China. We combine detailed data on energy use and business networks to study the effects of the regulation on both regulated firms and unregulated firms within the same conglomerate. While the program led regulated firms to decrease their energy use, this decrease was driven by a decline in production output and not by an increase in energy efficiency. We show that the program led to large increases in the output and energy use of unregulated firms in the same conglomerate. By shifting production to related firms, regulated conglomerates escaped close to 40% of the regulation-driven output reduction. The facts that regulated conglomerates were unable to fully shift lost output to related firms and that we find no impacts on the energy efficiency of regulated firms imply that regulated firms found it costly to increase their energy efficiency.

We calculate the shadow cost of the regulation using a model of conglomerate production that matches our setting and the reduced-form effects of the regulation. The model shows that even with the ability to shift some production to related firms, the regulation increased the cost of conglomerate production by 8.7%.

A welfare analysis of the aggregate effects of the policy on consumption and energy use characterizes the social cost of carbon that would be required for the Top 1,000 program to

raise welfare. Our results suggest that the program increases welfare as long as the social cost of carbon exceeds $160. We characterize uncertainty in this estimate by exploring a number of alternative model specifications and parameter values. Across these wide-ranging assumptions, we find that the SCC value that rationalizes the policy lies between $112 and $197. We also show that the government can improve the regulation of energy by targeting the energy use of conglomerates. These policies have lower shadow costs and are more effective from a welfare perspective.

Overall, this paper shows that the economic effects and the efficacy of policies that target large firms are modulated by substitution along ownership networks. Since ownership networks are public information, the results of our paper reveal a potential avenue for improvement of existing energy regulations.

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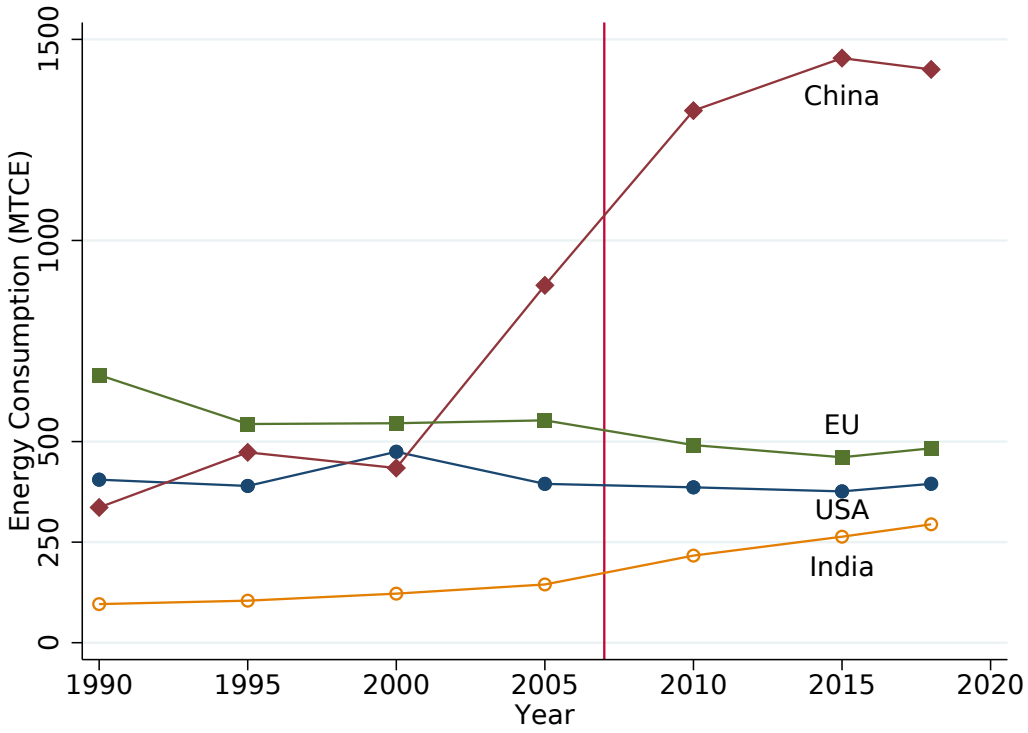
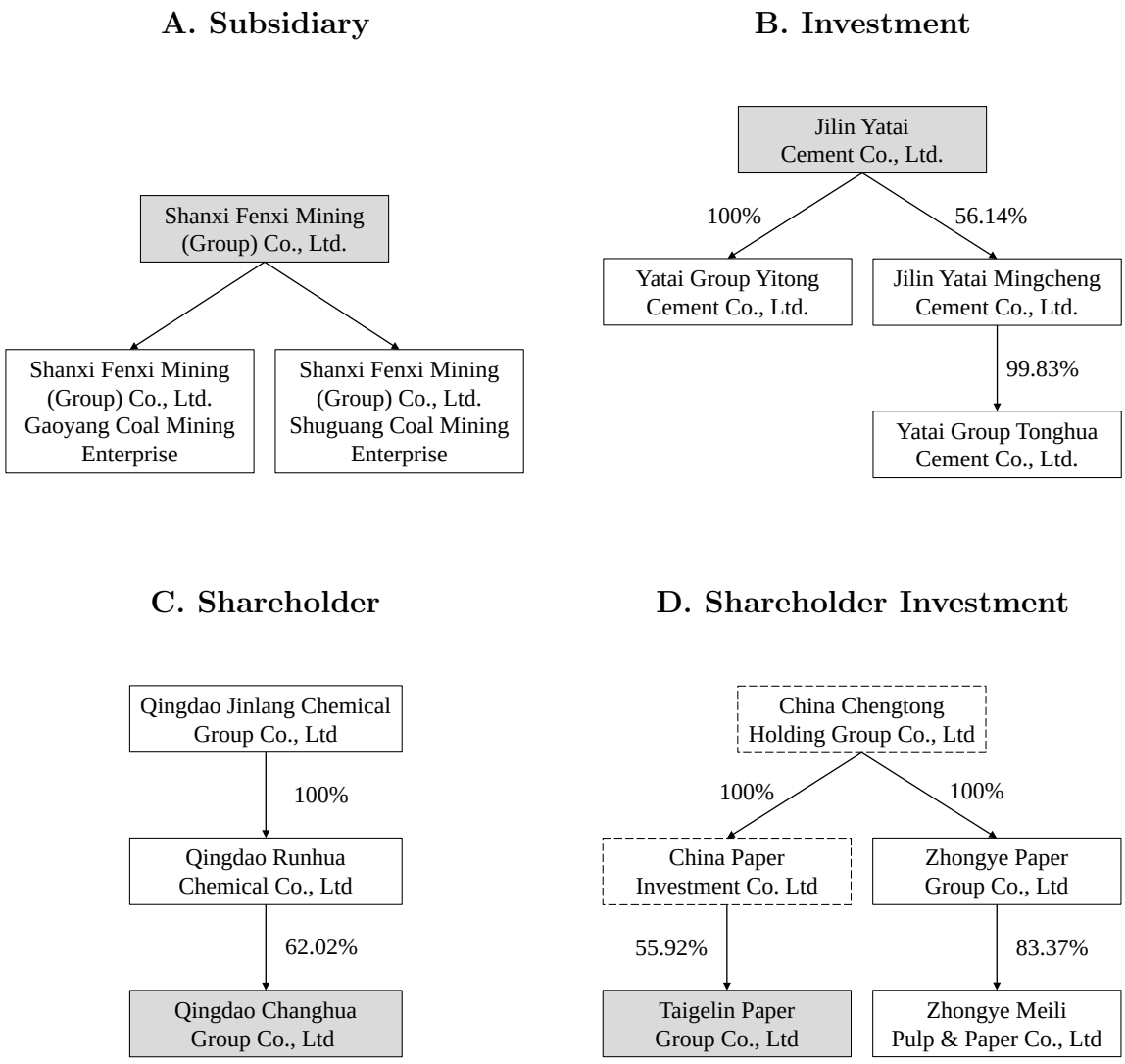
Figures

Figure 1: Cross-Country Differences in Industrial Energy Use



Notes: Authors' calculations using data from the IEA. This figure plots aggregate industrial energy consumption in China, the US, the EU and India from 1990 to 2018 using units of million tons of coal equivalent (MTCE). The industrial energy consumption of China increased dramatically after 2000, by more than threefold, while the industrial energy consumption of the US and EU remained relatively stable with a slight downward trend. The red line marks the start year of the Top 1,000 Energy Saving Program.

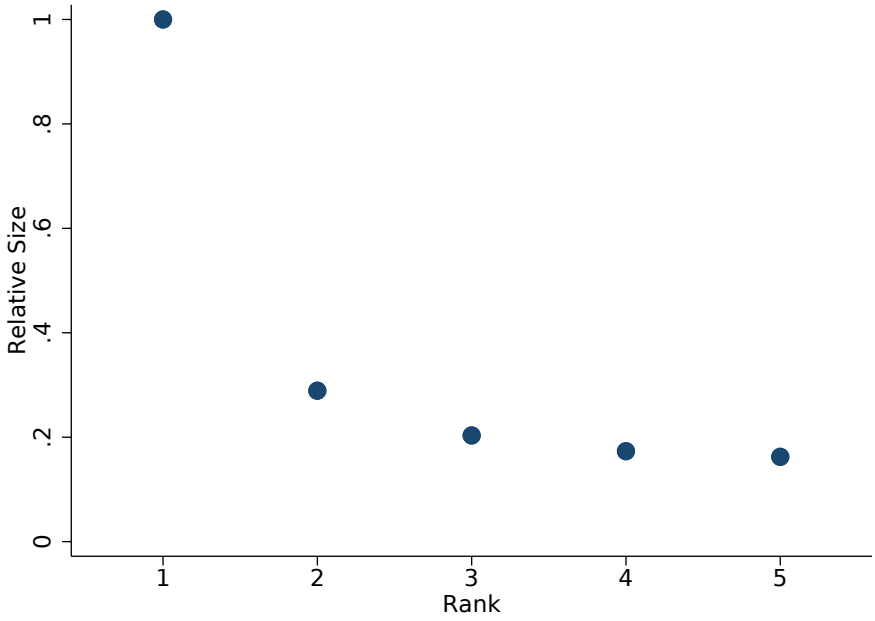
Figure 2: Examples of Firm Relations



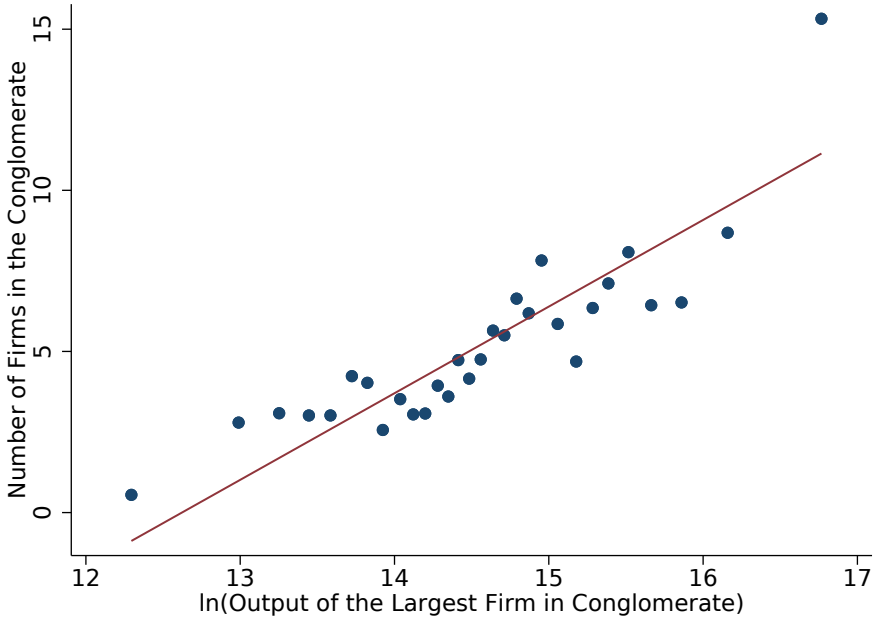
Notes: Authors' calculations using data from CARD. This figure shows examples of related firms, including wholly owned subsidiary firms in Panel A, investment firms in Panel B, shareholder firms in Panel C and shareholder investment firms in Panel D. Firms shaded in gray are part of the Top 1,000 program; firms without shading are part of the same conglomerate. In Panel D, we denote firms not in the same 4-digit industry as the Top 1,000 firm with dashed lines. Ownership share is reported next to each link. See Section 1.3 for the definition of related firms.

Figure 3: Conglomerate Size and Production Allocation

A. Relative Firm Size

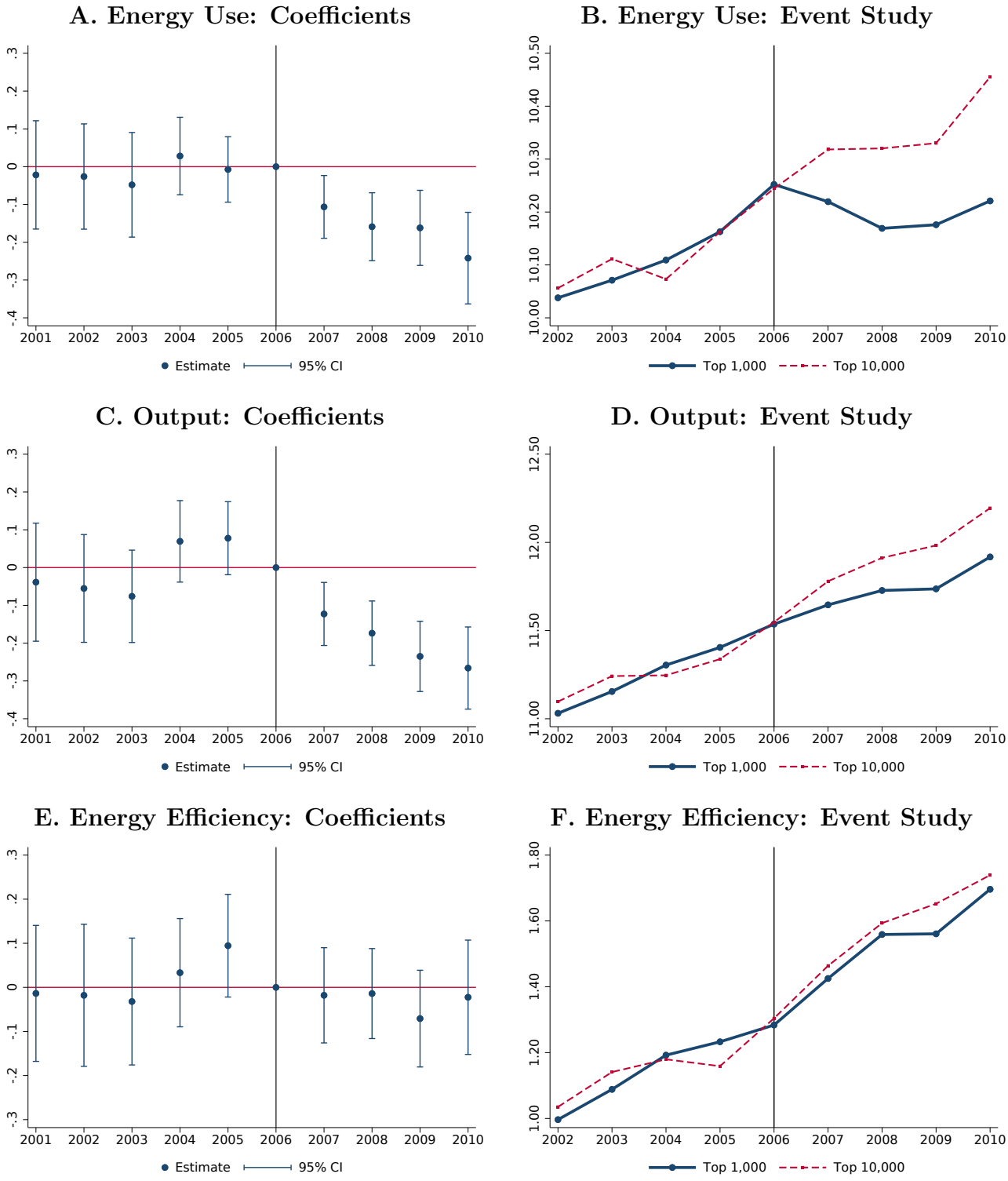


B. Output and Conglomerate Size



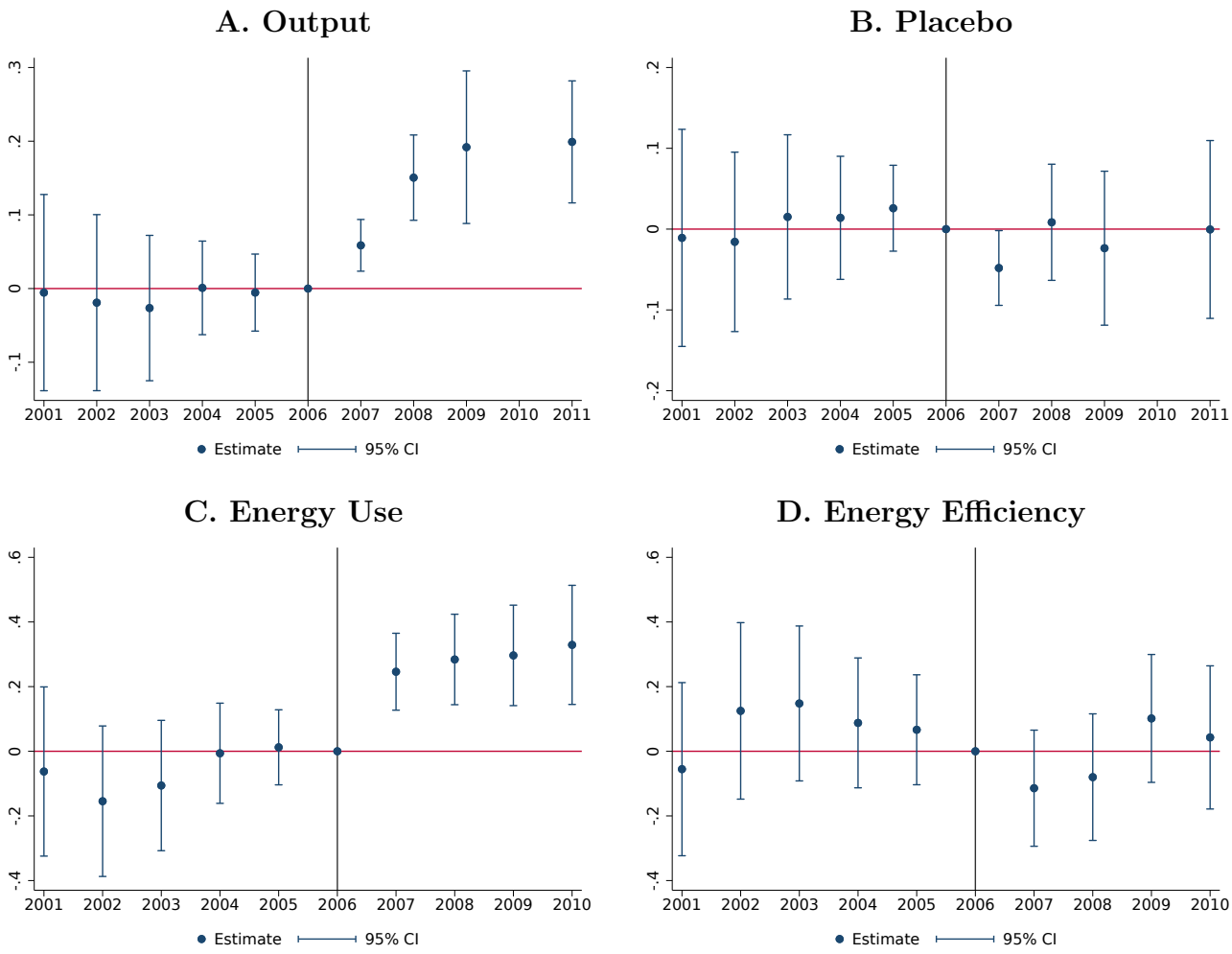
Notes: Authors' calculations using data from ASIF and CARD. This figure shows stylized facts about conglomerate size and relative firm size within conglomerate. Panel A plots the average relative size within a Top 1,000 conglomerate (each firm's size relative to the largest firm in the conglomerate). Firms are ranked by size from the largest to the smallest, and size is measured by industrial output. This figure shows that firm size declines very quickly in a conglomerate, with the second largest firm accounting for only 29% of the size of the largest. Panel B plots the results of a regression of firm number on log output of the largest firm in a Top 1,000 conglomerate. It shows that conglomerates with larger leading firms usually have more firms. See Section 1.3 for additional discussion46

Figure 4: Effects of the Program on Regulated Firms



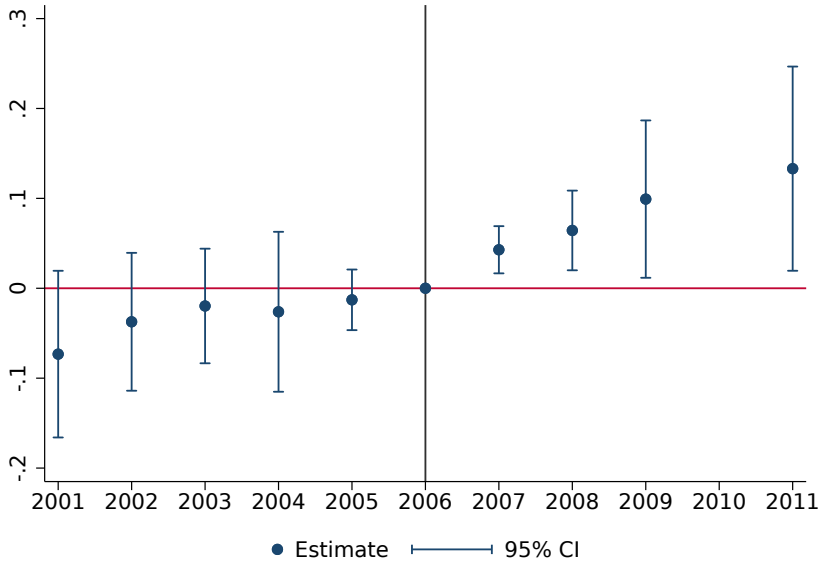
Notes: Authors' calculations using data from the CESD. This figure shows estimates of Equation 1 where the dependent variable is log firm energy consumption in Panels A and B, log firm output in Panels C and D, and log firm energy efficiency in Panels E and F. Energy efficiency is defined as output per unit of energy consumption. This figure shows that regulated firms (Top 1,000 firms) decreased their energy consumption and output substantially relative to similar control firms (Top 10,000 firms not related to Top 1,000 firms) after the regulation, while no improvement in energy efficiency in these regulated firms can be found. Point estimates are displayed in Table 3. See Section 2 for additional discussion. Standard errors are clustered at the firm level.

Figure 5: Spillover Effects on Related Firms



Notes: Authors' calculations using data from ASIF. This figure shows the effects of the Top 1,000 Energy Saving Program on the related parties of regulated firms. Panel A shows that related firms in the same 4-digit industry as regulated firms increased their output significantly after the policy implementation relative to similar control firms and that this effect persisted during the policy period. See Section 3 for a description of the procedure used to identify the comparison firms. The point estimate for Panel A is displayed in Panel A of Table 4. Panel B plots the output results for placebo firms (related firms in the same 2-digit industry but outside the 4-digit industry of regulated firms). This graph shows that placebo firms were not affected by the regulation. The point estimate for Panel B is displayed in Panel B of Table 4. Panels C and D show that related firms in the same 4-digit industry increased their energy consumption after the regulation but did not improve their energy efficiency relative to similar control firms. The point estimates for Panels C and D are displayed in Table 5. See Section 3 for additional discussion. The results of robustness checks using an alternative matching method are shown in Figure A.6. Standard errors are clustered at the firm level.

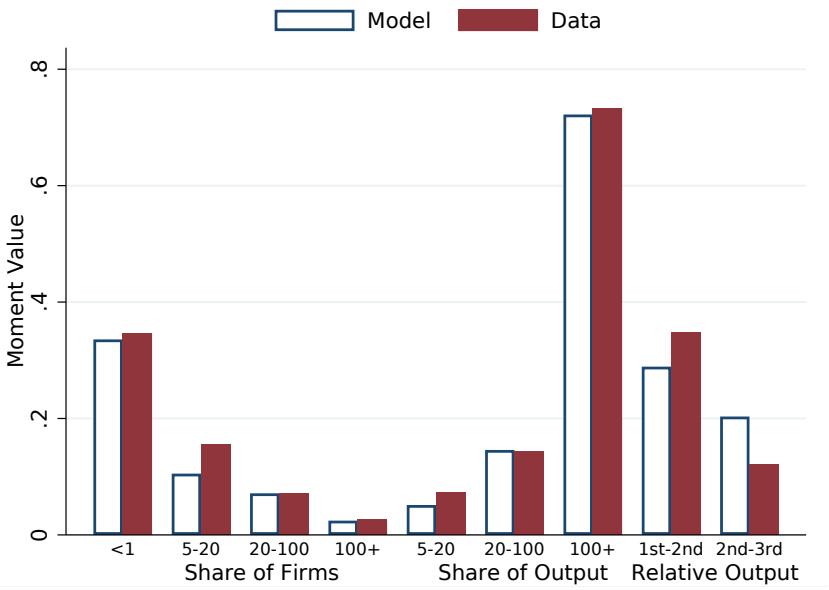
Figure 6: Industry-level Spillovers



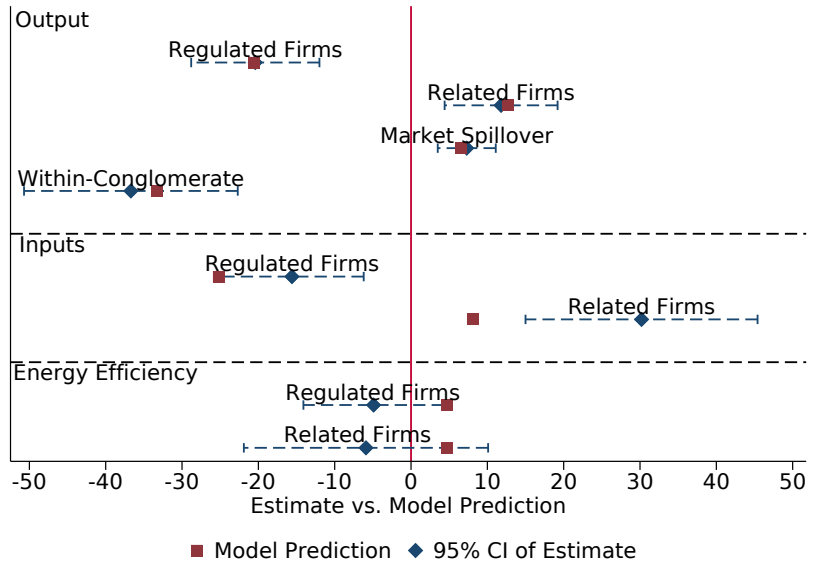
Notes: Authors' calculations using data from the ASIF. This figure shows estimates of Equation 3 where the dependent variable is log firm output. Consistent with the market spillover hypothesis, we see that unregulated firms in industries with stricter regulation increased their output significantly after the policy was implemented. Coefficient estimates and robustness checks are shown in Table 6 and Table A.16. See Section 3 for additional discussion. Standard errors are clustered at the firm level.

Figure 7: Structural Model Fit and Out-of-Sample Validation

A. Moments: Data vs. Model

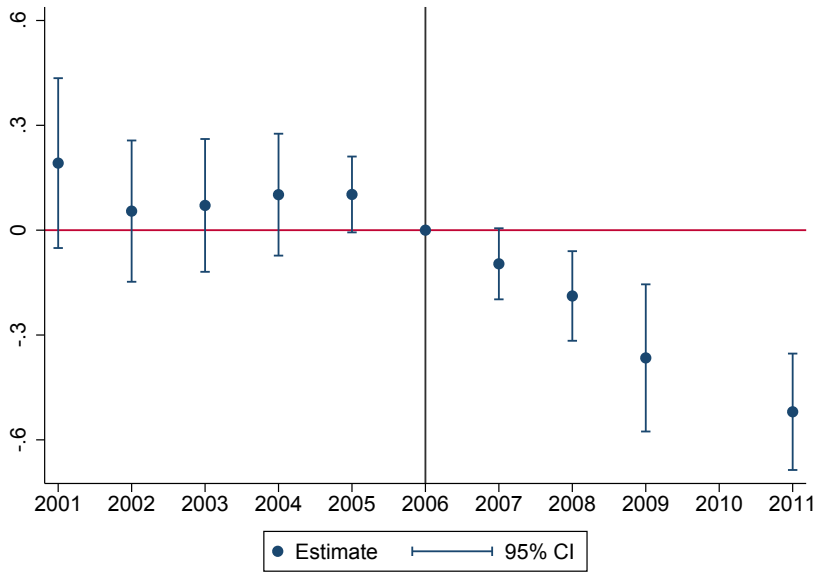


B. Out-of-Sample Validation: Difference-in-Differences Effects of the Program



Notes: This figure shows the model fitting for both the firm size distribution prior to the policy and the firm response after the policy. Panel A plots the size distribution of firms predicted by our model in blue bars and the size distribution calculated from the ASIF and economic census of 2004 in red bars. It shows that our model fits the data well for both the observed firm size distribution and the concentration of output prior to the regulation. Panel B plots the firm response predicted by the model in red squares and the firm response obtained from our previous difference-in-differences estimates in blue diamonds. The blue lines span the 95% confidence interval for our difference-in-differences estimates. This graph shows that our model does a good job of fitting the output, input, and efficiency response of firms, with almost all model-predicted values lying within the 95% confidence intervals. See Section 5.2 for additional discussion.

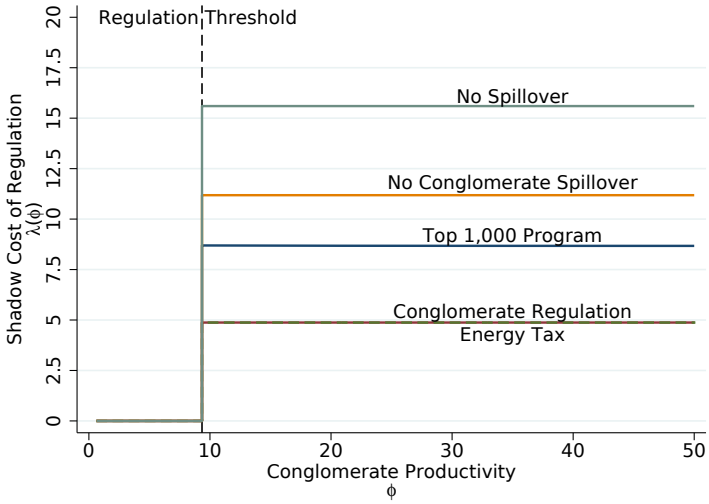
Figure 8: Within-Conglomerate Difference-in-Differences



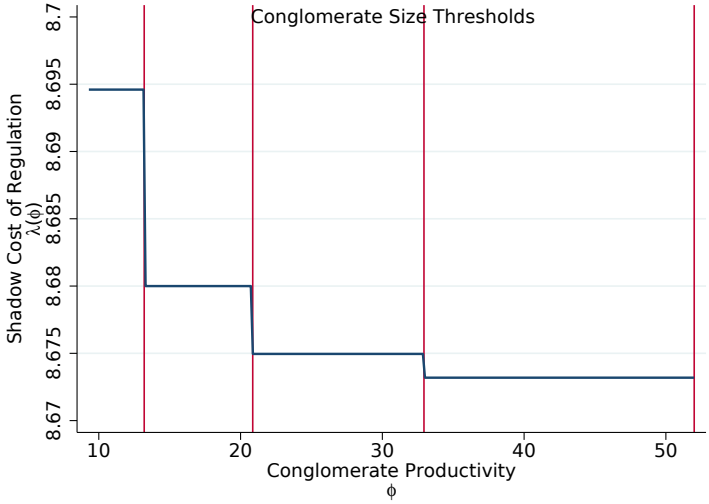
Notes: Authors' calculations using data from the ASIF. This figure plots the output change of regulated firms relative to their (same 4-digit industry) related firms within the same conglomerate. We see a strong and persistent output reallocation following the regulation from regulated firms to their related firms. Point estimates are displayed in Table 9. See Section 5.3 for additional discussion. Conglomerate-by-year fixed effects are included, and standard errors are clustered at the conglomerate level.

Figure 9: Model-Based Estimates of the Shadow Costs of Regulation

A. Shadow Costs of Alternative Regulations



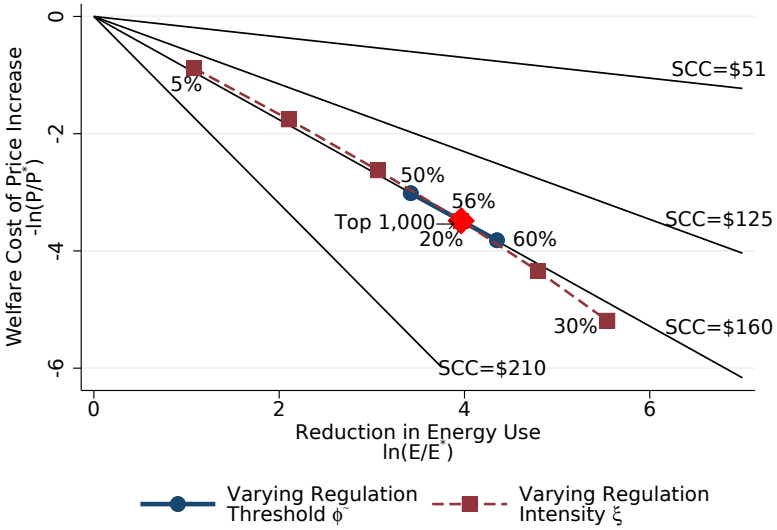
B. Size Distortions in Top 1,000 Program



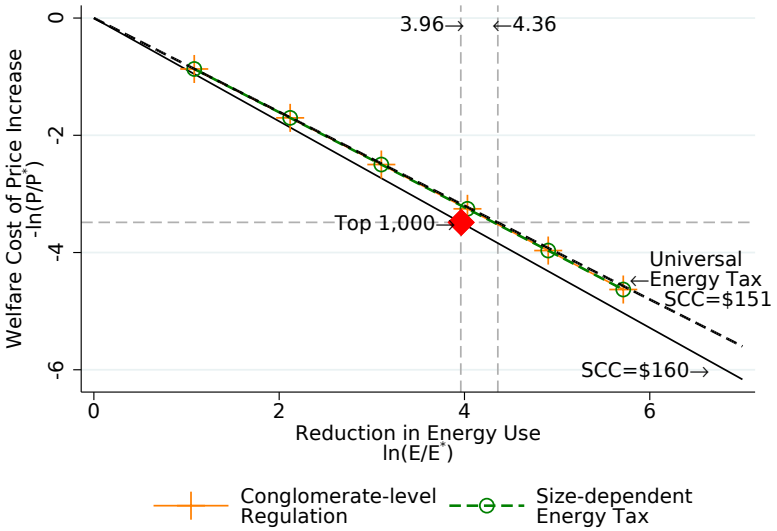
Notes: This figure shows the implied shadow cost of different regulations estimated by our model. Panel A plots the shadow cost of our baseline regulation (the Top 1,000 Energy Saving Program) with the blue line, the shadow cost of the counterfactual in which both conglomerate spillovers and market spillovers are shut down with the gray line, the shadow cost of the counterfactual in which only conglomerate spillovers are shut down with the yellow line, the shadow cost of regulating conglomerates with the same energy saving amount with the green line, and the shadow cost of imposing an energy tax with the same energy saving amount with the dashed red line. For each scenario, we solve the model and calculate the corresponding shadow cost. See Appendix E for the equilibrium conditions under these alternative regulations. We can see that both market spillovers and conglomerate spillovers lower the shadow cost substantially, while regulating conglomerates and imposing an energy tax can further lower the shadow cost by over 40% with the same amount of energy saving. Panel B zooms in to show the shadow cost under our baseline regulation. We see that shadow costs are no longer constant among different conglomerates as in Panel A. Conglomerates with more firms have a slightly lower shadow cost, while conglomerates with the same number of firms have the same shadow cost. See Section 6.1 and Section 6.2 for additional discussion.

Figure 10: Welfare Effects of Alternative Regulations

A. Changes to Top 1,000 Program



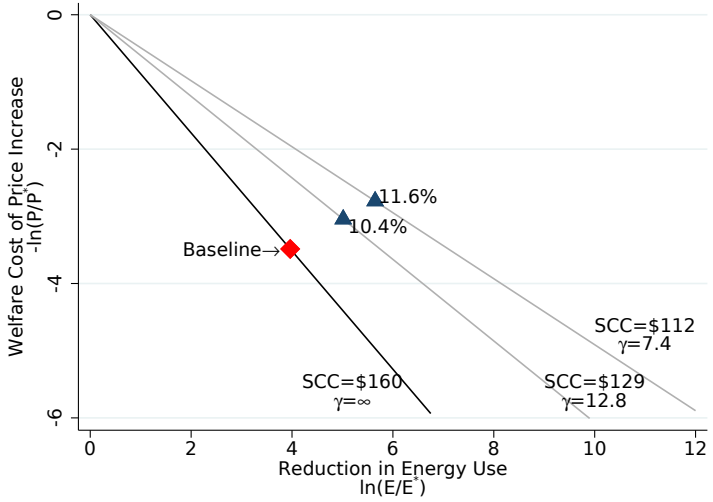
B. Alternative Regulations



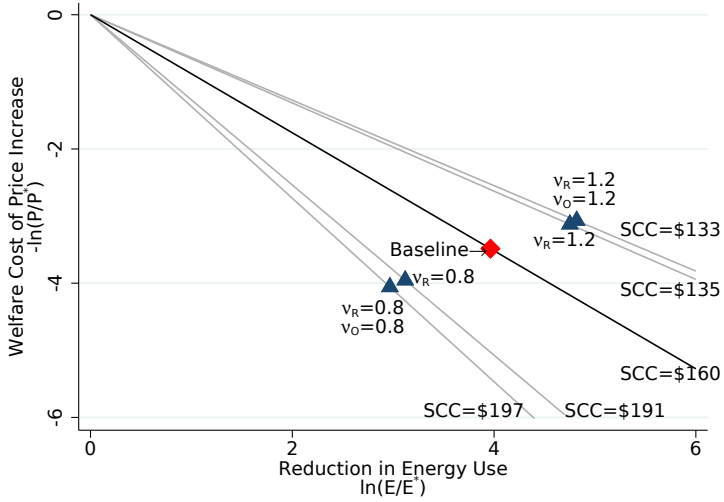
Notes: This figure shows the welfare effects of different regulations measured by the trade-off between reductions in energy use and the welfare cost of price increases. Panel A shows the welfare effects of the Top 1,000 program. The black lines are indifference curves for different SSCs. The red diamond shows that the Top 1,000 program led to an aggregate energy consumption reduction of close to 4% and a price level increase of about 3.5%, which can be rationalized with an SSC=$160. The navy line indicates that expanding or contracting policy coverage to cover between 50% and 60% of an industry's energy use does not change the fundamental trade-off between reductions in energy consumption and price increases. The crimson line indicates that increasing the input reduction quota from 5% to 30% makes this trade-off slightly worse. See Section 6.1 for additional discussion. Panel B shows the welfare effects under alternative types of regulations. Regulating conglomerates and imposing a size-dependent energy tax show a similar trade-off at an SSC=$152, which is a better performance than that of the original policy. A universal energy tax performs even better, with SSC=$151. See Section 6.2 for additional discussion.

Figure 11: Welfare Effects: Robustness

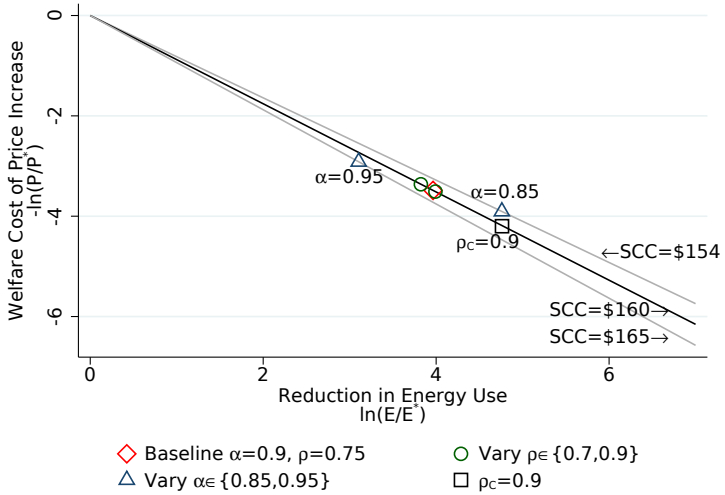
A. Endogenous Energy Efficiency



B. Heterogeneous Energy Efficiency



C. Alternative Parameters



Notes: This figure shows the robustness of the welfare effects of the Top 1,000 program. The black lines plot indifference curves for the baseline value of SCC=$160, and the light gray lines plot values of the SCC according to different extensions. Panel A shows the effects under different values of the parameter γ, which determines the cost of improving energy efficiency. See Section 7.1 for details. Panel B shows the effects when we assume preexisting differences in energy efficiency. $\nu_R > 1$ denotes that related firms are more energy efficient than Top 1,000 firms, while $\nu_O < 1$ denotes that unregulated and unrelated firms are less efficient than Top 1,000 firms and vice versa. See Section 7.2 for details. Panel C shows the effects when we assume different values of the calibrated parameters. Blue triangles hold $\alpha = 0.9$ and vary $\rho \in \{0.7, 0.9\}$, while green circles hold $\rho = 0.75$ and vary $\alpha \in \{0.85, 0.98\}$. See Section 7.3 for details. The black square in Panel C plots the effects when we assume that the outputs of firms in a conglomerate are imperfect substitutes (i.e., $\rho_c = 0.9$). See Section 7.4 for details. Across these wide-ranging assumptions, the SCC that rationalizes the Top 1,000 program lies between $112 and $197.

Tables

Table 1: Energy Consumption of Top 1,000 Firms in Different Industries

Industry	Energy Consumption (10,000 ton coal equiv.)	Proportion (%)	Firm Number
Iron and Steel	22528.63	30.72	249
Electric Power	16249.64	22.16	144
Chemical	10909.29	14.88	238
Petroleum and Petrochemical	10581.76	14.43	98
Mining	5278.77	7.20	60
Nonferrous	2993.08	4.08	70
Construction Materials	2913.19	3.97	93
Pulp and Paper	961.36	1.31	24
Textile	917.57	1.25	22

Notes: This table reports the number of firms and energy consumption of Top 1,000 firms in each industry in 2005 according to the National Development and Reform Commission (NDRC) and National Bureau of Statistics (NBS) of China (Bulletin on Top 1,000 Firms' Energy Consumption, 2007). The first column shows the industry name, the second column shows the aggregate energy consumption of Top 1,000 firms in each industry in 2005, the third column shows the proportion of energy consumption, and the last column shows the number of firms. A total of 998 of the 1008 Top 1,000 firms are included in this report.

Table 2: Summary Statistics

A. Firm-level Data

Source	Variables	Top 1,000			Top 10,000 (Excluding Top 1,000)		
		Obs	Mean	SD	Obs	Mean	SD
CESD	ln(Energy)	3,419	12.37	1.48	20,207	9.84	1.58
	ln(Output)	3,381	13.69	1.66	20,076	11.26	1.58
	ln(Efficiency)	3,381	1.31	1.45	20,076	1.42	1.71
ASIF	Soe	3,405	0.26	0.44	19,386	0.08	0.28
	ROA	3,236	0.04	0.09	17,790	0.07	0.15
	Age	3,253	23.95	19.61	18,202	12.64	12.18
	Export	3,415	0.30	0.46	20,151	0.11	0.31

B. Conglomerate Networks: Related Parties

Datasets	Two Levels			Six Levels
	25%	20%	51%	20%
CARD	46,178	50,846	30,096	77,783
CARD&ASIF	7,329	7,907	5,061	9,832
CARD&ASIF (same 2-digit industry)	3,992	4,137	2,941	4,800
CARD&ASIF (same 4-digit industry)	**2,466**	2,514	1,963	2,827

Notes: This table reports summary statistics for Top 1,000 firms, Top 10,000 firms, and the conglomerate networks of Top 1,000 firms. Panel A shows the mean characteristics and firm counts with nonmissing data from the ASIF and CESD for Top 1,000 and Top 10,000 firms. We exclude related firms from the same 4-digit industry as Top 10,000 firms for both datasets. Additionally, for the CESD data, we exclude all industries whose electricity consumption accounts for more than 30% of total industry energy consumption. Output value is in thousands of RMB. Energy is measured in tons of coal equivalent. Energy efficiency is defined as thousands RMB of output per ton of energy input. See Section 1.2 for a detailed data description and the cleaning procedure. Panel B shows the total number of related firms that Top 1,000 firms have under different definitions of related parties. With 2 levels and a 25% ownership requirement, Top 1,000 firms have 3,992 related firms in the same 2-digit industry in the ASIF and 2,466 related firms in the same 4-digit industry in the ASIF. See Section 1.3 for additional discussion.

Table 3: Effects of the Program on Regulated Firms

A. Energy Use

Variables	ln(Energy Use)			
Treat × Post	-0.125***	-0.156***	-0.156***	-0.128***
	(0.042)	(0.045)	(0.047)	(0.048)
Observations	23,607	23,602	23,151	20,571
R^2	0.887	0.890	0.892	0.898

B. Output

Variables	ln(Output)			
Treat × Post	-0.096**	-0.226***	-0.204***	-0.145***
	(0.040)	(0.041)	(0.042)	(0.042)
Observations	23,435	23,430	22,991	20,446
R^2	0.881	0.887	0.889	0.893

C. Energy Efficiency

Variables	ln(Energy Effiency)			
Treat × Post	0.032	-0.069	-0.049	-0.019
	(0.042)	(0.044)	(0.046)	(0.047)
Observations	23,435	23,430	22,991	20,446
R^2	0.837	0.840	0.842	0.848
Firm FE	Y	Y	Y	Y
Year FE	Y	Y	Y	Y
Industry × Year FE		Y	Y	Y
Province × Year FE			Y	Y
Firm-level Controls				Y

Notes: Authors' calculations using data from the CESD and ASIF. This table shows estimates of Equation 2 where Treat × Post is an indicator for regulated firms interacted with an indicator for years after 2006 and the dependent variable is log firm energy consumption in Panel A, log firm output in Panel B, and log firm energy efficiency in Panel C. The estimates in this table correspond to a pooled version of the regression displayed in Figure 4. The coefficient in column (4) means that regulated firms decreased energy consumption by 12.8% and output by 14.5%, while no significant energy efficiency improvement after the policy implementation can be found. See Section 2 for additional discussion and Table 2 for more information about the data and variables. Standard errors clustered at the firm level are shown in parentheses with p-values below. * $p<0.1$, ** $p<0.05$, *** $p<0.01$.

Table 4: Spillover Effects on the Output of Related Firms

A. Output

Variables	ln(Output)			
Related × Post	0.152***	0.147***	0.118***	0.127***
	(0.037)	(0.037)	(0.037)	(0.035)
Observations	18,423	18,420	18,418	17,905
R^2	0.865	0.873	0.881	0.889

B. Placebo Test on Output

Variables	ln(Output)			
Related × Post	-0.026	-0.025	-0.015	-0.003
	(0.040)	(0.039)	(0.039)	(0.038)
Observations	8,923	8,921	8,905	8,730
R^2	0.898	0.903	0.911	0.919

C. Heterogeneous Effects on Output by Firm Size

Variables	ln(Output)			
Related × Post(0%-30%)	0.104*	0.109**	0.048	0.078
	(0.054)	(0.052)	(0.052)	(0.051)
Related × Post(30%-60%)	0.130***	0.123***	0.096**	0.111**
	(0.047)	(0.045)	(0.046)	(0.043)
Related × Post(60%-100%)	0.164***	0.156***	0.161***	0.161***
	(0.045)	(0.044)	(0.043)	(0.040)
Observations	17,691	17,691	17,689	17,212
R^2	0.892	0.900	0.907	0.915
Firm FE	Y	Y	Y	Y
Year FE	Y	Y	Y	Y
Industry × Year FE		Y	Y	Y
Province × Year FE			Y	Y
Firm-level Controls				Y

Notes: Authors' calculations using data from the ASIF. This table shows estimates of Equation 2 where Related × Post is an indicator for related firms interacted with an indicator for years after 2006 and the dependent variable is log firm output. The estimates in Panel A correspond to a pooled version of the regression displayed in Panel A of Figure 5. It shows that related firms in the same 4-digit industries increased output by 11.8%–15.2% after the policy implementation. The estimates in Panel B correspond to a pooled version of the regression displayed in Panel B of Figure 5 and show that related firms outside the 4-digit industry of regulated firms (but still in the same 2-digit industry) were not significantly affected by the policy. Panel C shows estimates of heterogeneous spillover effects by terciles of firm size. We can see that the related spillovers are greater for larger related firms. See Section 3 for additional discussion. The results of robustness checks with additional matching methods are shown in Table A.9. Standard errors clustered at the firm level are shown in parentheses with p-values below. * $p<0.1$, ** $p<0.05$, *** $p<0.01$.

Table 5: Spillover Effects on Related Firms: Energy Use and Energy Efficiency

A. Energy Use

Variables	ln(Energy Use)			
Related × Post	0.322***	0.320***	0.302***	0.318***
	(0.075)	(0.073)	(0.076)	(0.094)
Observations	3,759	3,759	3,705	2,823
R^2	0.916	0.919	0.927	0.926

B. Energy Efficiency

Variables	ln(Energy Efficiency)			
Related × Post	-0.077	-0.077	-0.059	-0.087
	(0.078)	(0.077)	(0.080)	(0.099)
Observations	3,724	3,722	3,668	2,801
R^2	0.866	0.870	0.880	0.867
Firm FE	Y	Y	Y	Y
Year FE	Y	Y	Y	Y
Industry × Year FE		Y	Y	Y
Province × Year FE			Y	Y
Firm-level Controls				Y

Notes: Authors' calculations using data from the CESD and ASIF. This table shows estimates of Equation 2 where Related × Post is an indicator for same 4-digit industry related firms interacted with an indicator for years after 2006 and the dependent variable is log firm energy consumption in Panel A and log firm energy efficiency in Panel B. The estimates in this table correspond to a pooled version of the regression displayed in Panels C and D of Figure 5. This figure shows that same 4-digit related firms increased their energy consumption by 30.2%–32.2% after the policy implementation but that their energy efficiency did not improve significantly. See Section 3 for additional discussion. The results of robustness tests with additional matching methods are shown in Table A.10. Standard errors clustered at the firm level are shown in parentheses with p-values below. * $p<0.1$, ** $p<0.05$, *** $p<0.01$.

Table 6: Industry-level Spillovers

Variables	ln(Output)			
	All Sample		Energy-Intensive Industries	
Spillover × Post	0.081***	0.073***	0.083***	0.084**
	(0.022)	(0.019)	(0.023)	(0.027)
Observations	2,557,940	2,557,940	843,313	843,313
R^2	0.840	0.856	0.831	0.848
Firm FE	Y	Y	Y	Y
Year FE	Y	Y	Y	Y
Industry-level Controls	Y	Y	Y	Y
Firm-level Controls		Y		Y

Notes: Authors' calculations using data from the ASIF. This table shows estimates of Equation 3 where Spillover × Post is an indicator for industry-level exposure to the Top 1,000 program interacted with an indicator for years after 2006 and the dependent variable is log firm output. Exposure to Top 1,000 program is defined as the proportion of total energy saving targets of Top 1,000 firms relative to the total energy consumption in 2004 for each industry. The estimates in this table correspond to a pooled version of the regression displayed in Figure 6. The results show that the average market-level spillover led to a 7.3%–8.4% increase in the output of unregulated firms. See Section 3 for additional discussion. Standard errors clustered at the firm level are shown in parentheses with p-values below. * $p<0.1$, ** $p<0.05$, *** $p<0.01$.

Table 7: Structural Model Parameters

Parameter		Value	Target
1. Fixed Values			
Elasticity of substitution	$\sigma = \frac{1}{1-\rho}$	4.00	Melitz and Redding (2015)
Returns to scale	α	0.90	Burnside, Eichenbaum and Rebelo (1995)
Returns to scale (Labor Share)	α_l	0.80	Cost share of variable inputs
2. Method of Moments			
Efficiency depreciation	δ	0.900	Within-conglomerate distribution
		(0.003)	
Dispersion of ln-ability ϕ	σ_m	1.239	Firm size distribution
		(0.055)	
Survival threshold	ϕ_1	0.609	Share of small firms
		(0.166)	
3. Policy Parameters			
Policy threshold	$\tilde{\phi}$	9.29	Energy share of Top 1,000 firms
Input quota	$1-\xi$	0.20	11th Five Year Plan

Notes: This table summarizes the parameters that we set or estimate to solve the model. Standard errors are calculated using a bootstrapped variance-covariance matrix of data moments. See Section 5.1 for the detailed estimation procedure.

Table 8: Model Decomposition of Difference-in-Differences Estimates

	Allocation Effect	Residual Revenue Effect	Market Effect	Total Effect
A. Effect on Regulated Firms				
Top 1,000 Firms	-0.129	-0.037	0.026	-0.140
Control Firms	0	0.039	0.026	0.065
Difference-in-Differences	-0.129	-0.076	0	-0.205
B. Effect on Related Firms				
Related Firms	0.204	-0.037	0.026	0.193
Control Firms	0	0.039	0.026	0.065
Difference-in-Differences	0.204	-0.076	0	0.128
C. Within-Conglomerate Effect				
Difference-in-Differences	-0.333	0	0	-0.333

Notes: This table reports the decomposition results for difference-in-differences estimates according to the model. Panels A, B, and C in this table correspond to Panel B of Table 3, Panel A of Table 4, and Table 9 separately by decomposing the difference-in-differences estimates first into the effects on treated and control firms and then further into allocation effects, residual revenue effects and market effects. See Section 5.3 for additional discussion.

Table 9: Within-Conglomerate Difference-in-Differences

Variables	ln(Output)			
Treat × Post	-0.343***	-0.350***	-0.367***	-0.315***
	(0.067)	(0.068)	(0.070)	(0.067)
Observations	15,174	15,149	15,146	14,745
R^2	0.530	0.535	0.582	0.626
Treat	Y	Y	Y	Y
Conglomerate × Year FE	Y	Y	Y	Y
Industry × Year FE		Y	Y	Y
Province × Year FE			Y	Y
Firm-level Controls				Y

Notes: Authors' calculations using data from the ASIF. This table shows the output change of regulated firms relative to that of their (same 4-digit industry) related firms within the same conglomerate. Treat × Post is an indicator for regulated firms (Top 1,000 firms) interacted with an indicator for years after 2006, and the dependent variable is log firm output. The estimates in this table correspond to a pooled version of the regression displayed in Figure 8 and show that regulated firms experience a 31.5%–36.7% output decrease relative to the output of their related firms in the same conglomerate. See Section 5.3 for additional discussion. Conglomerate-by-year fixed effects are included, and standard errors clustered at the conglomerate level are shown in parentheses with p-values below. * $p<0.1$, ** $p<0.05$, *** $p<0.01$.

Online Appendix: Not For Publication

This appendix contains multiple additional analyses. Appendix A describes in more detail the data construction. Appendix B shows that our results are robust to accounting for competing policies in this time period. Appendix C shows that the program did not lead to a significant shift in production toward locations with higher emissions and population density. Appendix D provides a detailed derivation of our baseline model. Appendix E describes how we model alternative regulations. Appendix F examines the effects of the program when we shut down market and conglomerate-level spillovers. Finally, Appendix G details the extensions of the model.

A Details of the Data Merge

Table A.2 shows the results of our data construction. We merge the lists of regulated firms using both firm name and the unique legal identifier. Since the Top 1,000 and Top 10,000 firms are all large firms, the match rate with the ASIF is very high. We match over 99% of Top 1,000 firms and over 97% of Top 10,000 firms. We also have a fairly good match rate with the CESD, where we match over 80% of Top 1,000 and over 70% of Top 10,000 firms. Overall, our combined datasets capture the majority of the economic activity in Top 1,000 and Top 10,000 firms.

B Robustness of Effects on Regulated Firms to Competing Policies

This appendix explores the robustness of our results to competing polices. Specifically, in the same time period when the Top 1,000 program was implemented, the Chinese government also adopted the National Specially Monitored Firms (NSMF) program. This is an environmental policy targeting over 6,500 firms in China listed as high polluters in 2007 with a selection rule for firms' COD, NH_4^+, SO_2, smoke and industrial dust emissions in 2005. Half of Top 1,000 firms and 14% of Top 10,000 firms were included on the NSMF list.

We now show that our estimated effects of the Top 1,000 program are not driven by this competing policy. Consider first the effect of the NSMF program within the group of firms in the Top 1,000 program. Panel A of Table A.6 reports estimates of a difference-in-differences model of the effects of the NSMF program and shows that it had little effect on the energy use, output, and energy efficiency of Top 1,000 firms. We also consider whether the NSMF program impacts our estimates of the effects of the Top 1,000 program on regulated firms. Panel B reports estimates of the effects of the Top 1,000 program when we exclude all treated firms included under both polices. Panel B shows that we obtain results similar to those in our baseline regressions when

we leave out the all Top 1,000 firms included under the NSMF program. These findings suggest that taking the NSMF program into account does not affect our main results.

C Heterogeneous Effects of Spillovers by Local Density and Pollution

One important concern is that the spillovers that we identify may have shifted the location of production and of related emissions to more populated areas and areas with higher levels of preexisting industrial emissions. To address this concern, we first use data on city-level sulphur dioxide emissions and population density to generate the following measure of exposure: $\frac{City\ SO_2\ Emission \times Population}{CityArea}$. We then calculate the difference in this exposure measure between each pair of regulated and related firms. Next, we split our sample by terciles of this measure. Table A.20 shows that related firms in places with lower or similar exposure increased their output by 10%, while those in more exposed areas saw larger increases of close to 22%. However, because a higher share of the output of related firms was concentrated in less exposed areas (58% in relatively less exposed vs. 28% in relatively more exposed areas), we find similar increases in production across more and less exposed areas. Overall, the spillover effects of the regulation did not disproportionately shift production to areas with higher population density or higher preexisting levels of industrial emissions.

D Model Appendix

This appendix provides detailed model derivations.

D.1 Model Equilibrium

Recall that the conglomerate takes the prices of energy p_e, capital r, and the variable input bundle w as given. Given the Leontief technology, the conglomerate sets $l_i = e_i$ so that the cost of intermediate inputs is $w + p_e$. Holding the number of affiliates n constant, the conglomerate maximizes

$$\pi(\phi, n) = \max_{\{l_i\}_{i=1}^n, \{k_i\}_{i=1}^n} \left\{ R^{1-\rho} P^\rho \left[\sum_{i=1}^n \phi \delta^{i-1} k_i^{\alpha_k} l_i^{\alpha_l} \right]^\rho - (w + p_e) \sum_{i=1}^n l_i - r \sum_{i=1}^n k_i \right\}.$$

For a firm i, the first-order conditions for l_i and k_i imply that $l_i = \frac{\alpha_l}{\alpha_k} \frac{r}{(w+p_e)} k_i$.

Substituting this expression, we can write the profit maximization problem as

$$\pi(\phi, n) = \max_{\{k_i\}_{i=1}^n} \left\{ R^{1-\rho} P^\rho \left[\sum_{i=1}^n \phi \delta^{i-1} k_i^{\alpha} \left(\frac{\alpha_l}{\alpha_k} \frac{r}{(w + p_e)} \right)^{\alpha_l} \right]^\rho - \left(\frac{\alpha}{\alpha_k} r \right) \sum_{i=1}^n k_i \right\}.$$

Comparing the first-order conditions for k_1 and k_i, we find that $\frac{k_i}{k_1} = \delta^{\frac{i-1}{1-\alpha}}$. The final result from Proposition 1 follows since

$$q_i = \phi\delta^{i-1}k_i^{\alpha}\left(\frac{\alpha_l}{\alpha_k}\frac{r}{(w+p_e)}\right)^{\alpha_l} = \phi\delta^{\frac{i-1}{1-\alpha}}k_1^{\alpha}\left(\frac{\alpha_l}{\alpha_k}\frac{r}{(w+p_e)}\right)^{\alpha_l} = \delta^{\frac{i-1}{1-\alpha}}q_1.$$

Using these results, we can write the profit maximization problem in terms of $K_n = \sum_i^n k_i$. To do so, we define the conglomerate's total productivity $\phi\Delta_n = \phi[\sum_{i=1}^n(\delta^{i-1})^{\frac{1}{1-\alpha}}]^{1-\alpha}$ and the constant $C_\pi = (1-\alpha\rho)\left[\left(\frac{\rho\alpha_l}{w+p_e}\right)^{\alpha_l\rho}\left(\frac{\rho\alpha_k}{r}\right)^{\alpha_k\rho}\right]^{\frac{1}{1-\alpha\rho}}$ to obtain

$$\pi(\phi,n) = \max_{K_n}\left\{\frac{R^{1-\rho}P^{\rho}C_\pi^{1-\alpha\rho}}{(1-\alpha\rho)^{1-\alpha\rho}}\left(\frac{\rho\alpha_k}{r}\right)^{-\alpha\rho}(\phi\Delta_n)^{\rho}K_n^{\alpha\rho} - r\left(\frac{\alpha}{\alpha_k}\right)K_n\right\}.$$

The optimal capital K_n and the firm profits for a conglomerate of size n are then

$$K_n = \frac{R^{\frac{1-\rho}{1-\alpha\rho}}P^{\frac{\rho}{1-\alpha\rho}}C_\pi}{(1-\alpha\rho)}\frac{\rho\alpha_k}{r}(\phi\Delta_n)^{\frac{\rho}{1-\alpha\rho}} \quad \text{and} \quad \pi(\phi,n) = R^{\frac{1-\rho}{1-\alpha\rho}}P^{\frac{\rho}{1-\alpha\rho}}C_\pi(\phi\Delta_n)^{\frac{\rho}{1-\alpha\rho}}.$$

The optimal profit given ϕ is then

$$\pi(\phi) = \max_n \pi(\phi,n) - rfn = \max_n R^{\frac{1-\rho}{1-\alpha\rho}}P^{\frac{\rho}{1-\alpha\rho}}C_\pi \times (\phi\Delta_n)^{\frac{\rho}{1-\alpha\rho}} - rfn.$$

Solving for indifference points ϕ_n yields the result of Proposition 2 and the zero-profit condition (Equation 7).

We now compute the price level. For given quantities $q(\phi,n)$, the price level is given by

$$P^{-\rho} = R^{-\rho}\int_{\phi_1} q(\phi,n)^{\rho}\frac{g(\phi)M}{1-G(\phi_1)}d\phi.$$

To differentiate from the regulated case below, we use starred variables to denote prices and quantities in the unregulated case. To derive $q^*(\phi,n)$, note from Proposition 1 that $K_n = k_1\Delta_n^{\frac{1}{1-\alpha}}$ and also recall that $l_1 = \frac{\alpha_l}{\alpha_k}\frac{r}{(w+p_e)}k_1$. We then have

$$\begin{aligned} q^*(\phi,n) &= \Delta_n^{\frac{1}{1-\alpha}}q_1^*(\phi,n) \\ &= \Delta_n^{\frac{1}{1-\alpha}}\phi\left(\frac{\alpha_l}{\alpha_k}\frac{r}{(w+p_e)}\right)^{\alpha_l}k_1^{*\alpha} \\ &= (\phi\Delta_n)^{\frac{1}{1-\alpha\rho}}R^{\frac{(1-\rho)\alpha}{1-\alpha\rho}}P^{*\frac{\rho\alpha}{1-\alpha\rho}}\underbrace{\rho^{\frac{\alpha}{1-\alpha\rho}}\left[\left(\frac{\alpha_l}{w+p_e}\right)^{\alpha_l}\left(\frac{\alpha_k}{r}\right)^{\alpha_k}\right]^{\frac{1}{1-\alpha\rho}}}_{=C_Q}. \end{aligned} \tag{D.1}$$

The price level absent the regulation is then

$$\begin{aligned}
P^{*-\rho} &= R^{-\rho}\int_{\phi_1}\left((\phi\Delta_n)^{\frac{1}{1-\alpha\rho}}R^{\frac{(1-\rho)\alpha}{1-\alpha\rho}}P^{*\frac{\rho\alpha}{1-\alpha\rho}}C_Q\right)^{\rho}\frac{g(\phi)M}{1-G(\phi_1)}d\phi \\
P^{*\frac{-\rho}{1-\alpha\rho}}R^{\frac{(1-\alpha)\rho}{1-\alpha\rho}}C_Q^{-\rho} &= \int_{\phi_1}(\phi\Delta_n)^{\frac{\rho}{1-\alpha\rho}}\frac{g(\phi)M}{1-G(\phi_1)}d\phi. \\
P^{*\frac{-\rho}{1-\alpha\rho}}R^{\frac{(1-\alpha)\rho}{1-\alpha\rho}}C_Q^{-\rho}\frac{1-G(\phi_1)}{M} &= \int_{\phi_1}(\phi\Delta_n)^{\frac{\rho}{1-\alpha\rho}}g(\phi)d\phi \\
P^{*\frac{-\rho}{1-\alpha\rho}}R^{\frac{(1-\alpha)\rho}{1-\alpha\rho}}C_Q^{-\rho}\frac{1-G(\phi_1)}{M} &= \sum_n \Delta_n^{\frac{\rho}{1-\alpha\rho}}\underbrace{\int_{\phi_n}^{\phi_{n+1}}(\phi)^{\frac{\rho}{1-\alpha\rho}}g(\phi)d\phi}_{=\pi_n} = \sum_n \Delta_n^{\frac{\rho}{1-\alpha\rho}}\pi_n.
\end{aligned}$$

Given the assumption that ϕ follows a log-normal distribution, we can express

$$\pi_n = \int_{\phi_n}^{\phi_{n+1}}(\phi)^{\frac{\rho}{1-\alpha\rho}}g(\phi)d\phi = \exp\left\{\frac{\tilde{\sigma}^2}{2}\right\}[\Phi(b_{n+1}-\tilde{\sigma})-\Phi(b_n-\tilde{\sigma})],$$

where $\tilde{\sigma} = \frac{\rho}{1-\alpha\rho}\sigma_\phi$ and $b_n = \frac{\rho}{1-\alpha\rho}\frac{\ln(\phi_n)}{\tilde{\sigma}}$. Note also that Equations 6 and 7 imply that

$$\phi_{n+1} = \frac{\phi_1}{\left(\Delta_{n+1}^{\frac{\rho}{1-\rho\alpha}} - \Delta_n^{\frac{\rho}{1-\rho\alpha}}\right)^{\frac{1-\rho\alpha}{\rho}}}.$$

Thus, π_n depends on ϕ_1; it does not directly depend on equilibrium prices P^*.

D.2 Response to Top 1,000 Program

The Top 1,000 program limits energy use at the largest firm e_1 to a fraction $\xi < 1$ of the energy use in the unregulated case e_1^*; recall that we use starred variables to denote the optimal choices in the unregulated case. We assume that the number of firms n and the capital allocations $\{k_i^*\}_{i=1}^n$ are quasifixed but that the conglomerate can adjust $\{l_i\}_{i=1}^n$.

Regulated Conglomerates

Using the fact that $k_i^* = k_1^*\delta^{\frac{i-1}{1-\alpha}}$, we can write the profit maximization problem as

$$\max_{\{l_i\}_1^n}\left\{R^{1-\rho}P^{\rho}\left[\phi^*\sum_{i=1}^n\delta^{\frac{(i-1)(1-\alpha_l)}{1-\alpha}}l_i^{\alpha_l}\right]^{\rho} - (w+p_e)\sum_{i=1}^n l_i - r\sum_{i=1}^n k_i^*\right\} \text{ subject to } l_1 \leq \xi l_1^*,$$

where $\phi^* = \phi(k_1^*)^{\alpha_k}$. The first-order conditions for l_i $(1 \leq i \leq n)$ are then

$$\frac{\partial\pi}{\partial l_i} = \underbrace{R^{1-\rho}P^{\rho}}_{\text{Market Demand}}\underbrace{\rho\left[\phi^*\sum_{i=1}^n\delta^{\frac{(i-1)(1-\alpha_l)}{1-\alpha}}l_i^{\alpha_l}\right]^{\rho-1}}_{\text{Residual Revenue}}\underbrace{\phi^*\delta^{\frac{(i-1)(1-\alpha_l)}{1-\alpha}}\alpha_l(l_i)^{\alpha_l-1}}_{\text{Marginal Product}} = w+p_e+\underbrace{\lambda(\phi)\mathbb{I}[i=1]}_{\substack{\text{Shadow Cost}\\ \text{of Regulation}}}.$$

These conditions yield the results in Proposition 3.

We now show that given n, $\lambda(\phi)$ does not depend on ϕ. To do so, we note that an implication of Proposition 3 is that we can write total conglomerate production under the regulation as

$$q(\phi,n)=\sum_i^n q_i(\phi,n)=q_1(\phi,n)\left[1+\sum_{i>1}^n \delta^{\frac{i-1}{1-\alpha}}\left[1+\frac{\lambda(\phi)}{w+p_e}\right]^{\frac{\alpha_l}{1-\alpha_l}}\right].$$

In contrast, recall from Proposition 1 that in the unregulated case total conglomerate output is

$$q^*(\phi,n)=\sum_i^n q_i^*(\phi,n)=q_1^*(\phi,n)\sum_i^n \delta^{\frac{i-1}{1-\alpha}}.$$

To connect these expressions, note that since k_1^* is fixed and $l_1=\xi l_1^*$, we have that

$$q_1(\phi,n)=\phi(k_1^*)^{\alpha_k}(l_1)^{\alpha_l}=\phi(k_1^*)^{\alpha_k}(l_1^*)^{\alpha_l}\xi^{\alpha_l}=q_1^*(\phi,n)\xi^{\alpha_l}.$$

Together, the last three expression imply that

$$q(\phi,n)=q^*(\phi,n)\xi^{\alpha_l}\frac{\left[1+\sum_{i>1}^n \delta^{\frac{i-1}{1-\alpha}}\left[1+\frac{\lambda(\phi)}{w+p_e}\right]^{\frac{\alpha_l}{1-\alpha_l}}\right]}{\sum_i^n \delta^{\frac{i-1}{1-\alpha}}}=q^*(\phi,n)\underbrace{\left[\xi^{\alpha_l}\frac{1+(\Delta_n^{\frac{1}{1-\alpha}}-1)\left[1+\frac{\lambda(\phi)}{w+p_e}\right]^{\frac{\alpha_l}{1-\alpha_l}}}{\Delta_n^{\frac{1}{1-\alpha}}}\right]}_{=\xi_{q,n}}, \tag{D.2}$$

where $\xi_{q,n}$ captures the impact of the regulation on conglomerate output.

Using this expression and the fact that $l_1=\xi l_1^*$, we can rewrite the first-order condition for l_1 in terms of the capital and labor choices in the unregulated case:

$$\underbrace{R^{1-\rho}P^{*\rho}\rho\left[\phi\sum_{i=1}^n \delta^{\frac{i-1}{1-\alpha}}(k_i^*)^{\alpha_k}(l_i^*)^{\alpha_l}\right]^{\rho-1}\times\phi\alpha_l(k_1^*)^{\alpha_k}(l_1^*)^{\alpha_l-1}}_{\text{FOC Unregulated Case}}$$
$$\times(\xi)^{\alpha_l-1}\left(\frac{P}{P^*}\right)^{\rho}\left[\xi^{\alpha_l}\frac{1+(\Delta_n^{\frac{1}{1-\alpha}}-1)\left[1+\frac{\lambda(\phi)}{w+p_e}\right]^{\frac{\alpha_l}{1-\alpha_l}}}{\Delta_n^{\frac{1}{1-\alpha}}}\right]^{\rho-1}=w+p_e+\lambda(\phi),$$

where $\frac{P}{P^*}$ is the equilibrium change in the industry-level price. Using the fact that the first-order condition in the unregulated case equals $w+p_e$, we have

$$(\xi)^{\alpha_l-1}\left(\frac{P}{P^*}\right)^{\rho}\left[\xi^{\alpha_l}\frac{1+(\Delta_n^{\frac{1}{1-\alpha}}-1)\left[1+\frac{\lambda(\phi)}{w+p_e}\right]^{\frac{\alpha_l}{1-\alpha_l}}}{\Delta_n^{\frac{1}{1-\alpha}}}\right]^{(\rho-1)}=1+\frac{\lambda(\phi)}{w+p_e}. \tag{D.3}$$

This expression shows that conditional on n, the shadow cost does not depend on ϕ, and so we now write λ_n. The expression above is equivalent to

$$\left[1+\frac{\lambda_n}{w+p_e}\right]^{\frac{1}{1-\rho}}\left[1+(\Delta_n^{\frac{1}{1-\alpha}}-1)\left[1+\frac{\lambda_n}{w+p_e}\right]^{\frac{\alpha_l}{1-\alpha_l}}\right] \;=\; \left(\frac{P}{P^*}\right)^{\frac{\rho}{1-\rho}}\xi^{\frac{-(1-\alpha_l\rho)}{1-\rho}}\Delta_n^{\frac{1}{1-\alpha}}. \quad \text{(D.4)}$$

This expression does not have a general closed-form solution. Consider, however, the special case where $\frac{1}{1-\rho}=\frac{\alpha_l}{1-\alpha_l}$.[64] In this special case, we can write this expression as

$$(\Delta_n^{\frac{1}{1-\alpha}}-1)x^2+x-\left(\frac{P}{P^*}\right)^{\frac{\rho}{1-\rho}}\xi^{\frac{-(1-\alpha_l\rho)}{1-\rho}}\Delta_n^{\frac{1}{1-\alpha}}=0,$$

where $x=\left[1+\frac{\lambda_n}{w+p_e}\right]^{\frac{1}{1-\rho}}=\left[1+\frac{\lambda_n}{w+p_e}\right]^{\frac{\alpha_l}{1-\alpha_l}}$, which allows us to solve for λ_n using the quadratic formula. Focusing on the positive root implies

$$1+\frac{\lambda_n}{w+p_e}=\left\{\frac{-1+\sqrt{1+4(\Delta_n^{\frac{1}{1-\alpha}}-1)\left(\frac{P}{P^*}\right)^{\frac{\rho}{1-\rho}}\xi^{\frac{-(1-\alpha_l\rho)}{1-\rho}}\Delta_n^{\frac{1}{1-\alpha}}}}{2(\Delta_n^{\frac{1}{1-\alpha}}-1)}\right\}^{1-\rho}.$$

Note that λ_n depends on the equilibrium price P in both the expression above and in Equation D.4. In this case, we also have

$$\xi_{q,n}=\xi^{\alpha_l}\frac{1+\sqrt{1+4(\Delta_n^{\frac{1}{1-\alpha}}-1)\left(\frac{P}{P^*}\right)^{\frac{\rho}{1-\rho}}\xi^{\frac{-(1-\alpha_l\rho)}{1-\rho}}\Delta_n^{\frac{1}{1-\alpha}}}}{2\Delta_n^{\frac{1}{1-\alpha}}}.$$

Unregulated Conglomerates

Unregulated conglomerates are affected by the policy through the price adjustment in the product market. The first-order conditions for l_i $(1\leq i\leq n)$ are then

$$\frac{\partial\pi}{\partial l_i}=R^{1-\rho}P^{\rho}\rho\left[\phi^*\sum_{i=1}^{n}\delta^{\frac{(i-1)(1-\alpha_l)}{1-\alpha}}l_i^{\alpha_l}\right]^{\rho-1}\phi^*\delta^{\frac{(i-1)(1-\alpha_l)}{1-\alpha}}\alpha_l(l_i)^{\alpha_l-1} \;=\; w+p_e.$$

Since these firms do not face a shadow cost, the conditions of Proposition 1 continue to hold. Using these results to solve for l_1, we obtain

$$l_1=\left[\frac{R^{1-\rho}P^{\rho}\rho[\phi(k_1^*)^{\alpha_k}]^{\rho}\Delta_n^{\frac{\rho-1}{1-\alpha}}\alpha_l}{w+p_e}\right]^{\frac{1}{1-\alpha_l\rho}}.$$

This further implies that

$$l_1=l_1^*\left(\frac{P}{P^*}\right)^{\frac{\rho}{1-\alpha_l\rho}} \quad \text{(D.5)}$$

[64] While this is a knife-edge case, it holds in the empirically relevant case of $\rho=.75$ and $\alpha_l=0.8$, so that $\frac{1}{1-\rho}=\frac{\alpha_l}{1-\alpha_l}=4$.

and both

$$q_1(\phi,n) = q_1^*(\phi,n)\left(\frac{P}{P^*}\right)^{\frac{\alpha_l\rho}{1-\alpha_l\rho}} \quad \text{and} \quad q(\phi,n) = q^*(\phi,n)\left(\frac{P}{P^*}\right)^{\frac{\alpha_l\rho}{1-\alpha_l\rho}}. \tag{D.6}$$

D.2.1 Product Market Equilibrium

We now derive the equilibrium price under the Top 1,000 program. Recall that only conglomerates with $\phi \geq \tilde{\phi}$ have a regulated firm. Under the definition of $\xi_{q,n}$ in Equation D.2 for regulated firms and Equation D.6 for unregulated firms, the price level under the regulation is then

$$\begin{aligned} P^{-\rho} &= R^{-\rho}\int_{\phi_1}^{\tilde{\phi}}\left(\left(\frac{P}{P^*}\right)^{\frac{\alpha_l\rho}{1-\alpha_l\rho}}(\phi\Delta_n)^{\frac{1}{1-\alpha\rho}}R^{\frac{(1-\rho)\alpha}{1-\alpha\rho}}P^{*\frac{\rho\alpha}{1-\alpha\rho}}C_Q\right)^{\rho}\frac{g(\phi)M}{1-G(\phi_1)}d\phi \\ &+ R^{-\rho}\int_{\tilde{\phi}}\left(\xi_{q,n}(\phi\Delta_n)^{\frac{1}{1-\alpha\rho}}R^{\frac{(1-\rho)\alpha}{1-\alpha\rho}}P^{*\frac{\rho\alpha}{1-\alpha\rho}}C_Q\right)^{\rho}\frac{g(\phi)M}{1-G(\phi_1)}d\phi. \end{aligned}$$

As in the case of the unregulated equilibrium, we use π_n to denote the output of conglomerates with n affiliates. However, the regulation threshold $\tilde{\phi}$ in general does not line up with the size thresholds ϕ_n that define π_n. Let $\tilde{n}$ denote the smallest firm size for regulated conglomerates. We split $\pi_{\tilde{n}}$ into $\tilde{\pi}_1$ and $\tilde{\pi}_2$ as follows:

$$\tilde{\pi}_1 = \int_{\phi_{\tilde{n}}}^{\tilde{\phi}}(\phi)^{\frac{\rho}{1-\alpha\rho}}g(\phi)d\phi \quad \text{and} \quad \tilde{\pi}_2 = \int_{\tilde{\phi}}^{\phi_{\tilde{n}+1}}(\phi)^{\frac{\rho}{1-\alpha\rho}}g(\phi)d\phi.$$

We can then manipulate the expression for the equilibrium price as follows:

$$\begin{aligned} P^{-\rho}P^{*\frac{-\rho^2\alpha}{1-\alpha\rho}}R^{\frac{(1-\alpha)\rho}{1-\alpha\rho}}C_Q^{-\rho}\frac{1-G(\phi_1)}{M} &= \left(\frac{P}{P^*}\right)^{\frac{\alpha_l\rho^2}{1-\alpha_l\rho}}\left(\sum_{n=1}^{\tilde{n}-1}\Delta_n^{\frac{\rho}{1-\alpha\rho}}\pi_n + \Delta_{\tilde{n}}^{\frac{\rho}{1-\alpha\rho}}\tilde{\pi}_1\right) \\ &+ \xi_{q,\tilde{n}}^{\rho}\Delta_{\tilde{n}}^{\frac{\rho}{1-\alpha\rho}}\tilde{\pi}_2 + \sum_{n=\tilde{n}+1}\xi_{q,n}^{\rho}\Delta_n^{\frac{\rho}{1-\alpha\rho}}\pi_n. \end{aligned}$$

Note that this equation holds in the case absent the regulation if we set $\xi_{q,n} = 1$ and $P = P^*$. Let $s_{\tilde{\phi}} = \frac{\Delta_{\tilde{n}}^{\frac{\rho}{1-\alpha\rho}}\tilde{\pi}_2 + \sum_{n=\tilde{n}+1}\Delta_n^{\frac{\rho}{1-\alpha\rho}}\pi_n}{\sum_n \Delta_n^{\frac{\rho}{1-\alpha\rho}}\pi_n}$ be the output share of the Top 1,000 conglomerates prior to the regulation. Additionally, we introduce the notation:

$$\mathbb{E}_e\left[x_n\middle|\phi > \tilde{\phi}\right] = x_{\tilde{n}}\left(\frac{\Delta_n^{\frac{\rho}{1-\alpha\rho}}\tilde{\pi}_2}{\Delta_n^{\frac{\rho}{1-\alpha\rho}}\tilde{\pi}_2 + \sum_{n=\tilde{n}+1}\Delta_n^{\frac{\rho}{1-\alpha\rho}}\pi_n}\right) + \sum_{n=\tilde{n}+1}x_n\left(\frac{\Delta_n^{\frac{\rho}{1-\alpha\rho}}\pi_n}{\Delta_n^{\frac{\rho}{1-\alpha\rho}}\tilde{\pi}_2 + \sum_{n=\tilde{n}+1}\Delta_n^{\frac{\rho}{1-\alpha\rho}}\pi_n}\right)$$

to denote the average of a size-dependent variable x_n conditional on being part of the Top 1,000 program with respect to the distribution of energy use in the unregulated equilibrium.

Assuming that the regulation does not impact r and w, taking the ratio of price levels before and after the regulation, we obtain

$$\left(\frac{P}{P^*}\right)^{-\rho} = (1-s_{\tilde{\phi}})\left(\frac{P}{P^*}\right)^{\frac{\alpha_l\rho^2}{1-\alpha_l\rho}} + s_{\tilde{\phi}}\mathbb{E}_e\left[\xi_{q,n}^{\rho}\middle|\phi>\tilde{\phi}\right]. \tag{D.7}$$

Equations D.4 and D.7 jointly determine the shadow costs of the regulation $\{\lambda_n\}_{n\geq\tilde{n}}$ and the increase in the price level $\frac{P}{P^*}$.

D.2.2 Characterizing Energy Use

Recall that the energy use in firm 1 before the regulation is

$$e_1^*(\phi,n) = l_1^*(\phi,n) = \left(\frac{\alpha_l}{\alpha_k}\frac{r}{(w+p_e)}\right)k_1^*(\phi,n) = \left(\frac{\alpha_l}{\alpha_k}\frac{r}{(w+p_e)}\right)\left(\frac{K_n^*}{\Delta_n^{\frac{1}{1-\alpha}}}\right).$$

The energy use for the conglomerate before the regulation is then

$$\begin{aligned} e^*(\phi,n) &= \left(\frac{\alpha_l}{\alpha_k}\frac{r}{(w+p_e)}\right)K_n^* \\ &= (\phi\Delta_n)^{\frac{\rho}{1-\alpha\rho}}R^{\frac{1-\rho}{1-\alpha\rho}}P^{*\frac{\rho}{1-\alpha\rho}}\underbrace{\rho^{\frac{1}{1-\alpha\rho}}\left[\left(\frac{\alpha_l}{w+p_e}\right)^{1-\alpha_k\rho}\left(\frac{\alpha_k}{r}\right)^{\alpha_k\rho}\right]^{\frac{1}{1-\alpha\rho}}}_{=C_E}. \end{aligned} \tag{D.8}$$

The total energy use prior to the regulation is then

$$\begin{aligned} E^* &= \int_{\phi_1} e^*(\phi,n)\frac{g(\phi)M}{1-G(\phi_1)}d\phi \\ &= R^{\frac{1-\rho}{1-\alpha\rho}}P^{*\frac{\rho}{1-\alpha\rho}}\frac{C_E M}{1-G(\phi_1)}\sum_n(\Delta_n)^{\frac{\rho}{1-\alpha\rho}}\pi_n. \end{aligned}$$

Regulated Conglomerates

We now characterize the change in energy use for regulated conglomerates. The fact that $e_i = l_i$ and the results of Proposition 1 imply that the energy use for an unregulated conglomerate is

$$e^*(\phi,n) = \sum_i e_i^*(\phi,n) = e_1^*(\phi,n)\sum_i^n \delta^{\frac{i-1}{1-\alpha}}.$$

Proposition 3 implies that the energy use for a regulated conglomerate is

$$e(\phi,n) = \sum_i e_i(\phi,n) = e_1(\phi,n)\left[1+\sum_{i>1}^n \delta^{\frac{i-1}{1-\alpha}}\left[1+\frac{\lambda_n}{w+p_e}\right]^{\frac{1}{1-\alpha_l}}\right].$$

Using the fact that $e_1 = \xi e_1^*$, we then have

$$e(\phi, n) = e^*(\phi, n) \underbrace{\frac{\xi \left[1 + \sum_{i>1}^{n} \delta^{\frac{i-1}{1-\alpha}} \left[1 + \frac{\lambda_n}{w+p_e}\right]^{\frac{1}{1-\alpha_l}}\right]}{\sum_{i}^{n} \delta^{\frac{i-1}{1-\alpha}}}}_{=\xi_{e,n}},$$

where $\xi_{e,n}$ captures the effect of the regulation on the energy use of a regulated conglomerate.

Unregulated Conglomerates

Proposition 1 and Equation D.5 imply that for unregulated conglomerates,

$$e_1(\phi, n) = e_1^*(\phi, n) \left(\frac{P}{P^*}\right)^{\frac{\rho}{1-\alpha_l \rho}}$$

and additionally that

$$e(\phi, n) = e^*(\phi, n) \left(\frac{P}{P^*}\right)^{\frac{\rho}{1-\alpha_l \rho}}.$$

Aggregate Change in Energy

Putting the above together, total energy use after the regulation is now

$$\begin{aligned} E &= \int_{\phi_1} e(\phi, n) \frac{g(\phi)M}{1 - G(\phi_1)} d\phi = \int_{\phi_1}^{\tilde{\phi}} \left(\frac{P}{P^*}\right)^{\frac{\rho}{1-\alpha_l \rho}} e^*(\phi, n) \frac{g(\phi)M}{1 - G(\phi_1)} d\phi + \int_{\tilde{\phi}} \xi_{e,n} e^*(\phi, n) \frac{g(\phi)M}{1 - G(\phi_1)} d\phi \\ &= R^{\frac{1-\rho}{1-\alpha\rho}} P^{*\frac{\rho}{1-\alpha\rho}} \frac{C_E M}{1 - G(\phi_1)} \left[\left(\sum_{n=1}^{\tilde{n}-1} \Delta_n^{\frac{\rho}{1-\alpha\rho}} \pi_n + \Delta_{\tilde{n}}^{\frac{\rho}{1-\alpha\rho}} \tilde{\pi}_1 \right) \left(\frac{P}{P^*}\right)^{\frac{\rho}{1-\alpha_l \rho}} + \xi_{e,\tilde{n}} \Delta_{\tilde{n}}^{\frac{\rho}{1-\alpha\rho}} \tilde{\pi}_2 + \sum_{n=\tilde{n}+1} \xi_{e,n} \Delta_n^{\frac{\rho}{1-\alpha\rho}} \pi_n \right]. \end{aligned}$$

This implies that

$$\begin{aligned} \frac{E}{E^*} &= \frac{\left(\sum_{n=1}^{\tilde{n}-1} \Delta_n^{\frac{\rho}{1-\alpha\rho}} \pi_n + \Delta_{\tilde{n}}^{\frac{\rho}{1-\alpha\rho}} \tilde{\pi}_1 \right) \left(\frac{P}{P^*}\right)^{\frac{\rho}{1-\alpha_l \rho}} + \xi_{e,\tilde{n}} \Delta_{\tilde{n}}^{\frac{\rho}{1-\alpha\rho}} \tilde{\pi}_2 + \sum_{n=\tilde{n}+1} \xi_{e,n} \Delta_n^{\frac{\rho}{1-\alpha\rho}} \pi_n}{\sum_n (\Delta_n)^{\frac{\rho}{1-\alpha\rho}} \pi_n} \\ &= (1 - s_{\tilde{\phi}}) \left(\frac{P}{P^*}\right)^{\frac{\rho}{1-\alpha_l \rho}} + s_{\tilde{\phi}} \mathbb{E}_e \left[\xi_{e,n} \middle| \phi > \tilde{\phi} \right]. \end{aligned} \tag{D.9}$$

Equation D.9—along with the equilibrium price increase and shadow costs determined by Equations D.4 and D.7—allows us to compute the effect of the regulation on welfare.

D.2.3 Solving the New Equilibrium Using Reduced-Form Estimates

In Section 6, we present the full solution to the model using the derivations above. This appendix shows that we can also solve for an approximation of the equilibrium based on our reduced-form estimates. To do so, we make the assumption that λ and Δ are constant for regulated firms. Taking the value of λ implied by our reduced-form estimate of 8.95% and $\Delta^{\frac{1}{1-\alpha}} = 1.6$ (which approximates the value for $n = 6$), we use Proposition 4 to compute the production distortion $\xi_q = 0.9648$. Equation 14 delivers the equilibrium price change: $\ln\left(\frac{P}{P^*}\right) = 4.2\%$. We then compute that regulated conglomerates lower their energy use by 5.6%. Finally, we use these numbers to implement Equation 15, where we find that $\ln\left(\frac{E}{E^*}\right) = -3.65\%$. The advantage of this calculation is that it relies on only a handful of calibrated parameter values and the result of the within-conglomerate difference-in-differences estimation. In particular, this calculation does not rely on distributional assumptions for $G(\phi)$. It is thus reassuring that we obtain aggregate quantities close to those in the full model solution.

E Alternative Regulations

Conglomerate-level Regulation

Suppose that instead of regulating the energy use of the top firm, the government restricted the energy use of all firms in a conglomerate to at most ξ of the energy use at the Top 1,000 firm plus the energy use at related firms. The regulatory constraint would be

$$e(\phi, n) \leq \xi_{e,n} e^*(\phi, n).$$

Arguments similar to the derivation for Equation D.9 imply that

$$\frac{E^C}{E^*} = (1 - s_{\tilde{\phi}}) \left(\frac{P^C}{P^*}\right)^{\frac{\rho}{1-\alpha_l \rho}} + s_{\tilde{\phi}} \mathbb{E}_e \left[\xi_{e,n} | \, \phi > \tilde{\phi}\right], \tag{E.1}$$

where we use the superscript C to denote the case of the conglomerate-level regulation.

Since energy use in all firms contributes equally to the regulatory constraint, this regulation does not distort the allocation of inputs across related firms; i.e., Proposition 1 continues to hold. This implies that $l_i = \xi_{e,n} l_i^*$ for all firms i in the conglomerate. It further implies that

$$q(\phi, n) = (\xi_{e,n})^{\alpha_l} \, q^*(\phi, n).$$

Arguments similar to the derivation for Equation D.7 imply that

$$\left(\frac{P^C}{P^*}\right)^{-\rho} = (1 - s_{\tilde{\phi}}) \left(\frac{P^C}{P^*}\right)^{\frac{\alpha_l \rho^2}{1-\alpha_l \rho}} + s_{\tilde{\phi}} \mathbb{E}_e \left[(\xi_{e,n})^{\alpha_l \rho} | \, \phi > \tilde{\phi}\right]. \tag{E.2}$$

We now derive the shadow cost of this regulation. Substituting l_i into the first-order condition for firm 1 implies that

$$\underbrace{R^{1-\rho}P^{*\rho}\rho\left[\phi\sum_{i=1}^{n}\delta^{\frac{i-1}{1-\alpha}}(k_i^*)^{\alpha_k}(l_i^*)^{\alpha_l}\right]^{\rho-1}\times\phi\alpha_l(k_1^*)^{\alpha_k}(l_1^*)^{\alpha_l-1}}_{\text{FOC Unregulated Case}}$$
$$\times(\xi_{e,n})^{\alpha_l-1}\left(\frac{P^C}{P^*}\right)^{\rho}[(\xi_{e,n})^{\alpha_l}]^{\rho-1}=w+p_e+\lambda^C(\phi).$$

Using the fact that the first-order condition in the unregulated case equals $w+p_e$, we obtain

$$\left[1+\frac{\lambda_n^C}{w+p_e}\right]=\left(\frac{P^C}{P^*}\right)^{\rho}(\xi_{e,n})^{-(1-\alpha_l\rho)}.$$

Size-dependent Energy Tax

Suppose that the government instituted a per-unit energy tax for all the affiliates of conglomerates with $\phi>\tilde{\phi}$. As in the case above, this policy would not impact the within-conglomerate allocation of inputs of regulated firms, and Proposition 1 would continue to hold. That is, related firms would all reduce their energy use by the same proportion. Let λ_ξ^τ be the tax associated with a proportional energy reduction use of $1-\xi_\tau$. The first-order condition for firm 1 is then

$$\underbrace{R^{1-\rho}P^{*\rho}\rho\left[\phi\sum_{i=1}^{n}\delta^{\frac{i-1}{1-\alpha}}(k_i^*)^{\alpha_k}(l_i^*)^{\alpha_l}\right]^{\rho-1}\times\phi\alpha_l(k_1^*)^{\alpha_k}(l_1^*)^{\alpha_l-1}}_{\text{FOC Unregulated Case}}$$
$$\times(\xi_\tau)^{\alpha_l-1}\left(\frac{P^\tau}{P^*}\right)^{\rho}[\xi_\tau^{\alpha_l}]^{\rho-1}=w+p_e+\lambda_\xi^\tau,$$

where we use the superscript τ to denote this case. Using the fact that the first-order condition in the unregulated case equals $w+p_e$, we obtain

$$\left[1+\frac{\lambda_\xi^\tau}{w+p_e}\right]=\left(\frac{P^\tau}{P^*}\right)^{\rho}(\xi_\tau)^{-(1-\alpha_l\rho)}.$$

Since all related firms reduce their energy use by the same proportion, it follows that $e(\phi,n)=\xi_\tau e^*(\phi,n)$ for regulated firms. Arguments similar to the derivation for Equation D.9 imply that

$$\frac{E^\tau}{E^*} = (1-s_{\tilde{\phi}})\left(\frac{P^\tau}{P^*}\right)^{\frac{\rho}{1-\alpha_l\rho}}+s_{\tilde{\phi}}\xi_\tau. \tag{E.3}$$

Noting that $q(\phi,n)=\xi_\tau^{\alpha_l}q^*(\phi,n)$ then implies that

$$\left(\frac{P^\tau}{P^*}\right)^{-\rho} = (1-s_{\tilde{\phi}})\left(\frac{P^\tau}{P^*}\right)^{\frac{\alpha_l\rho^2}{1-\alpha_l\rho}}+s_{\tilde{\phi}}(\xi_\tau)^{\alpha_l\rho}. \tag{E.4}$$

To make this case comparable to the Top 1,000 regulation, we implement a tax that leads to the same average energy reduction:

$$\left[1+\frac{\lambda_\xi^\tau}{w+p_e}\right]=\left(\frac{P^\tau}{P^*}\right)^\rho\left(\mathbb{E}_e\left[\xi_{e,n}\left|\phi>\tilde{\phi}\right.\right]\right)^{-(1-\alpha_l\rho)};$$

that is, $\xi_\tau=\mathbb{E}_e\left[\xi_{e,n}\left|\phi>\tilde{\phi}\right.\right]$. Note that the aggregate effects differ to the extent that we obtain different price responses (and therefore different responses from unregulated firms).

F Inspecting the Effect Mechanisms of the Top 1,000 Regulation

Shutting down Market Leakage

In this case, firms believe that prices do not adjust. The perceived shadow cost is given by the solution to

$$\left[1+\frac{\lambda_n}{w+p_e}\right]^{\frac{1}{1-\rho}}\left[1+(\Delta_n^{\frac{1}{1-\alpha}}-1)\left[1+\frac{\lambda_n}{w+p_e}\right]^{\frac{\alpha_l}{1-\alpha_l}}\right] \;=\; \xi^{\frac{-(1-\alpha_l\rho)}{1-\rho}}\Delta_n^{\frac{1}{1-\alpha}}.$$

We recompute $\xi_{e,n}$ and $\xi_{q,n}$ based on these shadow costs. Aggregate energy use is then given by

$$\frac{E}{E^*} \;=\; (1-s_{\tilde{\phi}})+s_{\tilde{\phi}}\mathbb{E}_e\left[\xi_{e,n}\left|\phi>\tilde{\phi}\right.\right].$$

The new price is given by

$$\left(\frac{P}{P^*}\right)^{-\rho} \;=\; (1-s_{\tilde{\phi}})+s_{\tilde{\phi}}\mathbb{E}_e\left[\xi_{q,n}^\rho\left|\phi>\tilde{\phi}\right.\right].$$

The actual shadow cost follows Equation 14 by incorporating the equilibrium price adjustment.

Shutting down Conglomerate Leakage

In this case, we set $e_1(\phi,n)\leq\xi e_1^*(\phi,n)$. We further assume that firms related to regulated firms do not take into account the reduction in $e_1(\phi,n)$ but do respond to the market price increase, so that $e_i(\phi,n)=\left(\frac{P}{P^*}\right)^{\frac{\rho}{1-\alpha_l\rho}}e_i^*(\phi,n)$ for $i\geq 2$. We then have

$$\begin{aligned} e(\phi,n) &= \xi e_1^*(\phi,n)+\sum_{i=2}e_i^*(\phi,n)\left(\frac{P}{P^*}\right)^{\frac{\rho}{1-\alpha_l\rho}}=e_1^*(\phi,n)\left(\xi+\left(\frac{P}{P^*}\right)^{\frac{\rho}{1-\alpha_l\rho}}\left(\Delta_n^{\frac{1}{1-\alpha}}-1\right)\right) \\ &= e^*(\phi,n)\frac{\xi+\left(\frac{P}{P^*}\right)^{\frac{\rho}{1-\alpha_l\rho}}\left(\Delta_n^{\frac{1}{1-\alpha}}-1\right)}{\Delta_n^{\frac{1}{1-\alpha}}}. \end{aligned}$$

Aggregate energy use is then

$$\frac{E}{E^*} = (1-s_{\tilde{\phi}})\left(\frac{P}{P^*}\right)^{\frac{\rho}{1-\alpha_l\rho}} + s_{\tilde{\phi}}\mathbb{E}_e\left[\left.\frac{\xi+\left(\frac{P}{P^*}\right)^{\frac{\rho}{1-\alpha_l\rho}}\left(\Delta_n^{\frac{1}{1-\alpha}}-1\right)}{\Delta_n^{\frac{1}{1-\alpha}}}\right|\phi>\tilde{\phi}\right].$$

Similarly, the effect on total production is

$$\begin{aligned} q(\phi,n) &= \xi^{\alpha_l}q_1^*(\phi,n)+\sum_{i=2}q_i^*(\phi,n)\left(\frac{P}{P^*}\right)^{\frac{\alpha_l\rho}{1-\alpha_l\rho}} = q_1^*(\phi,n)\left(\xi^{\alpha_l}+\left(\frac{P}{P^*}\right)^{\frac{\alpha_l\rho}{1-\alpha_l\rho}}\left(\Delta_n^{\frac{1}{1-\alpha}}-1\right)\right) \\ &= q^*(\phi,n)\frac{\xi^{\alpha_l}+\left(\frac{P}{P^*}\right)^{\frac{\alpha_l\rho}{1-\alpha_l\rho}}\left(\Delta_n^{\frac{1}{1-\alpha}}-1\right)}{\Delta_n^{\frac{1}{1-\alpha}}}. \end{aligned}$$

Aggregate prices are then

$$\left(\frac{P}{P^*}\right)^{-\rho} = (1-s_{\tilde{\phi}})\left(\frac{P}{P^*}\right)^{\frac{\alpha_l\rho^2}{1-\alpha_l\rho}} + s_{\tilde{\phi}}\mathbb{E}_e\left[\left.\left(\frac{\xi^{\alpha_l}+\left(\frac{P}{P^*}\right)^{\frac{\alpha_l\rho}{1-\alpha_l\rho}}\left(\Delta_n^{\frac{1}{1-\alpha}}-1\right)}{\Delta_n^{\frac{1}{1-\alpha}}}\right)^{\rho}\right|\phi>\tilde{\phi}\right].$$

We now derive the shadow cost of the regulation for the Top 1,000 firm. Substituting l_i into the first-order condition for firm 1 implies that

$$\underbrace{R^{1-\rho}P^{*\rho}\rho\left[\phi\sum_{i=1}^{n}\delta^{\frac{i-1}{1-\alpha}}(k_i^*)^{\alpha_k}(l_i^*)^{\alpha_l}\right]^{\rho-1}\times\phi\alpha_l(k_1^*)^{\alpha_k}(l_1^*)^{\alpha_l-1}}_{\text{FOC Unregulated Case}}$$

$$\times(\xi)^{\alpha_l-1}\left(\frac{P}{P^*}\right)^{\rho}\left[\frac{\xi^{\alpha_l}+\left(\frac{P}{P^*}\right)^{\frac{\alpha_l\rho}{1-\alpha_l\rho}}\left(\Delta_n^{\frac{1}{1-\alpha}}-1\right)}{\Delta_n^{\frac{1}{1-\alpha}}}\right]^{\rho-1} = w+p_e+\lambda(\phi)$$

Using the fact that the first-order condition in the unregulated case equals $w+p_e$, we obtain

$$\left[1+\frac{\lambda_n}{w+p_e}\right] = \left(\frac{P}{P^*}\right)^{\rho}\xi^{-(1-\alpha_l)}\left(\frac{\xi^{\alpha_l}+\left(\frac{P}{P^*}\right)^{\frac{\alpha_l\rho}{1-\alpha_l\rho}}\left(\Delta_n^{\frac{1}{1-\alpha}}-1\right)}{\Delta_n^{\frac{1}{1-\alpha}}}\right)^{-(1-\rho)}.$$

Shutting down Both Market and Conglomerate Leakage

Energy use and production at regulated conglomerates is the same as in the case in which only the conglomerate leakage is shut down. Unregulated firms assume that there will be no price increase, such that the aggregate energy use is then

$$\frac{E}{E^*} = (1-s_{\tilde{\phi}})+s_{\tilde{\phi}}\mathbb{E}_e\left[\left.\frac{\xi-1+\Delta_n^{\frac{1}{1-\alpha}}}{\Delta_n^{\frac{1}{1-\alpha}}}\right|\phi>\tilde{\phi}\right].$$

Aggregate prices are then

$$\left(\frac{P}{P^*}\right)^{-\rho} = (1 - s_{\tilde{\phi}}) + s_{\tilde{\phi}}\mathbb{E}_e\left[\left(\frac{\xi^{\alpha_l} - 1 + \Delta_n^{\frac{1}{1-\alpha}}}{\Delta_n^{\frac{1}{1-\alpha}}}\right)^{\rho}\middle|\, \phi > \tilde{\phi}\right].$$

The actual shadow cost follows Equation 14 using the following definition of $\xi_q(\phi) = \frac{\xi - 1 + \Delta_n^{\frac{1}{1-\alpha}}}{\Delta_n^{\frac{1}{1-\alpha}}}$ and the equilibrium price above.

G Model Extensions

G.1 Endogenous Energy Efficiency

Assume that the conglomerate can improve energy efficiency at firm i, ν_i, by spending $l_i c(\nu_i)$, where $c'(\nu_i) > 0$ and $c''(\nu_i) \geq 0$. The conglomerate's problem is then

$$\pi(\phi, n) = \max_{\{l_i\}_{i=1}^n, \{\nu_i\}_{i=1}^n} \left\{ R^{1-\rho} P^{\rho} \left[\phi^* \sum_{i=1}^n \delta^{\frac{(i-1)(1-\alpha_l)}{1-\alpha}} l_i^{\alpha_l}\right]^{\rho} - \sum_{i=1}^n l_i \left(w + \frac{p_e}{\nu_i} + c(\nu_i)\right)\right\},$$

where we omit the cost of fixed capital. Absent the regulation, the conglomerate sets $c'(\nu^*)\nu^{*2} = p_e$ for all firms, so that Proposition 1 continues to hold.

We assume that $c(\nu) = \frac{\nu^{\gamma}}{1+\gamma}$, where $\gamma \geq 1$, so the effective price of energy is $(\nu^*)^{\gamma}$. Additionally, note that the Top 1,000 regulation does not impact the choice of ν_i for unregulated firms. Using these results and the fact that $\nu_i = \frac{l_i}{e_i}$, we can restate the conglomerate problem as

$$\pi(\phi, n) = \max_{\{l_i\}_{i=1}^n} \left\{ R^{1-\rho} P^{\rho} \left[\phi^* \sum_{i=1}^n \delta^{\frac{(i-1)(1-\alpha_l)}{1-\alpha}} l_i^{\alpha_l}\right]^{\rho} - (w + (\nu^*)^{\gamma}) \sum_{i=1}^n l_i - l_1 \left[\frac{1}{1+\gamma}\left(\frac{l_1}{\xi e_1^*}\right)^{\gamma} - (\nu^*)^{\gamma}\right]\right\},$$

where we substitute the regulatory constraint into the cost of energy efficiency and abstract away from the cost of the regulated energy.

Deriving the Shadow Cost of Regulation

The conglomerate's first-order conditions for l_i $(1 \leq i \leq n)$, i.e., $\frac{\partial \pi}{\partial l_i}$, are then

$$R^{1-\rho} P^{\rho} \rho \left[\phi^* \sum_{i=1}^n \delta^{\frac{(i-1)(1-\alpha_l)}{1-\alpha}} l_i^{\alpha_l}\right]^{\rho-1} \phi^* \delta^{\frac{(i-1)(1-\alpha_l)}{1-\alpha}} \alpha_l (l_i)^{\alpha_l - 1} = w + (\nu^*)^{\gamma} + \left[\left(\frac{l_1}{\xi e_1^*}\right)^{\gamma} - (\nu^*)^{\gamma}\right] \mathbb{I}[i = 1].$$

We can write the binding energy use constraint as $\xi e_1^* = e_1 = \frac{l_1}{\nu_1}$ so that $\nu_1 = \frac{l_1}{\xi e_1^*}$. It is also useful to write the share of variable input costs accounted for by energy as $s_e = \frac{(\nu^*)^{\gamma}}{w + (\nu^*)^{\gamma}}$. The shadow cost of the policy as a fraction of variable inputs is then

$$\frac{\lambda(\phi)}{w + (\nu^*)^{\gamma}} = \frac{1}{w + (\nu^*)^{\gamma}} \left[\left(\frac{l_1}{\xi e_1^*}\right)^{\gamma} - (\nu^*)^{\gamma}\right] = s_e \left(\left(\frac{\nu_1}{\nu^*}\right)^{\gamma} - 1\right).$$

Using these expressions, we can then write the ratios of these first-order conditions between $j \geq 2$ and the Top 1,000 firm as

$$\frac{l_j}{l_1} = \delta^{\frac{j-1}{1-\alpha}} \left[1 + s_e \left(\left(\frac{\nu_1}{\nu^*} \right)^{\gamma} - 1 \right) \right]^{\frac{1}{1-\alpha_l}} = \delta^{\frac{j-1}{1-\alpha}} \left[1 + \frac{\lambda(\phi)}{w + (\nu^*)^{\gamma}} \right]^{\frac{1}{1-\alpha_l}},$$

which confirms that the results of Proposition 3 extend to the case of endogenous energy efficiency. We can then write the first-order condition for the Top 1,000 firm as

$$\underbrace{R^{1-\rho}(P^*)^{\rho} \rho \left[\phi^* \sum_{i=1}^{n} \delta^{\frac{(i-1)(1-\alpha_l)}{1-\alpha}} (l_i^*)^{\alpha_l} \right]^{\rho-1} \phi^* \alpha_l (l_1^*)^{\alpha_l - 1}}_{\text{FOC Unregulated}} \left(\frac{P}{P^*} \right)^{\rho} \tag{G.1}$$

$$\left[\underbrace{\left(\frac{\xi \nu_1}{\nu^*} \right)^{\alpha_l} \frac{\left[1 + \left[1 + \frac{\lambda(\phi)}{w + (\nu^*)^{\gamma}} \right]^{\frac{\alpha_l}{1-\alpha_l}} \sum_{j>1} \delta^{\frac{j-1}{1-\alpha}} \right]}{\sum_i \delta^{\frac{j-1}{1-\alpha}}}}_{\xi^{\nu}_{q,n}} \right]^{\rho-1} \times \left(\frac{\xi \nu_1}{\nu^*} \right)^{\alpha_l - 1} = (w + (\nu^*)^{\gamma}) \left[1 + \frac{\lambda(\phi)}{w + (\nu^*)^{\gamma}} \right].$$

This equation also defines the relevant decrease in conglomerate-level production $\xi^{\nu}_{q,n}$, which we use to solve the new product market equilibrium (cf. Propositions 4–5). Noting that the first-order condition for the unregulated firm equals $w + (\nu^*)^{\gamma}$, we can derive the following expression

$$\left[1 + \frac{\lambda(\phi)}{w + (\nu^*)^{\gamma}} \right]^{\frac{1}{1-\rho}} \left[1 + (\Delta_n^{\frac{1}{1-\alpha}} - 1) \left[1 + \frac{\lambda(\phi)}{w + (\nu^*)^{\gamma}} \right]^{\frac{\alpha_l}{1-\alpha_l}} \right] = \left(\frac{P}{P^*} \right)^{\frac{\rho}{1-\rho}} \left(\frac{\xi \nu_1}{\nu^*} \right)^{\frac{-(1-\alpha_l \rho)}{1-\rho}} \Delta_n^{\frac{1}{1-\alpha}}. \tag{G.2}$$

This equation has one difference from Equation D.4. Since conglomerates can avoid the impact of the regulation by increasing the energy efficiency of the Top 1,000 firm, the effective regulation is now $\frac{\xi \nu_1}{\nu^*}$. That is, conglomerates have less of a need to reduce their energy use if they increase ν_1. This also implies that $\lambda(\phi)$ is decreasing in ν_1. Similar to Equation D.4, note that in this equation, the ratio $\frac{\nu_1}{\nu^*}$ is an implicit function of quantities that are common for firms with the same number of affiliates n. This implies that firms with different values of ϕ have the same shadow cost and improvement to energy efficiency as long as they belong to a conglomerate of the same size. We then write λ_n and $\nu_{1,n}$ to signify the dependence of these variables on n.

Aggregate Energy Use

Prior to the regulation, we have that $e^*(\phi, n) = \frac{l^*(\phi,n)}{\nu^*}$ for both regulated and unregulated firms. For unregulated firms, we still have $e(\phi, n) = \frac{l(\phi,n)}{\nu^*}$ since these firms do not change their

investment in energy efficiency. However, for regulated conglomerates, we have

$$\begin{aligned}
e(\phi,n) &= \frac{l_1}{\nu_{1,n}} + \frac{1}{\nu^*}\sum_{i>1} l_i = \frac{l_1}{\nu_{1,n}}\left(1 + \frac{\nu_{1,n}}{\nu^*}(\Delta_n^{\frac{1}{1-\alpha}} - 1)\left[1 + \frac{\lambda_n}{w + (\nu^*)^\gamma}\right]^{\frac{1}{1-\alpha_l}}\right) \\
&= e_1(\phi,n)\left(1 + \frac{\nu_{1,n}}{\nu^*}(\Delta_n^{\frac{1}{1-\alpha}} - 1)\left[1 + \frac{\lambda_n}{w + (\nu^*)^\gamma}\right]^{\frac{1}{1-\alpha_l}}\right) \\
&= e_1^*(\phi,n)\xi\left(1 + \frac{\nu_{1,n}}{\nu^*}(\Delta_n^{\frac{1}{1-\alpha}} - 1)\left[1 + \frac{\lambda_n}{w + (\nu^*)^\gamma}\right]^{\frac{1}{1-\alpha_l}}\right) \\
&= e^*(\phi,n)\underbrace{\left[\xi\frac{1 + \frac{\nu_{1,n}}{\nu^*}(\Delta_n^{\frac{1}{1-\alpha}} - 1)\left[1 + \frac{\lambda_n}{w+(\nu^*)^\gamma}\right]^{\frac{1}{1-\alpha_l}}}{\Delta_n^{\frac{1}{1-\alpha}}}\right]}_{\equiv \xi_{e,n}^{\nu}}.
\end{aligned}$$

The term $\xi_{e,n}^{\nu}$ incorporates the insight that the shifting of production to related firms now leads to a larger increase in total energy use since these firms do not improve their energy efficiency, i.e., $\frac{\nu_{1,n}}{\nu^*} > 1$. Using this term in Equation D.9 yields the aggregate change in energy use when firms can respond to the regulation by improving their energy efficiency.

Relation to Empirical Measures of Energy Efficiency

We now discuss how we connect the model to our difference-in-differences estimate of the effect of the Top 1,000 program on the energy efficiency of regulated firms. In the data, we measure energy efficiency as $\frac{R^{1-\rho}P^\rho q(\phi,n)^{\rho-1}q_1(\phi,n)}{e_1(\phi,n)}$. Note that for Top 1,000 firms,

$$\frac{R^{1-\rho}P^\rho q(\phi,n)^{\rho-1}q_1(\phi,n)}{e_1(\phi,n)} = \frac{R^{1-\rho}P^{*\rho}(q(\phi,n)^*)^{\rho-1}q_1^*(\phi,n)}{e_1^*(\phi,n)} \times \frac{\left(\frac{P}{P^*}\right)^\rho (\xi_{q,n}^{\nu})^{\rho-1}\left(\xi\frac{\nu_{1,n}}{\nu^*}\right)^{\alpha_l}}{\xi}.$$

Note also that the first term after the equation is the energy efficiency prior to the regulation. We can then manipulate the second term using Equation G.1 as follows:

$$\frac{\left(\frac{P}{P^*}\right)^\rho (\xi_{q,n}^{\nu})^{\rho-1}\left(\xi\frac{\nu_{1,n}}{\nu^*}\right)^{\alpha_l}}{\xi} = \left(\frac{\nu_{1,n}}{\nu^*}\right)\left[1 + s_e\left(\left(\frac{\nu_{1,n}}{\nu^*}\right)^\gamma - 1\right)\right].$$

The log time difference in energy efficiency for a given regulated firm is then

$$\ln\left(\frac{\nu_{1,n}}{\nu^*}\right) + \ln\left[1 + s_e\left(\left(\frac{\nu_{1,n}}{\nu^*}\right)^\gamma - 1\right)\right].$$

Note that the second term in this equation is equal to $\ln\left[1 + \frac{\lambda_n}{w+(\nu^*)^\gamma}\right]$.

Since unregulated firms do not have an incentive to invest in energy efficiency, their energy efficiency depends only on the output price. Recall from above that we have

$$\frac{e_1(\phi,n)}{e_1^*(\phi,n)} = \frac{e(\phi,n)}{e^*(\phi,n)} = \left(\frac{P}{P^*}\right)^{\frac{\rho}{1-\alpha_l\rho}} \quad \text{and} \quad \frac{q_1(\phi,n)}{q_1^*(\phi,n)} = \frac{q(\phi,n)}{q^*(\phi,n)} = \left(\frac{P}{P^*}\right)^{\frac{\alpha_l\rho}{1-\alpha_l\rho}}.$$

We then have

$$\begin{aligned}\frac{R^{1-\rho}P^{\rho}q(\phi,n)^{\rho-1}q_1(\phi,n)}{e_1(\phi,n)} &= \frac{R^{1-\rho}(P^*)^{\rho}(q(\phi,n)^*)^{\rho-1}q_1^*(\phi,n)\left(\frac{P}{P^*}\right)^{\rho}\left(\frac{P}{P^*}\right)^{\frac{\alpha_l\rho^2}{1-\alpha_l\rho}}}{e_1^*(\phi,n)\left(\frac{P}{P^*}\right)^{\frac{\rho}{1-\alpha_l\rho}}} \\ &= \frac{R^{1-\rho}(P^*)^{\rho}(q(\phi,n)^*)^{\rho-1}q_1^*(\phi,n)}{e_1^*(\phi,n)}.\end{aligned}$$

That is, the Top 1,000 program does not impact the energy efficiency of unregulated firms.

Letting β^{EE} denote the difference-in-differences estimate of the effect of the Top 1,000 program on energy efficiency, we then have

$$\beta^{EE} = \mathbb{E}\left[\ln\left(\frac{\nu_{1,n}}{\nu^*}\right)\middle|\,\phi > \tilde{\phi}\right] + \mathbb{E}\left[\ln\left[1 + s_e\left(\left(\frac{\nu_{1,n}}{\nu^*}\right)^{\gamma} - 1\right)\right]\middle|\,\phi > \tilde{\phi}\right]. \tag{G.3}$$

Calibration of γ

For a range of values of γ, we compute the following:

1. Solve for the values of $\{\nu_{1,n}\}_{n\geq\tilde{n}}$ and $\frac{P}{P^*}$ that jointly satisfy Equation G.2 and

$$\left(\frac{P}{P^*}\right)^{-\rho} = (1-s_{\tilde{\phi}})\left(\frac{P}{P^*}\right)^{\frac{\alpha_l\rho^2}{1-\alpha_l\rho}} + s_{\tilde{\phi}}\mathbb{E}_e\left[(\xi_{q,n}^{\nu})^{\rho}\middle|\,\phi > \tilde{\phi}\right].$$

2. Implement the right-hand side of Equation G.3.

We then choose the value of γ that is consistent with our empirical estimates of β^{EE}. Since we estimate zero or negative values for β^{EE}, we can bound γ by choosing the value that implies the upper bound of the confidence interval of β^{EE}.

G.2 Heterogeneous Energy Efficiency

We now explore the potential that regulated firms differ in their energy efficiency from other firms in the economy. We assume that regulated firms have energy efficiency ν_1, that related firms in the same conglomerate have ν_R, and that other firms in the economy have ν_O.

Unregulated Conglomerates

Firms in these conglomerates face an effective price for variable inputs of $w + \frac{p_e}{\nu_O}$. The results of Propositions 1–3 continue to hold for these firms. We therefore have that in this case

$$\begin{aligned}q^*(\phi,n) &= (\phi\Delta_n)^{\frac{1}{1-\alpha\rho}}R^{\frac{(1-\rho)\alpha}{1-\alpha\rho}}P^{*\frac{\rho\alpha}{1-\alpha\rho}}\rho^{\frac{\alpha}{1-\alpha\rho}}\left[\left(\frac{\alpha_l}{w+\frac{p_e}{\nu_O}}\right)^{\alpha_l}\left(\frac{\alpha_k}{r}\right)^{\alpha_k}\right]^{\frac{1}{1-\alpha\rho}} \\ &= (\phi\Delta_n)^{\frac{1}{1-\alpha\rho}}R^{\frac{(1-\rho)\alpha}{1-\alpha\rho}}P^{*\frac{\rho\alpha}{1-\alpha\rho}}\underbrace{\rho^{\frac{\alpha}{1-\alpha\rho}}\left[\left(\frac{\alpha_l}{w+\frac{p_e}{\nu_1}}\right)^{\alpha_l}\left(\frac{\alpha_k}{r}\right)^{\alpha_k}\right]^{\frac{1}{1-\alpha\rho}}}_{=C_Q}(d_O)^{\frac{-\alpha_l}{1-\alpha\rho}},\end{aligned}$$

where $d_O = 1 + s_e \frac{\nu_1 - \nu_O}{\nu_O}$ and $s_e = \frac{\frac{p_e}{\nu_1}}{w + \frac{p_e}{\nu_1}}$ is the share of energy in variable inputs for Top 1,000 firms. The optimal choice of l_1 is now

$$l_1 = \left[\frac{R^{1-\rho} P^\rho \rho [\phi (k_1^*)^{\alpha_k}]^\rho \Delta_n^{\frac{\rho-1}{1-\alpha}} \alpha_l}{w + \frac{p_e}{\nu_O}} \right]^{\frac{1}{1-\alpha_l \rho}} \quad \text{so that} \quad l_1 = l_1^* \left(\frac{P}{P^*} \right)^{\frac{\rho}{1-\alpha_l \rho}}.$$

That is, this difference in energy efficiency does not impact how unregulated firms respond to changes in the output price in terms of their use of intermediate inputs. Moreover, since $l_1 = \nu_O e_1$ and $l_1^* = \nu_O e_1^*$, we also have that $\frac{l_1}{l_*} = \frac{e_1}{e_1^*}$. These results then imply that

$$q_1(\phi, n) = q_1^*(\phi, n) \left(\frac{P}{P^*} \right)^{\frac{\alpha_l \rho}{1-\alpha_l \rho}} \quad \text{and} \quad q(\phi, n) = q^*(\phi, n) \left(\frac{P}{P^*} \right)^{\frac{\alpha_l \rho}{1-\alpha_l \rho}}. \tag{G.4}$$

Regulated Conglomerates

Since $\nu_1 \neq \nu_R$, the effective cost of inputs differs across regulated and related firms in the same conglomerate. This difference in input costs influences the within-conglomerate distribution of production. Within a given firm, we have that

$$l_i = \frac{\alpha_l}{\alpha_k} \frac{r}{w + \frac{p_e}{\nu_R}} k_i = \frac{\alpha_l}{\alpha_k} \frac{r}{w + \frac{p_e}{\nu_1}} k_i \frac{1}{1 + s_e \frac{\nu_1 - \nu_R}{\nu_R}} = \frac{\alpha_l}{\alpha_k} \frac{r}{w + \frac{p_e}{\nu_1}} k_i \frac{1}{d_i},$$

where $d_i = 1 + s_e \frac{\nu_1 - \nu_i}{\nu_i}$. The choice of capital across firms is now

$$\pi(\phi, n) = \max_{\{k_i\}_{i=1}^n} \left\{ R^{1-\rho} P^\rho \left[\sum_{i=1}^n \phi \delta^{i-1} k_i^\alpha \left(\frac{\alpha_l}{\alpha_k} \frac{r}{\left(w + \frac{p_e}{\nu_1} \right) d_i} \right)^{\alpha_l} \right]^\rho - \left(\frac{\alpha}{\alpha_k} r \right) \sum_{i=1}^n k_i \right\}.$$

Comparing the first-order conditions for k_1 and k_i, we find that $\frac{k_i}{k_1} = \delta^{\frac{i-1}{1-\alpha}} d_i^{\frac{-\alpha_l}{1-\alpha}}$. We then have

$$\frac{l_i}{l_1} = \delta^{\frac{i-1}{1-\alpha}} d_i^{\frac{-\alpha_l}{1-\alpha} - 1} = \delta^{\frac{i-1}{1-\alpha}} d_i^{\frac{-(1-\alpha_k)}{1-\alpha}}.$$

Production is then

$$q_i = \phi \delta^{i-1} k_i^\alpha \left(\frac{\alpha_l}{\alpha_k} \frac{r}{\left(w + \frac{p_e}{\nu_1} \right) d_i} \right)^{\alpha_l} = \phi \delta^{\frac{i-1}{1-\alpha}} k_1^\alpha \left(\frac{\alpha_l}{\alpha_k} \frac{r}{\left(w + \frac{p_e}{\nu_1} \right)} \right)^{\alpha_l} d_i^{\frac{-\alpha_l}{1-\alpha}} = \delta^{\frac{i-1}{1-\alpha}} d_i^{\frac{-\alpha_l}{1-\alpha}} q_1.$$

Let $d_R = d_i$ for $i > 1$, and recall that $d_1 = 1$. Total capital is then

$$K_n = k_1 \left(1 + d_R^{\frac{-\alpha_l}{1-\alpha}} \sum_{i>1} \delta^{\frac{i-1}{1-\alpha}} \right) = k_1 \left(1 + d_R^{\frac{-\alpha_l}{1-\alpha}} (\Delta_n^{\frac{1}{1-\alpha}} - 1) \right).$$

Define $\hat{\Delta}_n = \left(1 + d_R^{\frac{-\alpha_l}{1-\alpha}}(\Delta_n^{\frac{1}{1-\alpha}} - 1)\right)^{1-\alpha}$. The analysis for the optimal choice of K_n now holds with $\hat{\Delta}_n$ in place of Δ_n. In the case of regulated firms, we have

$$q^*(\phi, n) = \left(\phi\hat{\Delta}_n\right)^{\frac{1}{1-\alpha\rho}} R^{\frac{(1-\rho)\alpha}{1-\alpha\rho}} P^{*\frac{\rho\alpha}{1-\alpha\rho}} \underbrace{\rho^{\frac{\alpha}{1-\alpha\rho}} \left[\left(\frac{\alpha_l}{w + \frac{p_e}{\nu_1}}\right)^{\alpha_l} \left(\frac{\alpha_k}{r}\right)^{\alpha_k}\right]^{\frac{1}{1-\alpha\rho}}}_{=C_Q}. \quad \text{(G.5)}$$

Moreover, the thresholds defining the optimal number of conglomerates in Proposition 2 continue to hold using $\hat{\Delta}_n$. Note, however, that our assumption that energy costs change discontinuously at $\tilde{\phi}$ implies that regulated and unregulated conglomerates have different thresholds ϕ_n. Let $\{\phi_n^O\}$ be the set of size thresholds for unregulated conglomerates and $\{\phi_n^R\}$ be the set of related conglomerates. Let n' be the largest firm size for unregulated firms (so that $\phi_{n'+1}^O > \tilde{\phi}$) and n'' be the smallest size of regulated conglomerates (so that $\phi_{n''}^R < \tilde{\phi}$). The combined set of size thresholds is then $\{\{\phi_n^O\}_{n=1}^{n'}, \tilde{\phi}, \{\phi_n^R\}_{n=n''+1}\}$. We include $\tilde{\phi}$ in this list since it is possible that the change in energy efficiency for regulated firms leads to a change in firm size, though (depending on the differences in energy efficiency) this may not always be the case.

Consider now the response of the firms to the regulation. Using the fact that $k_i^* = k_1^* \delta^{\frac{i-1}{1-\alpha}} d_i^{\frac{-\alpha_l}{1-\alpha}}$, we can write the profit maximization problem as

$$\max_{\{l_i\}_1^n} \left\{ R^{1-\rho} P^\rho \left[\phi^* \sum_{i=1}^n \delta^{\frac{(i-1)(1-\alpha_l)}{1-\alpha}} l_i^{\alpha_l} d_i^{\frac{-\alpha_l\alpha_k}{1-\alpha}}\right]^\rho - \left(w + \frac{p_e}{\nu_1}\right) \sum_{i=1}^n d_i l_i - r \sum_{i=1}^n k_i^* \right\} \text{ subject to } l_1 \leq \xi l_1^*,$$

where $\phi^* = \phi(k_1^*)^{\alpha_k}$. The first-order conditions for l_i $(1 \leq i \leq n)$ are then

$$\underbrace{R^{1-\rho}P^\rho}_{\text{Market Demand}} \underbrace{\rho\left[\phi^* \sum_{i=1}^n \delta^{\frac{(i-1)(1-\alpha_l)}{1-\alpha}} l_i^{\alpha_l} d_i^{\frac{-\alpha_l\alpha_k}{1-\alpha}}\right]^{\rho-1}}_{\text{Residual Revenue}} \underbrace{\phi^* \delta^{\frac{(i-1)(1-\alpha_l)}{1-\alpha}} \alpha_l (l_i)^{\alpha_l - 1} d_i^{\frac{-\alpha_l\alpha_k}{1-\alpha}}}_{\text{Marginal Product}} = \left(w + \frac{p_e}{\nu_1}\right) d_i + \underbrace{\lambda(\phi)\mathbb{I}[i=1]}_{\substack{\text{Shadow Cost} \\ \text{of Regulation}}}.$$

Taking the ratio of the conditions for l_1 and $l_i (i > 1)$, we have

$$\left(\frac{l_i}{l_1}\right)^{1-\alpha_l} = \delta^{\frac{(i-1)(1-\alpha_l)}{1-\alpha}} \left[1 + \frac{\lambda(\phi)}{\left(w + \frac{p_e}{\nu_1}\right)}\right] d_i^{\frac{-\alpha_l\alpha_k}{1-\alpha} - 1}$$

$$\left(\frac{l_i}{l_1}\right)^{1-\alpha_l} = \delta^{\frac{(i-1)(1-\alpha_l)}{1-\alpha}} \left[1 + \frac{\lambda(\phi)}{\left(w + \frac{p_e}{\nu_1}\right)}\right] d_i^{\frac{-(1-\alpha_l)(1-\alpha_k)}{1-\alpha}}$$

$$\frac{l_i}{l_1} = \delta^{\frac{(i-1)}{1-\alpha}} \left[1 + \frac{\lambda(\phi)}{\left(w + \frac{p_e}{\nu_1}\right)}\right]^{\frac{1}{1-\alpha_l}} d_i^{\frac{-(1-\alpha_k)}{1-\alpha}}.$$

The residual revenue term now becomes

$$\phi(k_1^*)^{\alpha_k} l_1^{\alpha_l} \left[1 + \sum_{i>1} \delta^{\frac{i-1}{1-\alpha}} d_i^{\frac{-\alpha_l}{1-\alpha}} \left[1 + \frac{\lambda(\phi)}{\left(w + \frac{p_e}{\nu_1}\right)}\right]^{\frac{\alpha_l}{1-\alpha_l}}\right] = \phi(k_1^*)^{\alpha_k}(l_1^*)^{\alpha_l} \xi^{\alpha_l} \left[1 + (\hat{\Delta}_n^{\frac{1}{1-\alpha}} - 1)\left[1 + \frac{\lambda(\phi)}{\left(w + \frac{p_e}{\nu_1}\right)}\right]^{\frac{\alpha_l}{1-\alpha_l}}\right].$$

The first-order condition for the regulated firm is then

$$\underbrace{R^{1-\rho} P^{*\rho} \rho \left[\phi \sum_{i=1}^{n} \delta^{\frac{i-1}{1-\alpha}} (k_i^*)^{\alpha_k} (l_i^*)^{\alpha_l}\right]^{\rho-1} \times \phi \alpha_l (k_1^*)^{\alpha_k} (l_1^*)^{\alpha_l - 1}}_{\text{FOC Unregulated Case}}$$

$$\times (\xi)^{\alpha_l - 1} \left(\frac{P}{P^*}\right)^{\rho} \left[\underbrace{\xi^{\alpha_l} \frac{1 + (\hat{\Delta}_n^{\frac{1}{1-\alpha}} - 1)\left[1 + \frac{\lambda(\phi)}{\left(w + \frac{p_e}{\nu_1}\right)}\right]^{\frac{\alpha_l}{1-\alpha_l}}}{\hat{\Delta}_n^{\frac{1}{1-\alpha}}}}_{\equiv \xi_{q,n}^d}\right]^{\rho-1} = \left(w + \frac{p_e}{\nu_1}\right) + \lambda(\phi),$$

where $\frac{q(\phi,n)}{q^*(\phi,n)} = \xi_{q,n}^d$. Using the fact that the first-order condition in the unregulated case equals $\left(w + \frac{p_e}{\nu_1}\right)$, we obtain

$$1 + \frac{\lambda(\phi)}{\left(w + \frac{p_e}{\nu_1}\right)} = (\xi)^{\alpha_l - 1} \left(\frac{P}{P^*}\right)^{\rho} (\xi_{q,n}^d)^{(\rho-1)}. \tag{G.6}$$

Product Market Equilibrium

The price level absent the regulation is then

$$\begin{aligned}
P^{*-\rho} &= R^{-\rho} \int_{\phi_1}^{\tilde{\phi}} \left((\phi\Delta_n)^{\frac{1}{1-\alpha\rho}} R^{\frac{(1-\rho)\alpha}{1-\alpha\rho}} P^{*\frac{\rho\alpha}{1-\alpha\rho}} C_Q (d_O)^{\frac{-\alpha_l}{1-\alpha\rho}}\right)^{\rho} \frac{g(\phi)M}{1-G(\phi_1)} d\phi \\
&+ R^{-\rho} \int_{\tilde{\phi}_1} \left(\left(\phi\hat{\Delta}_n\right)^{\frac{1}{1-\alpha\rho}} R^{\frac{(1-\rho)\alpha}{1-\alpha\rho}} P^{*\frac{\rho\alpha}{1-\alpha\rho}} C_Q\right)^{\rho} \frac{g(\phi)M}{1-G(\phi_1)} d\phi \\
P^{*\frac{-\rho}{1-\alpha\rho}} R^{\frac{(1-\alpha)\rho}{1-\alpha\rho}} C_Q^{-\rho} \frac{1-G(\phi_1)}{M} &= \int_{\phi_1}^{\tilde{\phi}} \left(\phi\Delta_n d_O^{-\alpha_l}\right)^{\frac{\rho}{1-\alpha\rho}} g(\phi) d\phi + \int_{\tilde{\phi}} \left(\phi\hat{\Delta}_n\right)^{\frac{\rho}{1-\alpha\rho}} g(\phi) d\phi \\
P^{*\frac{-\rho}{1-\alpha\rho}} R^{\frac{(1-\alpha)\rho}{1-\alpha\rho}} C_Q^{-\rho} \frac{1-G(\phi_1)}{M} &= \sum_{n=1}^{\tilde{n}-1} (\Delta_n d_O^{-\alpha_l})^{\frac{\rho}{1-\alpha\rho}} \pi_n + (\Delta_{\tilde{n}} d_O^{-\alpha_l})^{\frac{\rho}{1-\alpha\rho}} \tilde{\pi}_1 \\
&+ (\hat{\Delta}_{\tilde{n}})^{\frac{\rho}{1-\alpha\rho}} \tilde{\pi}_2 + \sum_{n=\tilde{n}+1} (\hat{\Delta}_n)^{\frac{\rho}{1-\alpha\rho}} \pi_n.
\end{aligned}$$

After the regulation, the equilibrium is then

$$\begin{aligned}
P^{-\rho} &= R^{-\rho} \int_{\phi_1}^{\tilde{\phi}} \left(\left(\frac{P}{P^*}\right)^{\frac{\alpha_l \rho}{1-\alpha_l \rho}} (\phi\Delta_n)^{\frac{1}{1-\alpha\rho}} R^{\frac{(1-\rho)\alpha}{1-\alpha\rho}} P^{*\frac{\rho\alpha}{1-\alpha\rho}} C_Q (d_O)^{\frac{-\alpha_l}{1-\alpha\rho}}\right)^{\rho} \frac{g(\phi)M}{1-G(\phi_1)} d\phi \\
&+ R^{-\rho} \int_{\tilde{\phi}} \left(\xi_{q,n}^d \left(\phi\hat{\Delta}_n\right)^{\frac{1}{1-\alpha\rho}} R^{\frac{(1-\rho)\alpha}{1-\alpha\rho}} P^{*\frac{\rho\alpha}{1-\alpha\rho}} C_Q\right)^{\rho} \frac{g(\phi)M}{1-G(\phi_1)} d\phi
\end{aligned}$$

$$
\begin{aligned}
P^{-\rho}P^{*\frac{-\rho^2\alpha}{1-\alpha\rho}}R^{\frac{(1-\alpha)\rho}{1-\alpha\rho}}C_Q^{-\rho}\frac{1-G(\phi_1)}{M} &= \int_{\phi_1}^{\tilde{\phi}}\left(\frac{P}{P^*}\right)^{\frac{\alpha_l\rho^2}{1-\alpha_l\rho}}\left(\phi\Delta_n d_O^{-\alpha_l}\right)^{\frac{\rho}{1-\alpha\rho}}g(\phi)d\phi + \int_{\tilde{\phi}}(\xi_{q,n}^d)^\rho\left(\phi\hat{\Delta}_n\right)^{\frac{\rho}{1-\alpha\rho}}g(\phi)d\phi \\
P^{-\rho}P^{*\frac{-\rho^2\alpha}{1-\alpha\rho}}R^{\frac{(1-\alpha)\rho}{1-\alpha\rho}}C_Q^{-\rho}\frac{1-G(\phi_1)}{M} &= \sum_{n=1}^{\tilde{n}-1}\left(\frac{P}{P^*}\right)^{\frac{\alpha_l\rho^2}{1-\alpha_l\rho}}(\Delta_n d_O^{-\alpha_l})^{\frac{\rho}{1-\alpha\rho}}\pi_n + \left(\frac{P}{P^*}\right)^{\frac{\alpha_l\rho^2}{1-\alpha_l\rho}}(\Delta_{\tilde{n}}d_O^{-\alpha_l})^{\frac{\rho}{1-\alpha\rho}}\tilde{\pi}_1 \\
&+ (\xi_{q,\tilde{n}}^d)^\rho(\hat{\Delta}_{\tilde{n}})^{\frac{\rho}{1-\alpha\rho}}\tilde{\pi}_2 + \sum_{n=\tilde{n}+1}(\xi_{q,n}^d)^\rho(\hat{\Delta}_n)^{\frac{\rho}{1-\alpha\rho}}\pi_n.
\end{aligned}
$$

Comparing the regulated and unregulated equilibrium conditions, we then have

$$
\left(\frac{P}{P^*}\right)^{-\rho} = (1-s_{\tilde{\phi}}^d)\left(\frac{P}{P^*}\right)^{\frac{\alpha_l\rho^2}{1-\alpha_l\rho}} + s_{\tilde{\phi}}^d\mathbb{E}_e\left[(\xi_{q,n}^d)^\rho\,\middle|\,\phi>\tilde{\phi}\right],
$$

where $s_{\tilde{\phi}}^d = \frac{(\hat{\Delta}_{\tilde{n}})^{\frac{\rho}{1-\alpha\rho}}\tilde{\pi}_2 + \sum_{n=\tilde{n}+1}(\hat{\Delta}_n)^{\frac{\rho}{1-\alpha\rho}}\pi_n}{(d_O)^{\frac{-\alpha_l\rho}{1-\alpha\rho}}\left[\sum_{n=1}^{\tilde{n}-1}(\Delta_n)^{\frac{\rho}{1-\alpha\rho}}\pi_n + (\Delta_{\tilde{n}})^{\frac{\rho}{1-\alpha\rho}}\tilde{\pi}_1\right] + (\hat{\Delta}_{\tilde{n}})^{\frac{\rho}{1-\alpha\rho}}\tilde{\pi}_2 + \sum_{n=\tilde{n}+1}(\hat{\Delta}_n)^{\frac{\rho}{1-\alpha\rho}}\pi_n}$ and where $\mathbb{E}_e$ takes the expectation of the distribution of energy use among regulated firms. This case differs from our baseline case in that we use the $\hat{\Delta}_n$ expressions to calculate $\mathbb{E}_e$.

Aggregate Energy Use

Total intermediate inputs for a regulated conglomerate are

$$
\frac{l(\phi,n)}{l^*(\phi,n)} = \xi\frac{\left[1+(\Delta_n^{\frac{1}{1-\alpha}}-1)d_R^{\frac{-(1-\alpha_k)}{1-\alpha}}\left[1+\frac{\lambda(\phi)}{\left(w+\frac{p_e}{\nu_1}\right)}\right]^{\frac{1}{1-\alpha_l}}\right]}{1+(\Delta_n^{\frac{1}{1-\alpha}}-1)d_R^{\frac{-(1-\alpha_k)}{1-\alpha}}}.
$$

To compute total energy use, however, we need to take into account differences in energy efficiency across firms in the conglomerate. Absent regulation, we have

$$
e^*(\phi,n) = \frac{l_1^*}{\nu_1} + \frac{1}{\nu_R}\sum_{i>1}l_i^* = \frac{1}{\nu_1}\left(l_1^* + \frac{\nu_1}{\nu_R}\sum_{i>1}l_i^*\right) = \frac{1}{\nu_1}l_1^*\left(1+\frac{\nu_1}{\nu_R}(\Delta_n^{\frac{1}{1-\alpha}}-1)d_R^{\frac{-(1-\alpha_k)}{1-\alpha}}\right).
$$

After the regulation, we have

$$
e(\phi,n) = \frac{1}{\nu_1}l_1\left(1+\frac{\nu_1}{\nu_R}(\Delta_n^{\frac{1}{1-\alpha}}-1)d_R^{\frac{-(1-\alpha_k)}{1-\alpha}}\left[1+\frac{\lambda(\phi)}{\left(w+\frac{p_e}{\nu_1}\right)}\right]^{\frac{1}{1-\alpha_l}}\right).
$$

We then have

$$
\frac{e(\phi,n)}{e^*(\phi,n)} = \xi\frac{1+\frac{\nu_1}{\nu_R}(\Delta_n^{\frac{1}{1-\alpha}}-1)d_R^{\frac{-(1-\alpha_k)}{1-\alpha}}\left[1+\frac{\lambda(\phi)}{\left(w+\frac{p_e}{\nu_1}\right)}\right]^{\frac{1}{1-\alpha_l}}}{1+\frac{\nu_1}{\nu_R}(\Delta_n^{\frac{1}{1-\alpha}}-1)d_R^{\frac{-(1-\alpha_k)}{1-\alpha}}} \equiv \xi_{e,n}^d.
$$

To obtain an expression for $e^*(\phi,n)$ for regulated firms, recall that

$$\begin{aligned} l^*(\phi,n) &= l_1^*\left(1+d_R^{\frac{-(1-\alpha_k)}{1-\alpha}}(\Delta_n^{\frac{1}{1-\alpha}}-1)\right) \\ l^*(\phi,n) &= \left(\phi\hat{\Delta}_n\right)^{\frac{\rho}{1-\alpha\rho}} R^{\frac{1-\rho}{1-\alpha\rho}} P^{*\frac{\rho}{1-\alpha\rho}} \underbrace{\rho^{\frac{1}{1-\alpha\rho}}\left[\left(\frac{\alpha_l}{w+\frac{p_e}{\nu_1}}\right)^{1-\alpha_k\rho}\left(\frac{\alpha_k}{r}\right)^{\alpha_k\rho}\right]^{\frac{1}{1-\alpha\rho}}}_{=C_E} \end{aligned}$$

so that

$$e^*(\phi,n)=\left(\phi\hat{\Delta}_n\right)^{\frac{\rho}{1-\alpha\rho}} R^{\frac{1-\rho}{1-\alpha\rho}} P^{*\frac{\rho}{1-\alpha\rho}} C_E \frac{\frac{1}{\nu_1}\left(1+\frac{\nu_1}{\nu_R}(\Delta_n^{\frac{1}{1-\alpha}}-1)d_R^{\frac{-(1-\alpha_k)}{1-\alpha}}\right)}{\left(1+d_R^{\frac{-(1-\alpha_k)}{1-\alpha}}(\Delta_n^{\frac{1}{1-\alpha}}-1)\right)},$$

where the last terms adjust for the composition of energy use across establishments with different energy efficiency.

Consider now the unregulated firms. Since all firms in unregulated conglomerates have the same energy efficiency, we have

$$\frac{e(\phi,n)}{e^*(\phi,n)}=\frac{l(\phi,n)}{l^*(\phi,n)}=\left(\frac{P}{P^*}\right)^{\frac{\rho}{1-\alpha_l\rho}}$$

and

$$e^*(\phi,n)=\frac{l^*(\phi,n)}{\nu_O}=\frac{1}{\nu_O}\left(\phi\Delta_n\right)^{\frac{\rho}{1-\alpha\rho}} R^{\frac{1-\rho}{1-\alpha\rho}} P^{*\frac{\rho}{1-\alpha\rho}} \underbrace{\rho^{\frac{1}{1-\alpha\rho}}\left[\left(\frac{\alpha_l}{w+\frac{p_e}{\nu_1}}\right)^{1-\alpha_k\rho}\left(\frac{\alpha_k}{r}\right)^{\alpha_k\rho}\right]^{\frac{1}{1-\alpha\rho}}}_{=C_E}(d_O)^{\frac{-(1-\alpha_k\rho)}{1-\alpha\rho}}.$$

The total energy use prior to the regulation is then

$$\begin{aligned} E^* &= \int_{\phi_1} e^*(\phi,n)\frac{g(\phi)M}{1-G(\phi_1)}d\phi \\ &= R^{\frac{1-\rho}{1-\alpha\rho}} P^{*\frac{\rho}{1-\alpha\rho}} \frac{C_E M}{1-G(\phi_1)}\left[\frac{(d_O)^{\frac{-(1-\alpha_k\rho)}{1-\alpha\rho}}}{\nu_O}\left(\sum_{n=1}^{\tilde{n}-1}(\Delta_n)^{\frac{\rho}{1-\alpha\rho}}\pi_n+(\Delta_{\tilde{n}})^{\frac{\rho}{1-\alpha\rho}}\tilde{\pi}_1\right)\right. \\ &+ \left.\left(\hat{\Delta}_{\tilde{n}}\right)^{\frac{\rho}{1-\alpha\rho}}\frac{\frac{1}{\nu_1}\left(1+\frac{\nu_1}{\nu_R}(\Delta_{\tilde{n}}^{\frac{1}{1-\alpha}}-1)d_R^{\frac{-(1-\alpha_k)}{1-\alpha}}\right)}{\left(1+d_R^{\frac{-(1-\alpha_k)}{1-\alpha}}(\Delta_{\tilde{n}}^{\frac{1}{1-\alpha}}-1)\right)}\tilde{\pi}_2+\sum_{n=\tilde{n}+1}\left(\hat{\Delta}_n\right)^{\frac{\rho}{1-\alpha\rho}}\frac{\frac{1}{\nu_1}\left(1+\frac{\nu_1}{\nu_R}(\Delta_n^{\frac{1}{1-\alpha}}-1)d_R^{\frac{-(1-\alpha_k)}{1-\alpha}}\right)}{\left(1+d_R^{\frac{-(1-\alpha_k)}{1-\alpha}}(\Delta_n^{\frac{1}{1-\alpha}}-1)\right)}\pi_n\right] \end{aligned}$$

The total energy use after the regulation is then

$$\begin{aligned}
E &= \int_{\phi_1} e(\phi,n)\frac{g(\phi)M}{1-G(\phi_1)}d\phi \\
&= R^{\frac{1-\rho}{1-\alpha\rho}}P^{*\frac{\rho}{1-\alpha\rho}}\frac{C_E M}{1-G(\phi_1)}\left[\left(\frac{P}{P^*}\right)^{\frac{\rho}{1-\alpha_l\rho}}\frac{(d_O)^{\frac{-(1-\alpha_k\rho)}{1-\alpha\rho}}}{\nu_O}\left(\sum_{n=1}^{\tilde{n}-1}(\Delta_n)^{\frac{\rho}{1-\alpha\rho}}\pi_n+(\Delta_{\tilde{n}})^{\frac{\rho}{1-\alpha\rho}}\tilde{\pi}_1\right)\right. \\
&+ \xi^d_{e,\tilde{n}}\left(\hat{\Delta}_{\tilde{n}}\right)^{\frac{\rho}{1-\alpha\rho}}\frac{\frac{1}{\nu_1}\left(1+\frac{\nu_1}{\nu_R}(\Delta_{\tilde{n}}^{\frac{1}{1-\alpha}}-1)d_R^{\frac{-(1-\alpha_k)}{1-\alpha}}\right)}{\left(1+d_R^{\frac{-(1-\alpha_k)}{1-\alpha}}(\Delta_{\tilde{n}}^{\frac{1}{1-\alpha}}-1)\right)}\tilde{\pi}_2 \\
&+ \left.\sum_{n=\tilde{n}+1}\xi^d_{e,n}\left(\hat{\Delta}_n\right)^{\frac{\rho}{1-\alpha\rho}}\frac{\frac{1}{\nu_1}\left(1+\frac{\nu_1}{\nu_R}(\Delta_n^{\frac{1}{1-\alpha}}-1)d_R^{\frac{-(1-\alpha_k)}{1-\alpha}}\right)}{\left(1+d_R^{\frac{-(1-\alpha_k)}{1-\alpha}}(\Delta_n^{\frac{1}{1-\alpha}}-1)\right)}\pi_n\right].
\end{aligned}$$

The change in aggregate energy use is then

$$\frac{E}{E^*}=(1-s^e_{\tilde{\phi}})\left(\frac{P}{P^*}\right)^{\frac{\rho}{1-\alpha_l\rho}}+s^e_{\tilde{\phi}}\mathbb{E}_e\left[\xi^d_{e,n}\left|\phi>\tilde{\phi}\right.\right],$$

where

$$\frac{1-s^e_{\tilde{\phi}}}{s^e_{\tilde{\phi}}}=\frac{\frac{(d_O)^{\frac{-(1-\alpha_k\rho)}{1-\alpha\rho}}}{\nu_O}\left(\sum_{n=1}^{\tilde{n}-1}(\Delta_n)^{\frac{\rho}{1-\alpha\rho}}\pi_n+(\Delta_{\tilde{n}})^{\frac{\rho}{1-\alpha\rho}}\tilde{\pi}_1\right)}{\left(\hat{\Delta}_{\tilde{n}}\right)^{\frac{\rho}{1-\alpha\rho}}\frac{\frac{1}{\nu_1}\left(1+\frac{\nu_1}{\nu_R}(\Delta_{\tilde{n}}^{\frac{1}{1-\alpha}}-1)d_R^{\frac{-(1-\alpha_k)}{1-\alpha}}\right)}{\left(1+d_R^{\frac{-(1-\alpha_k)}{1-\alpha}}(\Delta_{\tilde{n}}^{\frac{1}{1-\alpha}}-1)\right)}\tilde{\pi}_2+\sum_{n=\tilde{n}+1}\left(\hat{\Delta}_n\right)^{\frac{\rho}{1-\alpha\rho}}\frac{\frac{1}{\nu_1}\left(1+\frac{\nu_1}{\nu_R}(\Delta_n^{\frac{1}{1-\alpha}}-1)d_R^{\frac{-(1-\alpha_k)}{1-\alpha}}\right)}{\left(1+d_R^{\frac{-(1-\alpha_k)}{1-\alpha}}(\Delta_n^{\frac{1}{1-\alpha}}-1)\right)}\pi_n}$$

and where we evaluate $\mathbb{E}_e$ using the conditional probabilities

$$\mathbb{P}r\left[n=n'\left|\phi>\tilde{\phi}\right.\right]=\frac{\left(\hat{\Delta}_{n'}\right)^{\frac{\rho}{1-\alpha\rho}}\frac{\frac{1}{\nu_1}\left(1+\frac{\nu_1}{\nu_R}(\Delta_{n'}^{\frac{1}{1-\alpha}}-1)d_R^{\frac{-(1-\alpha_k)}{1-\alpha}}\right)}{\left(1+d_R^{\frac{-(1-\alpha_k)}{1-\alpha}}(\Delta_{n'}^{\frac{1}{1-\alpha}}-1)\right)}\pi_{n'}}{\left(\hat{\Delta}_{\tilde{n}}\right)^{\frac{\rho}{1-\alpha\rho}}\frac{\frac{1}{\nu_1}\left(1+\frac{\nu_1}{\nu_R}(\Delta_{\tilde{n}}^{\frac{1}{1-\alpha}}-1)d_R^{\frac{-(1-\alpha_k)}{1-\alpha}}\right)}{\left(1+d_R^{\frac{-(1-\alpha_k)}{1-\alpha}}(\Delta_{\tilde{n}}^{\frac{1}{1-\alpha}}-1)\right)}\tilde{\pi}_2+\sum_{n=\tilde{n}+1}\left(\hat{\Delta}_n\right)^{\frac{\rho}{1-\alpha\rho}}\frac{\frac{1}{\nu_1}\left(1+\frac{\nu_1}{\nu_R}(\Delta_n^{\frac{1}{1-\alpha}}-1)d_R^{\frac{-(1-\alpha_k)}{1-\alpha}}\right)}{\left(1+d_R^{\frac{-(1-\alpha_k)}{1-\alpha}}(\Delta_n^{\frac{1}{1-\alpha}}-1)\right)}\pi_n}.$$

G.3 Imperfect Substitution within Conglomerates

We now consider the possibility that the outputs of affiliates within the same conglomerate are not perfect substitutes. In particular, we assume that the conglomerate-level composite good $q(\omega)$ can be represented as affiliate output, such that

$$q(\omega)=\left(\sum_i q(\omega,i)^{\rho_c}\right)^{1/\rho_c}, \quad \text{where } 0<\rho<\rho_c<1.$$

The residual demand for the ith affiliate of conglomerate ω, i.e., (ω, i), is

$$p(\omega, i) = R^{1-\rho} P^{\rho} q(\omega)^{\rho-\rho_c} q(\omega, i)^{\rho_c - 1}.$$

The profit maximization problem for the conglomerate is now

$$\begin{aligned} & \max_{\{l_i\}_{i=1}^n, \{k_i\}_{i=1}^n} R^{1-\rho} P^{\rho} q(\phi)^{\rho-\rho_c} \sum_i q(\phi, i)^{\rho_c} - (w + p_e) \sum_i l_i - r \sum_i k_i \\ = & \max_{\{l_i\}_{i=1}^n, \{k_i\}_{i=1}^n} R^{1-\rho} P^{\rho} \left[\sum_i q(\phi, i)^{\rho_c} \right]^{\rho/\rho_c} - (w + p_e) \sum_i l_i - r \sum_i k_i, \end{aligned}$$

where $q(\phi, i) = \phi \delta^{i-1} k_i^{\alpha_k} l_i^{\alpha_l}$. The first-order conditions for $l_1, ...l_n$ imply that $\frac{l(\phi,i)}{l(\phi,1)} = \left(\frac{q(\phi,i)}{q(\phi,1)} \right)^{\rho_c}$. Since the capital-labor ratio remains $\frac{l_i}{k_i} = \frac{\alpha_l}{\alpha_k} \frac{r}{w+p_e}$, substituting into $q(\phi, i)$ allows us to express the first-order conditions as

$$\frac{k_i}{k_1} = \frac{l_i}{l_1} = \frac{e_i}{e_1} = \delta^{\frac{(i-1)\rho_c}{1-\alpha\rho_c}} \quad \text{and} \quad \frac{q_i}{q_1} = \delta^{\frac{(i-1)}{1-\alpha\rho_c}}.$$

These expression reduce to Proposition 1 when $\rho_c = 1$. To understand how values of $\rho_c < 1$ impact the use of inputs within the conglomerate, note that in the exponent for the first expression, a lower value of ρ_c decreases the numerator and increase the denominator. Both forces work to reduce the magnitude of the exponent such that the use of inputs depreciates more slowly in firm rank given the same δ.

We now define $\Delta_n^C = \left[\sum_{i=1}^n (\delta^{(i-1)})^{\frac{\rho_c}{1-\alpha\rho_c}} \right]^{\frac{1-\alpha\rho_c}{\rho_c}}$, so that $\frac{k_1}{K_n} = \frac{l_1}{L_n} = \frac{1}{(\Delta_n^C)^{\frac{\rho_c}{1-\alpha\rho_c}}}$. Total composite output is then

$$\begin{aligned} q(\phi)^{\rho_c} &= \left(\frac{\alpha_l}{\alpha_k} \frac{r}{w + p_e} \right)^{\alpha_l \rho_c} \phi^{\rho_c} \sum_i (\delta^{(i-1)\rho_c}) (\delta^{\frac{(i-1)\rho_c}{1-\alpha\rho_c}} k_1)^{\alpha\rho_c} \\ &= \left(\frac{\alpha_l}{\alpha_k} \frac{r}{w + p_e} \right)^{\alpha_l \rho_c} \phi^{\rho_c} k_1^{\alpha\rho_c} (\Delta_n^C)^{\frac{\rho_c}{1-\alpha\rho_c}} = \left(\frac{\alpha_l}{\alpha_k} \frac{r}{w + p_e} \right)^{\alpha_l \rho_c} (\phi \Delta_n^C)^{\rho_c} K_n^{\alpha\rho_c}. \end{aligned}$$

We can then rewrite the optimization problem as

$$\max_{K_n} R^{1-\rho} P^{\rho} \left(\frac{\alpha_l}{\alpha_k} \frac{r}{w + p_e} \right)^{\rho\alpha_l} (\phi \Delta_n^C)^{\rho} K_n^{\alpha\rho} - \left(\frac{\alpha_l}{\alpha_k} r + r \right) K_n,$$

where we represent total variable costs as $(w + p_e) L_n = \left(\frac{\alpha_l}{\alpha_k} r \right) K_n$. Note that this optimization problem is exactly the same as our in baseline model, except for the new definition of Δ_n^C. The within-conglomerate revenue share is now $\left(\frac{\delta^{i-1}}{\Delta_n^C} \right)^{\frac{\rho_c}{1-\alpha\rho_c}}$, which equals the share in the case of perfect substitution when $\rho_c = 1$. Similarly, the results of Proposition 2 continue to hold using the new Δ_n^C.

Regulated Conglomerates

Given ϕ and k_i^*, we can write $q(\phi)^{\rho_c}$ as

$$\phi^{\rho_c}\sum_i(\delta^{(i-1)\rho_c})(\delta^{\frac{(i-1)\rho_c}{1-\alpha\rho_c}}k_1^*)^{\alpha_k\rho_c}l_i^{\alpha_l\rho_c}\equiv(\phi(k_1^*)^{\alpha_k})^{\rho_c}\sum_i(\delta^{(i-1)\rho_c})^{\frac{(1-\alpha_l\rho_c)}{1-\alpha\rho_c}}l_i^{\alpha_l\rho_c}.$$

We can similarly define the short-run response as

$$\max_{\{l_i\}_{i=1}^n\}}R^{1-\rho}P^{\rho}\left[\phi^*\left(\sum_i\delta^{\frac{(i-1)\rho_c(1-\alpha_l\rho_c)}{1-\alpha\rho_c}}l_i^{\alpha_l\rho_c}\right)^{1/\rho_c}\right]^{\rho}-(w+p_e)\sum_i l_i.$$

The first-order condition in this case becomes

$$R^{1-\rho}P^{\rho}\rho\left[\phi^*\left(\sum_i\delta^{\frac{(i-1)\rho_c(1-\alpha_l\rho_c)}{1-\alpha\rho_c}}l_i^{\alpha_l\rho_c}\right)^{1/\rho_c}\right]^{\rho-1}\times\phi^*\delta^{\frac{(i-1)\rho_c(1-\alpha_l\rho_c)}{1-\alpha\rho_c}}\alpha_l\rho_c(l_i)^{\alpha_l\rho_c-1}=w+p_e+\lambda(\phi)I[i=1].$$

The within-conglomerate input allocation is now

$$\frac{l_j}{l_2}=\delta^{\frac{(j-2)\rho_c}{1-\alpha\rho_c}},j>2\quad\text{and}\quad\frac{l_i}{l_1}=\delta^{\frac{(i-1)\rho_c}{1-\alpha\rho_c}}\left[1+\frac{\lambda(\phi)}{w+p_e}\right]^{\frac{1}{1-\alpha_l\rho_c}}.$$

The conglomerate composite output is then

$$q(\phi,n)=q_1(\phi,n)\left[1+\sum_{i>1}\delta^{\frac{(i-1)\rho_c}{1-\alpha\rho_c}}\left[1+\frac{\lambda(\phi)}{w+p_e}\right]^{\frac{\alpha_l\rho_c}{1-\alpha_l\rho_c}}\right]^{1/\rho_c}.$$

Recalling that the original preregulation optimal composite output is

$$q^*(\phi,n)=q_1^*(\phi,n)\left[\sum_i^n\delta^{\frac{(i-1)\rho_c}{1-\alpha\rho_c}}\right]^{1/\rho_c}\equiv q_1^*(\phi,n)(\Delta_n^C)^{\frac{1}{1-\alpha\rho_c}}$$

and using the fact that $q_1(\phi,n)=q_1^*(\phi,n)\xi^{\alpha_l}$, we obtain

$$q(\phi,n)=q^*(\phi,n)\underbrace{\left[\xi^{\alpha_l}\frac{\left(1+((\Delta_n^C)^{\frac{\rho_c}{1-\alpha\rho_c}}-1)\left[1+\frac{\lambda(\phi)}{w+p_e}\right]^{\frac{\alpha_l\rho_c}{1-\alpha_l\rho_c}}\right)^{1/\rho_c}}{(\Delta_n^C)^{\frac{1}{1-\alpha\rho_c}}}\right]}_{\xi_{q,n}^C(\phi)}.$$

Using similar arguments from our baseline model, we have that the shadow cost of the regulation takes the form

$$1+\frac{\lambda(\phi)}{w+p_e}=(\xi)^{\alpha_l\rho_c-1}\left(\frac{P}{P^*}\right)^{\rho}(\xi_{q,n}^C)^{\rho-1}.$$

As in previous cases, the shadow cost depends only on n. Unregulated conglomerates are not affected by imperfect substitution within regulated conglomerates. We thus still have that

$$l_1 = l_1^* \left(\frac{P}{P^*} \right)^{\frac{\rho}{1-\alpha_l \rho}}$$

and

$$q(\phi, n) = q^*(\phi, n) \left(\frac{P}{P^*} \right)^{\frac{\rho}{1-\alpha_l \rho}}.$$

Product Market Equilibrium

We now again define the industry price index in terms of quantity of both regulated and unregulated conglomerates. The equilibrium price is defined by

$$P = \left[\int_{\phi_1} p(\phi, n)^{\frac{\rho}{\rho-1}} \frac{M}{1 - G(\phi_1)} dG \right]^{\frac{\rho-1}{\rho}} \quad \text{where} \quad p(\phi, n)^{\frac{\rho_c}{\rho_c - 1}} = \sum_{i=1}^{n} p(\phi, i)^{\frac{\rho_c}{\rho_c - 1}}.$$

Substituting the residual demand curve $p(\phi, i) = R^{1-\rho} P^{\rho} q(\phi, n)^{\rho - \rho_c} q(\phi, i)^{\rho_c - 1}$, we have the composite conglomerate price index

$$p(\phi, n) = R^{1-\rho} P^{\rho} q(\phi, n)^{\rho - \rho_c} \left(\sum_i q(\phi, i)^{\rho_c} \right)^{\frac{\rho_c - 1}{\rho_c}} \equiv R^{1-\rho} P^{\rho} q(\phi, n)^{\rho - 1}.$$

Substituting this expression into the aggregate price index P, we have

$$P^{\frac{\rho}{\rho-1}} = \int_{\phi_1} (R^{1-\rho} P^{\rho})^{\frac{\rho}{\rho-1}} q(\phi, n)^{\rho} \frac{M}{1 - G(\phi_1)} dG,$$

which is equivalent to $P^{-\rho} = R^{-\rho} \int_{\phi_1} q(\phi, n)^{\rho} \frac{M}{1-G(\phi_1)} dG$. That is, the equation describing the change in equilibrium prices, Equation D.7, continues to hold with the new definition of Δ_n^C and $\xi_{q,n}^C$.

Aggregate Energy Use

Consider first the regulated conglomerate. Using the fact that $e^*(\phi, n) = e_1^*(\phi, n) \sum_i \delta^{\frac{(i-1)\rho_c}{1-\alpha\rho_c}} = e_1^*(\phi, n)(\Delta_n^C)^{\frac{\rho_c}{1-\alpha\rho_c}}$, we have that

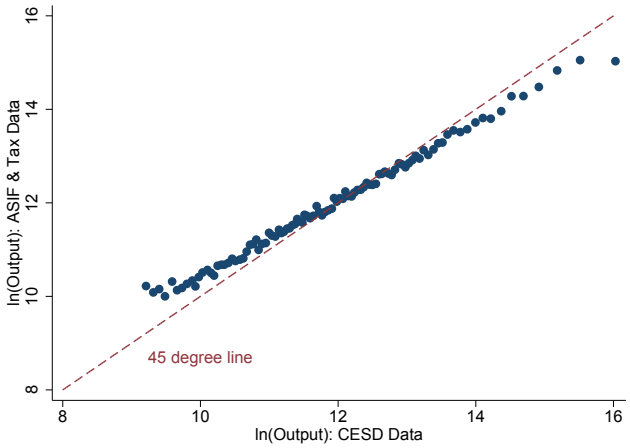
$$\begin{aligned} e(\phi, n) &= e_1(\phi, n) \left[1 + \sum_{i>1} \delta^{\frac{(i-1)\rho_c}{1-\alpha\rho_c}} \left[1 + \frac{\lambda_n}{w + p_e} \right]^{\frac{1}{1-\alpha_l \rho_c}} \right] \\ &= e^*(\phi, n) \underbrace{\left[\xi \frac{\left(1 + ((\Delta_n^C)^{\frac{\rho_c}{1-\alpha\rho_c}} - 1) \left[1 + \frac{\lambda_n}{w+p_e} \right]^{\frac{1}{1-\alpha_l \rho_c}} \right)}{(\Delta_n^C)^{\frac{\rho_c}{1-\alpha\rho_c}}} \right]}_{\xi_{e,n}^C}. \end{aligned}$$

The rest of the aggregation results then similarly carry through with $\xi_{e,n}^C$ defined as above.

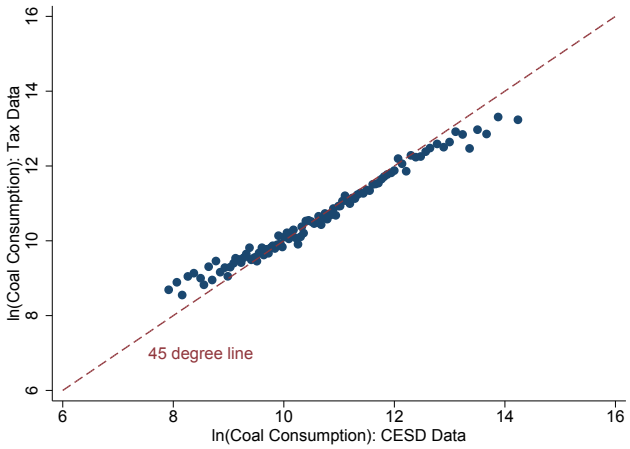
Appendix Figures

Figure A.1: Data Comparison: ASIF, CESD, Tax Data

A. Comparison of Output Data, 2001–2010

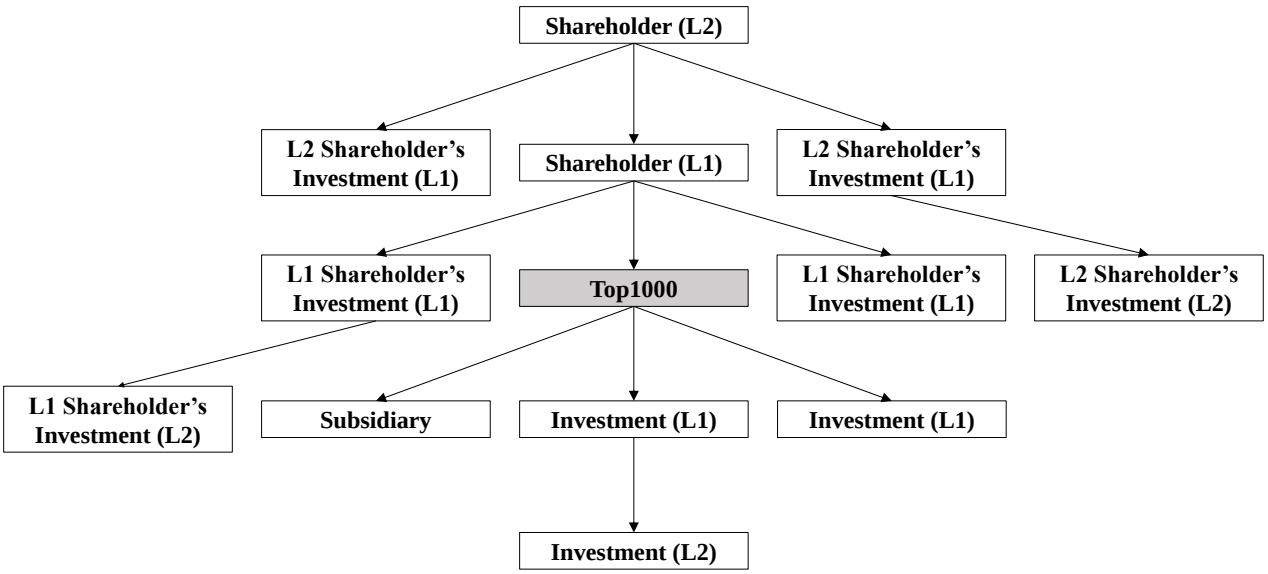


B. Comparison of Coal Consumption, 2007–2010



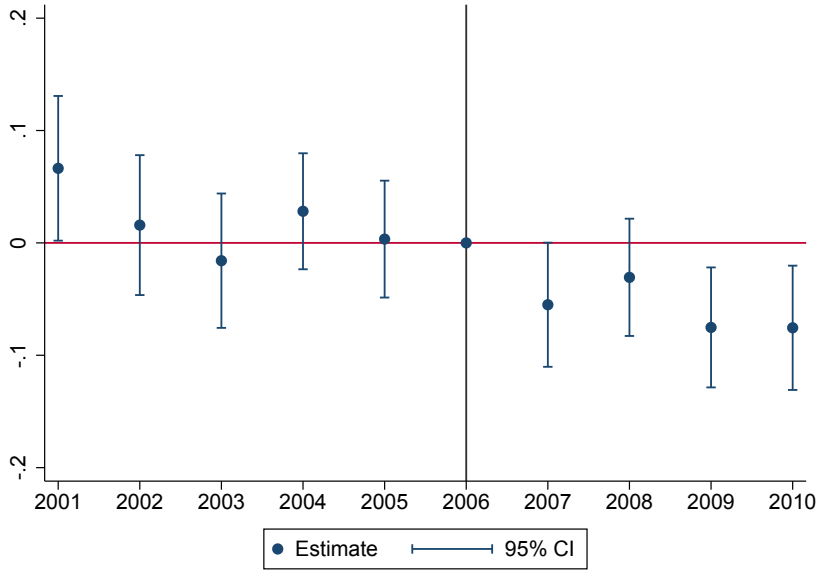
Notes: Authors' calculations using data from ASIF, CESD and ATS. This figure shows the comparison of output and energy consumption data between the ASIF, ATS and CESD. Panel A shows that the output data from ASIF and tax data are highly correlated with those from CESD. This panel uses data from the ASIF in 2001–2006 and ATS in 2007–2010. Panel B shows that coal consumption figures from the tax data almost mirror those from the CESD (tax data are available only after 2007).

Figure A.2: Types of Related Parties



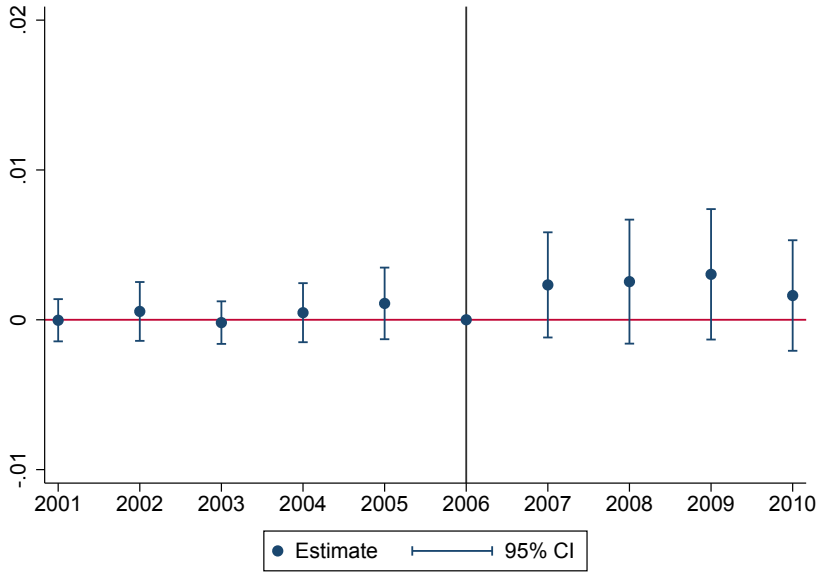
Notes: This figure depicts all possible types of firm relations within 2 levels of ownership. See Section 1.2 for the definition of each related type, and see Figure 2 for examples.

Figure A.3: Effects of Policy on the Investment of Regulated Firms



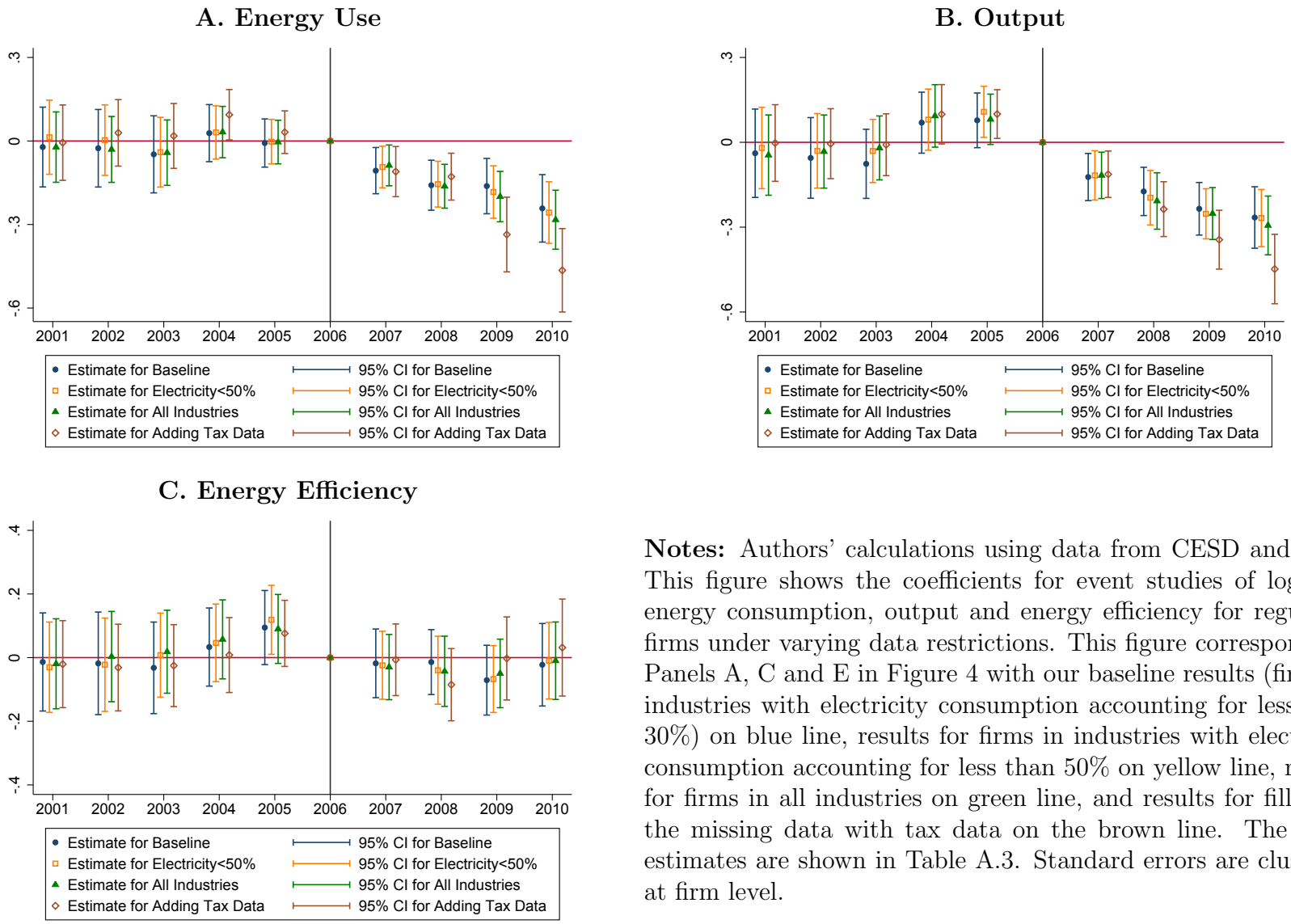
Notes: Authors' calculations using data from the ASIF and ATS. This figure shows estimates of Equation 1 where the dependent variable is firm investment choice. Investment choice is defined as whether a firm invests. See Section 1 for more information about the data-generating procedure. This figure shows that regulated firms were less likely to invest than similar control firms (Top 10,000 firms not related to Top 1,000 firms) after the regulation. The point estimates are displayed in Table A.8. See Section 2 for additional discussion. Standard errors are clustered at the firm level.

Figure A.4: Innovation in Top 1,000 Firms: Energy-Saving Patent Applications



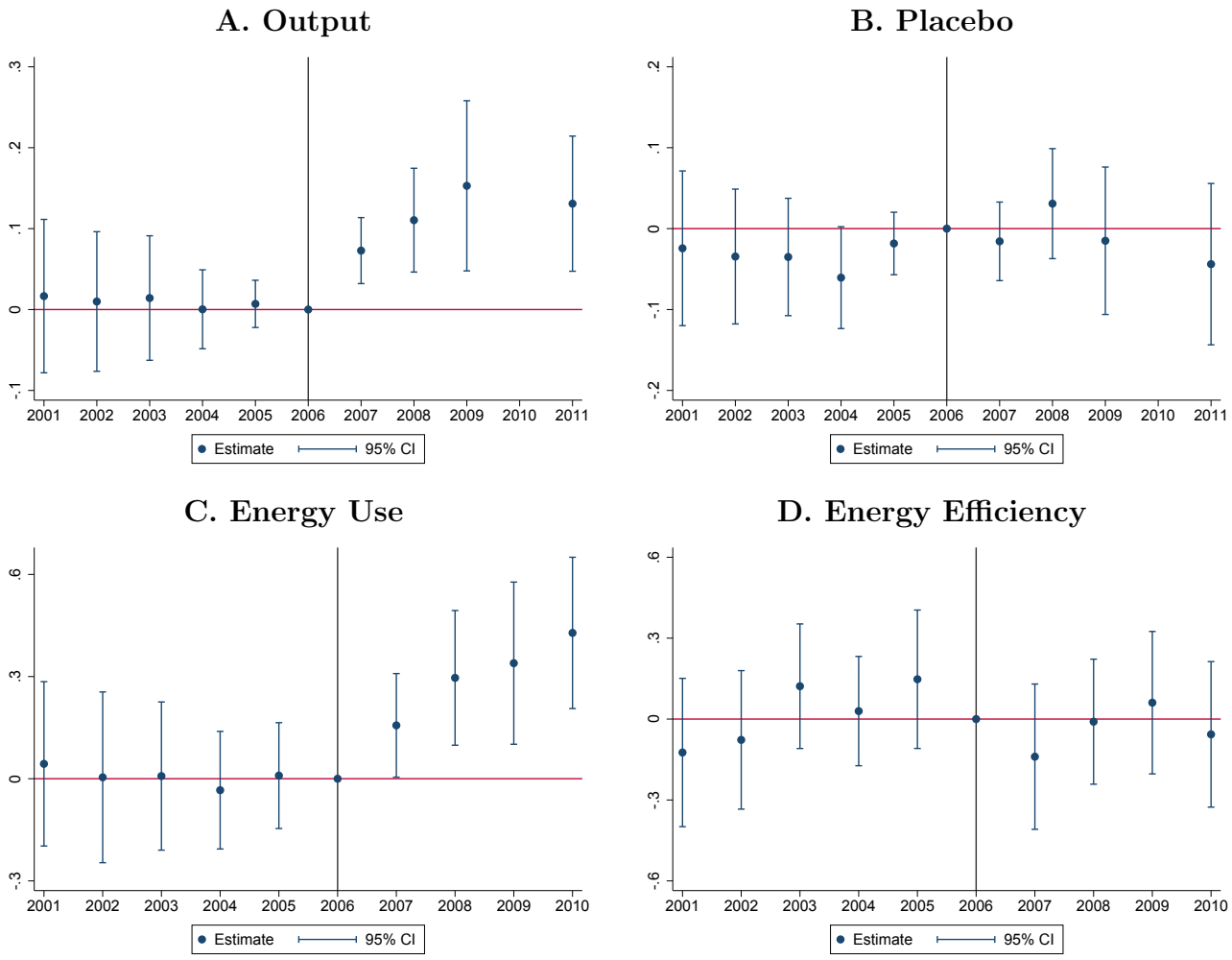
Notes: Authors' calculations using data from Incopat. This figure shows estimates of Equation 1 where the dependent variable is log firm patent applications. No significant effects on patent application can be found for regulated firms relative to similar control firms (Top 10,000 firms not related to Top 1,000 firms). Standard errors are clustered at the firm level.

Figure A.5: Robustness to Different Samples



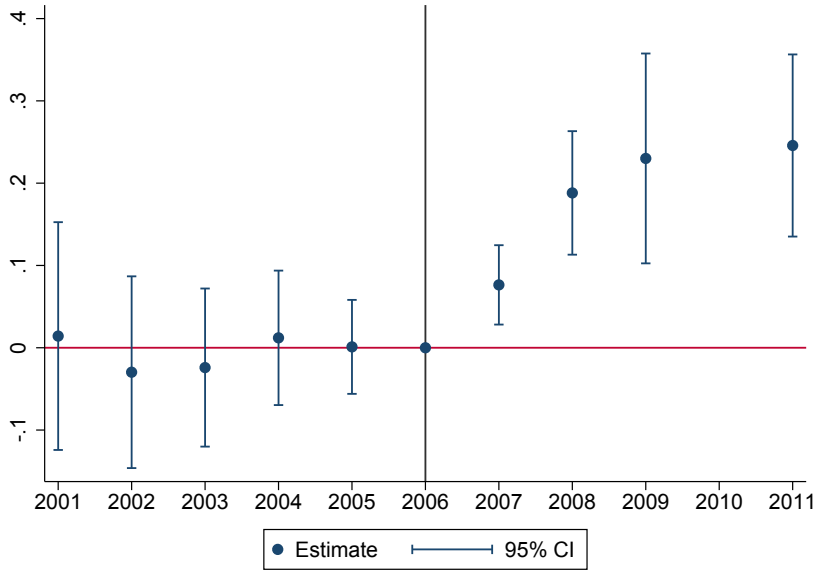
Notes: Authors' calculations using data from CESD and ATS. This figure shows the coefficients for event studies of log firm energy consumption, output and energy efficiency for regulated firms under varying data restrictions. This figure corresponds to Panels A, C and E in Figure 4 with our baseline results (firms in industries with electricity consumption accounting for less than 30%) on blue line, results for firms in industries with electricity consumption accounting for less than 50% on yellow line, results for firms in all industries on green line, and results for filling in the missing data with tax data on the brown line. The point estimates are shown in Table A.3. Standard errors are clustered at firm level.

Figure A.6: Robustness of Spillovers to Related Firms: Entropy Matching



Notes: Authors' calculations using data from the ASIF and CESD. This figure shows the coefficients for event studies of log output, log energy consumption and log energy efficiency for firms related to regulated firms and event studies of log firm output for placebo firms. This figure corresponds to Figure 5 but deploys the additional matching method of entropy matching. The point estimates are displayed in Table A.9 and Table A.10. Standard errors are clustered at the firm level.

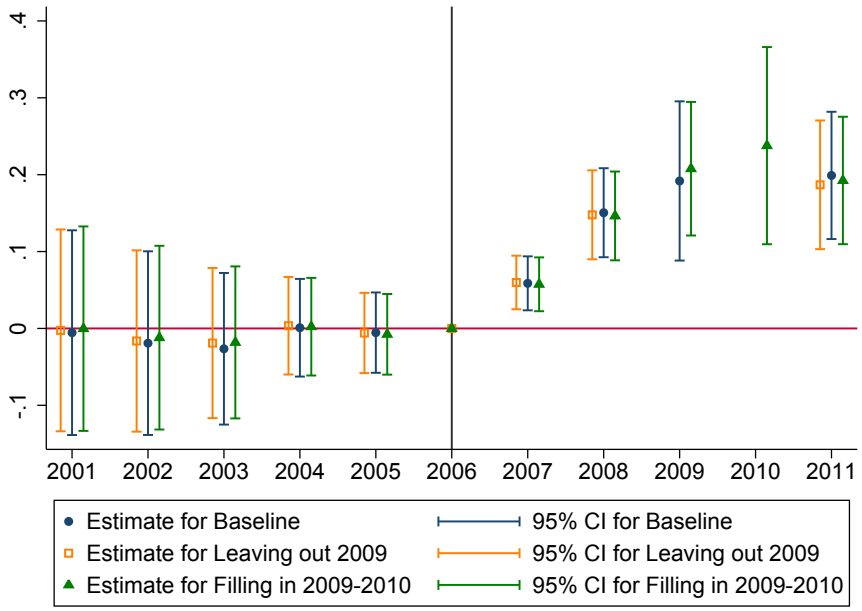
Figure A.7: Robustness to Dropping Electric Power Generation and Supply



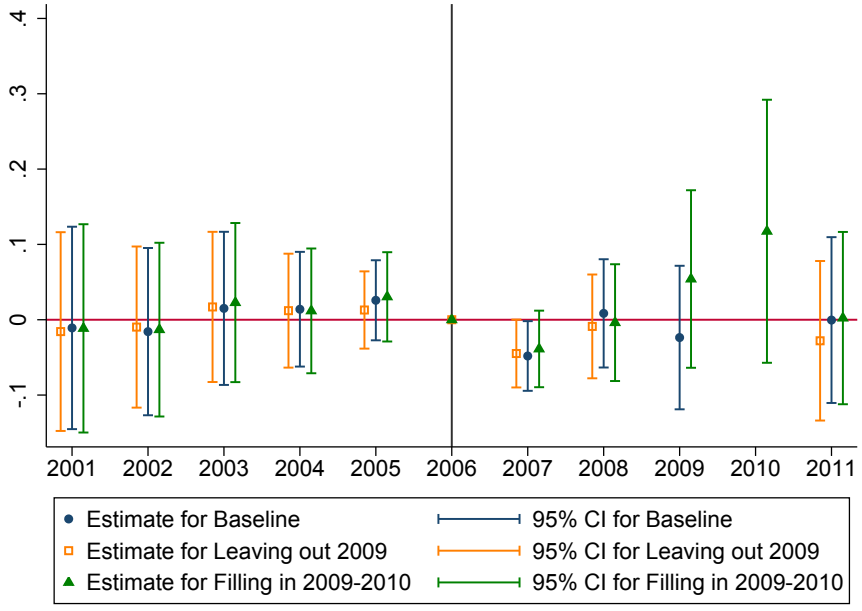
Notes: Authors' calculations using data from ASIF. This figure shows the coefficients for an event study of log firm output for firms related to regulated firms where related firms are restricted to those in industries other than electric power generation and supply. This figure corresponds to Panel A of Figure 5 but drops all observations in the electric power generation and supply industry. The point estimates are shown in Table A.12. Standard errors are clustered at the firm level.

Figure A.8: Data Quality Robustness for Related Spillovers

A. Output

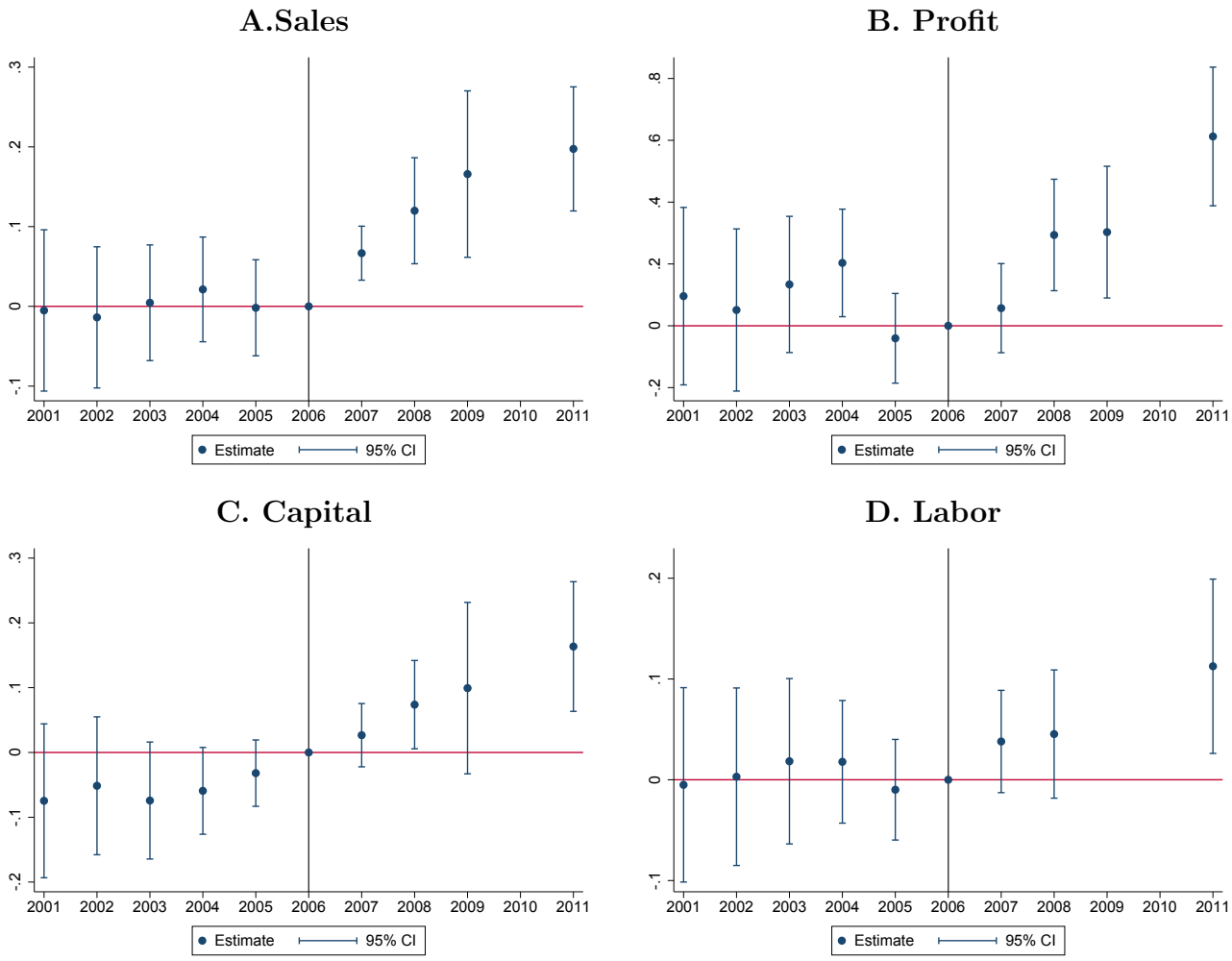


B. Placebo



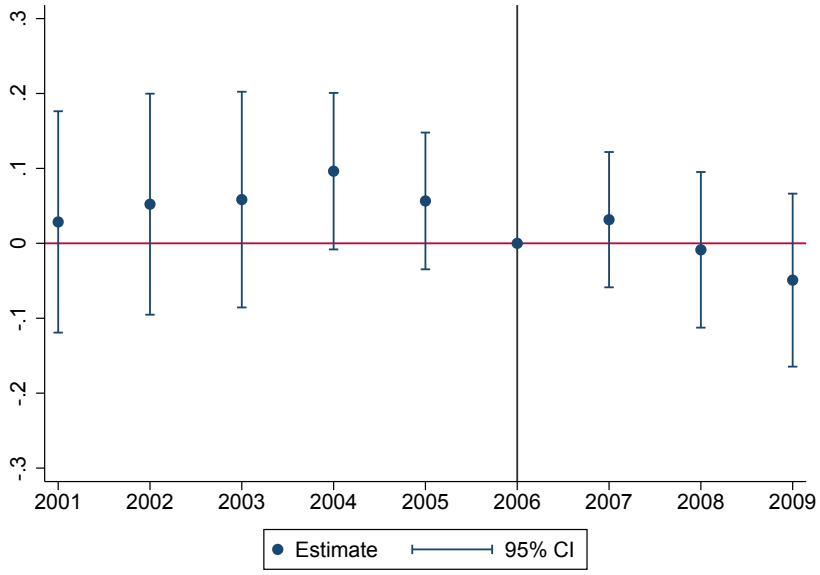
Notes: Authors' calculations using ASIF and ATS. This figure shows the coefficients for event studies of log firm output for related firms and placebo firms with different datasets. This figure corresponds to Panels A and B in Figure 5 but drops the data for 2009 from the ASIF on the yellow line and fills in the 2009–2010 data with tax data on the green line. The point estimates are shown in Table A.13. Standard errors are clustered at the firm level.

Figure A.9: Additional Spillover Effects of the Program



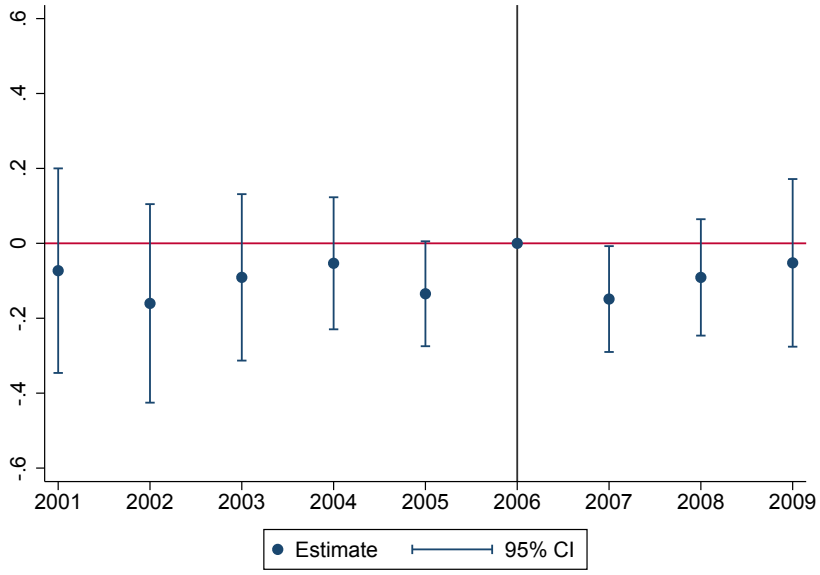
Notes: Authors' calculations using data from the ASIF. This figure shows the coefficients for event studies of log firm sales, profit, capital and labor for firms related to regulated firms. It shows that the Top 1,000 Energy Saving Program had a persistent effect on the production and performance of related firms. The point estimates are displayed in Table A.14. Standard errors are clustered at the firm level.

Figure A.10: Robustness of Effects on the Energy Efficiency of Regulated Firms



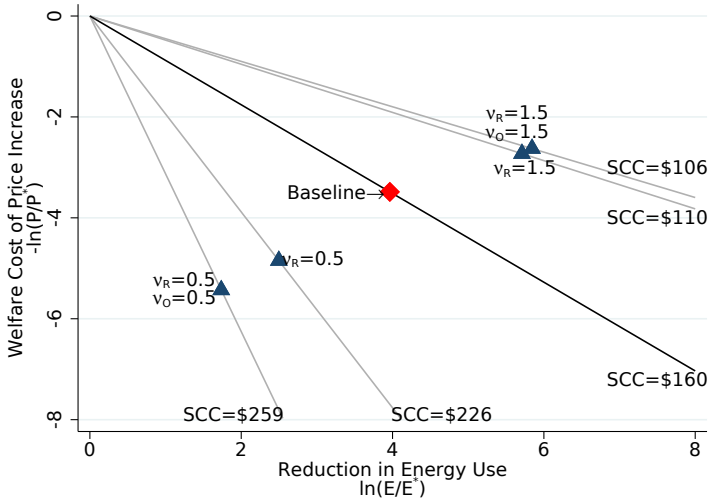
Notes: Authors' calculations using data from the CESD and ASIF. This figure shows the coefficients for an event study of log firm energy efficiency in regulated firms, where energy efficiency is defined as the inverse of the energy share in variable input costs. Variable input is calculated from the ASIF in terms of sales cost. This figure corresponds to Panel E of Figure 4 but with an alternative definition of energy efficiency. The point estimates are shown in Table A.18. Standard errors are clustered at the firm level.

Figure A.11: Robustness of Effects on the Energy Efficiency of Related Firms



Notes: Authors' calculations using data from the CESD and ASIF. This figure shows the coefficients for an event study of log firm energy efficiency in firms related to regulated firms, where energy efficiency is defined as the inverse of the energy share in variable input costs. Variable input is calculated from the ASIF in terms of sales cost. This figure corresponds to Panel D of Figure 5 but with an alternative definition of energy efficiency. The point estimates are shown in Table A.19. Standard errors are clustered at the firm level.

Figure A.12: Welfare Effects: Additional Robustness to Differences in Energy Efficiency



Notes: This figure shows the robustness of the welfare effects of the Top 1,000 program. The black lines plot indifference curves for the baseline value of SCC=$160, and the light gray lines plot values of the SCC according to different extensions. As discussed in Section 7.2, we explore the robustness of our results to allowing for preexisting differences in energy efficiency. $\nu_R > 1$ denotes that related firms are more energy efficient than Top 1,000 firms, while $\nu_O < 1$ denotes that unregulated and unrelated firms are less efficient than Top 1,000 firms and vice versa. See Section 7.2 for details. While Panel B of Figure 11 allows for differences in energy efficiency of up to 20%, this figure further allows differences in energy efficiency of up to 50%. Across these values, the SCC that rationalizes the Top 1,000 program lies between $106 and $259.

Appendix Tables

Table A.1: Policy Compliance

Type	Orig.list	Evaluation			
Year		2007	2008	2009	2010
Firm number	1008	953	922	901	881
Noncompliant firms	-	74	36	28	15
Noncompliance rate	-	7.76%	3.90%	3.11%	1.70%

Notes: Authors' calculations using data from the NDRC. This table shows the compliance of Top 1,000 firms during the 11FYP. The first row shows the number of Top 1,000 firms evaluated by the government in each year, the second row shows the number of noncompliant firms, and the last row shows the corresponding noncompliance rate. By the end of the 11FYP, 98.3% of evaluated Top 1,000 firms achieved their energy saving targets. See Section 1.1 for additional discussion.

Table A.2: Dataset Matching

Datasets	Top 1,000		Top 10,000	
	Number	Ratio	Number	Ratio
List	1008	-	14641	-
ASIF	1001	99.31%	14300	97.67%
CESD	818	81.15%	10722	73.23%
ASIF & CESD	809	80.26%	9481	64.76%
ASIF & ATS	446	44.25%	6622	45.23%

Notes: Authors' calculations using data from the ASIF, CESD and ATS. This table shows the result of dataset matching. Over 99% of the Top 1,000 firms and over 97% of the Top 10,000 firms can be found in the ASIF, and over 80% of the Top 1,000 firms and over 70% of the Top 10,000 firms can be found in the CESD. See Section 1.2 for additional discussion.

Table A.3: Robustness to Different Samples

Variables	ln(Energy Use)	ln(Output)	ln(Energy Efficiency)	Top1000
Baseline	-0.156***	-0.204***	-0.049	427
	(0.047)	(0.042)	(0.046)	
Electricity<20%	-0.133***	-0.178***	-0.045	397
	(0.050)	(0.045)	(0.050)	
Electricity<50%	-0.170***	-0.233***	-0.064	479
	(0.043)	(0.042)	(0.045)	
All Industries	-0.172***	-0.236***	-0.063	520
	(0.042)	(0.040)	(0.044)	
Add Tax Data	-0.284***	-0.319***	-0.025	609
	(0.049)	(0.041)	(0.047)	
Firm FE	Y	Y	Y	
Industry × Year FE	Y	Y	Y	
Province × Year FE	Y	Y	Y	

Notes: Authors' calculations using data from the CESD and ATS. This table reports the estimates from regressions of log firm energy consumption, output and energy efficiency on regulated firms interacted with an indicator for years after 2006 under varying data restrictions. The estimates shown in this table correspond to Equation 2 and the baseline estimates in Table 3 with various samples. Row (1) is our baseline results. Rows (2) and (3) show the results after we drop industries with electricity consumption accounting for more than 20% and 50%, respectively (our baseline setting is 30%). Row (4) shows the results for keeping all firms regardless of their industries. Row (5) shows the results for filling in missing data with the tax data. Column (4) shows the number of regulated firms in each regression. Standard errors clustered at the firm level are shown in parentheses with p-values below. * $p<0.1$, ** $p<0.05$, *** $p<0.01$.

Table A.4: Robustness to Entry and Exit: Regulated Firm Response

Variables	ln(Energy Use)	ln(Output)	ln(Energy Efficiency)
Treat × Post	-0.141***	-0.170***	-0.029
	(0.049)	(0.044)	(0.048)
Observations	18,506	18,385	18,385
R^2	0.886	0.890	0.831
Firm FE	Y	Y	Y
Industry × Year FE	Y	Y	Y
Province × Year FE	Y	Y	Y

Notes: Authors' calculations using data from the CESD. This table reports the estimates from regressions of log firm energy consumption, output and energy efficiency on regulated firms interacted with an indicator for years after 2006 when we exclude firm entry and exit. The estimates shown in this table correspond to Equation 2 and the baseline estimates in Table 3 with the exclusion of firms that enter the CESD data after 2006 or exit before 2010. Standard errors clustered at the firm level are shown in parentheses with p-values below. * $p<0.1$, ** $p<0.05$, *** $p<0.01$.

Table A.5: Approximately Balanced Panel: Regulated Firm Response

Variables	ln(Energy Use)	ln(Output)	ln(Energy Efficiency)
Treat × Post	-0.153**	-0.145**	0.006
	(0.069)	(0.057)	(0.065)
Observations	10,336	10,265	10,265
R^2	0.892	0.910	0.835
Firm FE	Y	Y	Y
Industry × Year FE	Y	Y	Y
Province × Year FE	Y	Y	Y

Notes: Authors' calculations using data from the CESD. This table reports the estimates from regressions of log firm energy consumption, output and energy efficiency on regulated firms interacted with an indicator for years after 2006 with an approximately balanced panel. The estimates shown in this table correspond to Equation 2 and the baseline estimates in Table 3 with the exclusion of firms with missing data for two years or more. Standard errors clustered at the firm level are shown in parentheses with p-values below. * $p<0.1$, ** $p<0.05$, *** $p<0.01$.

Table A.6: Robustness to Consideration of Concurrent Policies

A. Effects of Concurrent Policies on Top 1,000 Firms

	ln(Energy Use)	ln(Output)	ln(Energy Efficiency)
Monitor × Post	-0.003	0.023	0.019
	(0.097)	(0.089)	(0.106)
Observations	3,358	3,322	3,322
R^2	0.865	0.899	0.812
Firm FE	Y	Y	Y
Industry × Year FE	Y	Y	Y
Province × Year FE	Y	Y	Y

B. Robustness to Effects on Top 1,000 Firms

	ln(Energy Use)	ln(Output)	ln(Energy Efficiency)
Treat × Post	-0.186**	-0.234***	-0.046
	(0.075)	(0.080)	(0.083)
Observations	20,655	20,511	20,511
R^2	0.864	0.858	0.847
Firm FE	Y	Y	Y
Industry × Year FE	Y	Y	Y
Province × Year FE	Y	Y	Y

Notes: Authors' calculations using data from the CESD. This table shows that our estimated effects of the Top 1000 program are robust to consideration of a concurrent policy—the National Specially Monitored Firms (NSMF) program. Panel A estimates a difference-in-differences model to show the effects of the NSMF program within the Top 1,000 firm sample. We can see that the NSMF program had little effect on the energy consumption, output and energy efficiency of Top 1,000 firms. Panel B estimates the same regression as in Table 3 while excluding all treated firms included under both polices. It shows that taking the NSMF program into account does not affect our main results. See Section B for both detailed description of the NSMF program and additional discussion. Standard errors clustered at the firm level are shown in parentheses with p-values below. * $p<0.1$, ** $p<0.05$, *** $p<0.01$.

Table A.7: Heterogeneous Effects on Regulated Firms by Industry

Variables	ln(Output)				
	Baseline	Drop Power	Processing	Materials	Mining
Treat × Post	-0.204***	-0.206***	-0.219***	-0.153***	-0.251
	(0.042)	(0.042)	(0.073)	(0.053)	(0.275)
Observations	22,991	21,748	5,440	12,662	545
R^2	0.889	0.887	0.893	0.865	0.863
Firm FE	Y	Y	Y	Y	Y
Industry × Year FE	Y	Y	Y	Y	Y
Province × Year FE	Y	Y	Y	Y	Y

Notes: Authors' calculations using data from the CESD. This table shows estimates of Equation 2 by industry where Treat × Post is an indicator for regulated firms interacted with an indicator for years after 2006 and the dependent variable is log firm output, corresponding to Panel B of Table 3. Column (1) is our baseline result. Column (2) shows the results after we drop the production and supply of electric power and heating power industry. Column (3) shows the results for processing industries, including smelting and pressing of ferrous metals, smelting and pressing of nonferrous metals, processing of petroleum, coking, and processing of nuclear fuel. Column (4) shows the result for material industries, including the manufacture of raw chemical materials and chemical products and the manufacture of nonmetallic mineral products. Column (5) shows the result for mining industries, including mining and washing of coal and extraction of petroleum and natural gas. This table shows no significant differences in regulated firm response among different industries. Standard errors clustered at the firm level are shown in parentheses with p-values below. * $p<0.1$, ** $p<0.05$, *** $p<0.01$.

Table A.8: Effects of Policy on Investment in Regulated Firms

Variables	If Firm Invest			
Treat × Post	-0.056***	-0.070***	-0.070***	-0.071***
	(0.013)	(0.014)	(0.014)	(0.014)
Observations	47,231	47,211	47,208	45,675
R^2	0.192	0.201	0.209	0.214
Firm FE	Y	Y	Y	Y
Year FE	Y	Y	Y	Y
Industry × Year FE		Y	Y	Y
Province × Year FE			Y	Y
Firm-level Controls				Y

Notes: Authors' calculations using ASIF and ATS. This table shows estimates of Equation 2 where Treat × Post is an indicator for regulated firms interacted with an indicator for years after 2006 and the dependent variable is firm investment choice. Investment choice is defined as whether a firm invests. See Section 1 for more information about the data-generating procedure. This table corresponds to a pooled version of the regression displayed in Figure A.3. It shows that regulated firms decrease their possibility of investment by 5.6%–7.1% relative to similar control firms (Top 10,000 firms not related to Top 1,000 firms) after the policy implementation. See Section 2 for additional discussion. Standard errors clustered at the firm level are shown in parentheses with p-values below. * $p<0.1$, ** $p<0.05$, *** $p<0.01$.

Table A.9: Robustness of Spillovers to Related Firms on Output: Entropy Matching

A. Output

Variables	ln(Output)			
Related × Post	0.143***	0.139***	0.106***	0.133***
	(0.039)	(0.038)	(0.037)	(0.036)
Observations	119,064	119,064	119,064	116,064
R^2	0.874	0.881	0.890	0.896

B. Placebo Test on Output

Variables	ln(Output)			
Related × Post	0.016	0.019	0.020	0.036
	(0.041)	(0.040)	(0.039)	(0.038)
Observations	150,997	150,997	150,997	147,431
R^2	0.909	0.914	0.922	0.929

C. Heterogeneous Effects on Output by Firm Size

Variables	ln(Output)			
Related × Post(0%-30%)	0.097	0.096	0.001	0.039
	(0.070)	(0.068)	(0.065)	(0.063)
Related × Post(30%-60%)	0.171***	0.166***	0.123**	0.156***
	(0.060)	(0.058)	(0.054)	(0.053)
Related × Post(60%-100%)	0.178***	0.172***	0.179***	0.191***
	(0.058)	(0.056)	(0.054)	(0.052)
Observations	95,258	95,258	95,258	92,847
R^2	0.874	0.881	0.891	0.897
Firm FE	Y	Y	Y	Y
Year FE	Y	Y	Y	Y
Industry × Year FE		Y	Y	Y
Province × Year FE			Y	Y
Firm-level Controls				Y

Notes: Authors' calculations using data from the ASIF. This table shows estimates of Equation 2 with an alternative matching method, where Related × Post is an indicator for related firms in the same 4-digit industry interacted with an indicator for years after 2006 in Panels A and C and an indicator for related firms in the same 2-digit industry (but not the same 4-digit industry) interacted with an indicator for years after 2006 in Panel B. This table corresponds to Table 4 but deploys the additional matching method of entropy matching. Panels A and B correspond to a pooled version of the regression displayed in Panels A and B of Figure A.6. Standard errors clustered at the firm level are shown in parentheses with p-values below. * $p<0.1$, ** $p<0.05$, *** $p<0.01$.

Table A.10: Robustness of Spillovers to Related Firms on Energy Use and Energy Efficiency: Entropy Matching

A. Energy Use

Variables	ln(Energy Use)			
Related × Post	0.247**	0.248***	0.289***	0.263**
	(0.097)	(0.095)	(0.090)	(0.104)
Observations	20,254	20,254	20,101	14,507
R^2	0.855	0.858	0.871	0.879

B. Energy Efficiency

Variables	ln(Energy Efficiency)			
Related × Post	-0.021	-0.019	-0.056	-0.039
	(0.099)	(0.098)	(0.103)	(0.104)
Observations	20,122	20,122	19,971	14,424
R^2	0.822	0.826	0.839	0.845
Firm FE	Y	Y	Y	Y
Year FE	Y	Y	Y	Y
Industry × Year FE		Y	Y	Y
Province × Year FE			Y	Y
Firm-level Controls				Y

Notes: Authors' calculations using data from the CESD and ASIF. This table shows estimates of Equation 2 with an alternative matching method, where Related × Post is an indicator for related firms in the same 4-digit industry interacted with an indicator for years after 2006 and the dependent variables are log firm energy consumption in Panel A and log firm energy efficiency in Panel B. This table corresponds to Table 5 but deploys the additional matching method of entropy matching and corresponds to a pooled version of the regression displayed in Panels C and D of Figure A.6. Standard errors clustered at the firm level are shown in parentheses with p-values below. * $p<0.1$, ** $p<0.05$, *** $p<0.01$.

Table A.11: Spillover Effects on the Output of Related Firms: Robustness to Different Definitions of Related Parties

Variables	ln(Output)				
	Baseline	Drop Changes	6 Level, 20%	2 Level, 20%	2 Level, 51%
Related × Post	0.127***	0.125***	0.133***	0.124***	0.154***
	(0.035)	(0.036)	(0.033)	(0.035)	(0.039)
Observations	17,905	17,030	20,036	18,185	14,589
R^2	0.889	0.889	0.889	0.888	0.892
Firm FE	Y	Y	Y	Y	Y
Industry × Year FE	Y	Y	Y	Y	Y
Province × Year FE	Y	Y	Y	Y	Y
Firm-level Controls	Y	Y	Y	Y	Y

Notes: Authors' calculations using data from the ASIF. This table shows estimates of Equation 2 where Related × Post is an indicator for related firms interacted with an indicator for years after 2006 and the dependent variable is log firm output. This table corresponds to Table 4 but uses different definitions for related parties. Column (1) is our baseline result. Column (2) shows the results after we drop all related firms with shareholding changes after the policy implementation (which account for 3.89% of total related firms). It shows that our results are robust to dropping related firms with shareholding changes. Column (3) shows the results for related firms within six levels of shareholder links and with an ownership requirement of at least 20%. It shows that under this broader definition, related firms increased output by 13.3% after the policy implementation; this means that the conglomerate shift accounts for 46.0% ($\approx 2.80 \times 17.9\% \times 13.3\%/14.5\%$) of the output decline in regulated firms. Column (4) shows the results for related firms within two levels of shareholder links and with an ownership requirement of at least 20%. It shows that under this definition, related firms increased output by 12.4% after the policy implementation; this means that the conglomerate shift accounts for 41% ($\approx 2.49 \times 19.3\% \times 12.4\%/14.5\%$) of the output decline in regulated firms. Column (5) shows the results for related firms within two levels of shareholder links and with an ownership requirement of more than 50%. It shows that under this narrower definition, related firms increased output by 15.4% after the policy implementation; this means that the conglomerate shift accounts for 41% ($\approx 1.95 \times 19.9\% \times 15.4\%/14.5\%$) of the output decline in regulated firms. See Section 3 for additional discussion. Standard errors clustered at the firm level are shown in parentheses with p-values below. * $p<0.1$, ** $p<0.05$, *** $p<0.01$.

Table A.12: Robustness to Dropping Electric Power Generation and Supply

Variables	ln(Output)			
Related*Post	0.180***	0.173***	0.163***	0.167***
	(0.043)	(0.041)	(0.039)	(0.037)
Observations	11,232	11,229	11,222	10,982
R^2	0.850	0.862	0.872	0.883
Firm FE	Y	Y	Y	Y
Year FE	Y	Y	Y	Y
Industry × Year FE		Y	Y	Y
Province × Year FE			Y	Y
Firm-level Controls				Y

Notes: Authors' calculations using data from the ASIF. This table shows estimates of Equation 2 where Related × Post is an indicator for related firms in industries other than electric power generation and supply interacted with an indicator for years after 2006 and the dependent variable is log firm output. This table corresponds to Panel A of Table 4 but with the exclusion of all firms in the electric power generation and supply industry and corresponds to a pooled version of the regression displayed in Figure A.7. Standard errors clustered at the firm level are shown in parentheses with p-values below. * $p<0.1$, ** $p<0.05$, *** $p<0.01$.

Table A.13: Data Quality Robustness of Spillovers to Related Firms

A. Output: Leave out 2009 in ASIF Data

Variables	ln(Output)			
Related × Post	0.131***	0.125***	0.102***	0.111***
	(0.034)	(0.033)	(0.033)	(0.031)
Observations	16,454	16,452	16,450	15,970
R^2	0.890	0.898	0.905	0.913

B. Output: Fill in 2009–2010 with Tax Data

Variables	ln(Output)			
Related × Post	0.159***	0.156***	0.137***	0.135***
	(0.037)	(0.037)	(0.037)	(0.035)
Observations	19,293	19,289	19,287	18,735
R^2	0.869	0.876	0.885	0.893

C. Placebo: Leave out 2009 in ASIF Data

Variables	ln(Output)			
Related × Post	-0.033	-0.031	-0.025	-0.019
	(0.039)	(0.037)	(0.038)	(0.037)
Observations	7,971	7,970	7,955	7,809
R^2	0.908	0.914	0.921	0.927

D. Placebo: Fill in 2009–2010 with Tax Data

Variables	ln(Output)			
Related × Post	0.000	-0.003	-0.005	-0.007
	(0.041)	(0.040)	(0.040)	(0.039)
Observations	9,289	9,288	9,268	9,104
R^2	0.875	0.880	0.889	0.897
Firm FE	Y	Y	Y	Y
Year FE	Y	Y	Y	Y
Industry × Year FE		Y	Y	Y
Province × Year FE			Y	Y
Firm-level Controls				Y

Notes: Authors' calculations using ASIF and tax data. This table shows estimates of Equation 2 with different datasets, where Related × Post is an indicator for related firms in the same 4-digit industry interacted with an indicator for years after 2006, and the dependent variable is log firm output. Panels A and C correspond to Panels A and B in Table 4 but with the exclusion of the 2009 data from the ASIF. Panels B and D correspond to Panels A and B in Table 4 but with the 2009–2010 data filled in with tax data. The estimates in this table also correspond to a pooled version of the regression displayed in Figure A.8. Standard errors clustered at the firm level are shown in parentheses with p-values below. * $p<0.1$, ** $p<0.05$, *** $p<0.01$.

Table A.14: Additional Spillover Effects of the Program

Variables	ln(Sale)	ln(Profit)	ln(Capital)	ln(Labor)
Related × Post	0.115***	0.190***	0.114***	0.063**
	(0.033)	(0.055)	(0.040)	(0.026)
Observations	17,867	13,147	17,901	15,966
R^2	0.893	0.826	0.904	0.897
Firm FE	Y	Y	Y	Y
Industry × Year FE	Y	Y	Y	Y
Province × Year FE	Y	Y	Y	Y
Firm-level Controls	Y	Y	Y	Y

Notes: Authors' calculations using data from the ASIF. This table shows estimates of Equation 2 where Related × Post is an indicator for related firms interacted with an indicator for years after 2006 and the dependent variables are log firm sales, profit, capital and labor. The estimates in this table correspond to a pooled version of the regression displayed in Figure A.9. They show that related firms in the same 4-digit industries increased sales by 11.5%, profit by 19.0%, capital by 11.4%, and labor by 6.3% after the policy implementation. Standard errors clustered at the firm level are shown in parentheses with p-values below. * $p<0.1$, ** $p<0.05$, *** $p<0.01$.

Table A.15: Spillover Effects on the Output of Related Firms: Heterogeneous Effects by Industry

Variables	ln(Output)				
	Baseline	Drop Power	Processing	Materials	Mining
Related × Post	0.118***	0.164***	0.105	0.180***	0.197**
	(0.037)	(0.040)	(0.096)	(0.056)	(0.080)
Observations	18,418	11,152	2,586	5,566	2,641
R^2	0.881	0.872	0.871	0.846	0.883
Firm FE	Y	Y	Y	Y	Y
Industry × Year FE	Y	Y	Y	Y	Y
Province × Year FE	Y	Y	Y	Y	Y

Notes: Authors' calculations using data from the ASIF. This table shows estimates of Equation 2 by industry where Related × Post is an indicator for related firms interacted with an indicator for years after 2006 and the dependent variable is log firm output, corresponding to Panel A of Table 4. Column (1) is our baseline result. Column (2) shows the results after we drop the production and supply of electric power and heat power industry. Column (3) shows the result for processing industries, including smelting and pressing of ferrous metals, smelting and pressing of nonferrous metals, processing of petroleum, coking, and processing of nuclear fuel. Column (4) shows the result for material industries, including manufacture of raw chemical materials and chemical products and manufacture of nonmetallic mineral products. Column (5) shows the results for mining industries, including mining and washing of coal and extraction of petroleum and natural gas. This table shows that we do not find significant differences in the response of related firms across different industries. Standard errors clustered at the firm level are shown in parentheses with p-values below. * $p<0.1$, ** $p<0.05$, *** $p<0.01$.

Table A.16: Robustness to Entry: Market Spillovers

Variables	ln(Output)			
	All Sample		Energy-intensive Industries	
Spillover × Post	0.083***	0.075***	0.092***	0.092***
	(0.022)	(0.020)	(0.021)	(0.025)
Observations	2,129,911	2,129,911	716,518	716,518
R^2	0.847	0.862	0.837	0.853
Firm FE	Y	Y	Y	Y
Year FE	Y	Y	Y	Y
Industry-level Controls	Y	Y	Y	Y
Firm-level Controls		Y		Y

Notes: Authors' calculations using data from the ASIF. This table shows estimates of Equation 3 where Spillover × Post is an indicator for industry-level exposure to the Top 1,000 program interacted with an indicator for years after 2006 and the dependent variable is log firm output. This table corresponds Table 6 with the exclusion of firms that enter the CESD data after 2006. It shows that average market-level spillovers led to a 7.5%–9.2% increase in output for unregulated existing firms. See Section 3 for additional discussion. Standard errors clustered at the firm level are shown in parentheses with p-values below. * $p<0.1$, ** $p<0.05$, *** $p<0.01$.

Table A.17: Structural Estimation: Robustness to Alternative Specifications

	Data	Baseline	Low ρ	High ρ	Low α	High α	Imperfect Substitution
1. Fixed Values							
Elasticity of substitution ρ		0.750	0.700	0.900	0.750	0.750	0.750
Within-conglomerate Elasticity of substitution ρ_c							0.900
Return to scale α		0.900	0.900	0.900	0.850	0.950	0.900
2. Method of Moments							
Efficiency depreciation δ		0.900	0.900	0.900	0.853	0.949	0.800
		(0.003)	(0.003)	(0.003)	(0.005)	(0.001)	(0.007)
Dispersion of ln-ability σ_m		1.239	1.500	0.579	1.359	1.063	1.271
		(0.055)	(0.060)	(0.045)	(0.087)	(0.053)	(0.097)
Survival threshold ϕ_1		0.609	0.461	0.792	0.579	0.435	0.985
		(0.166)	(0.134)	(0.193)	(0.273)	(0.118)	(0.535)
3. Policy Parameters							
Policy threshold $\tilde{\phi}$		9.289	14.093	2.658	10.915	6.050	10.977
4. Moments							
Share of firms $< 1M$	0.336	0.347	0.350	0.350	0.347	0.351	0.344
Share of firms $5 - 20M$	0.105	0.155	0.155	0.160	0.157	0.156	0.156
Share of firms $20 - 100M$	0.071	0.072	0.072	0.076	0.073	0.074	0.071
Share of firms $100M+$	0.025	0.026	0.026	0.027	0.027	0.027	0.025
Share of Output $5 - 20M$	0.051	0.072	0.072	0.074	0.073	0.073	0.072
Share of Output $20 - 100M$	0.146	0.144	0.144	0.152	0.147	0.148	0.142
Share of Output $100M+$	0.722	0.733	0.733	0.723	0.729	0.729	0.734
Relative Output 1st-2nd	0.289	0.348	0.350	0.347	0.347	0.350	0.347
Relative Output 2nd-3rd	0.203	0.121	0.122	0.120	0.120	0.122	0.121

Notes: This table summarizes the parameters that we set or estimate. Panel 1 lists the various parameter values that we calibrate. Across all cases, we set α_l to match the cost share of variable inputs, given α. Panel 2 reports the estimated parameter moments with standard errors in parentheses. See Section 5.1 for the detailed estimation procedure. Panel 3 reports the policy threshold $\tilde{\phi}$. This threshold is selected to match the share of energy use by regulated firms, which itself depends on the parameter values. Panel 4 reports the data moments and the moments predicted by the model parameters. Section 7.3 discusses the results when we vary α or ρ, and Section 7.4 discusses the results when we set $\rho_c = 0.9$.

Table A.18: Robustness of Effects on the Energy Efficiency of Regulated Firms

Variables	ln(Variable Input/Energy)			
Treat × Post	-0.020	-0.082*	-0.053	-0.029
	(0.043)	(0.047)	(0.048)	(0.048)
Observations	17,096	17,091	16,824	16,452
R^2	0.865	0.868	0.872	0.873
Firm FE	Y	Y	Y	Y
Year FE	Y	Y	Y	Y
Industry × Year FE		Y	Y	Y
Province × Year FE			Y	Y
Firm-level Controls				Y

Notes: Authors' calculations using data from the CESD and ASIF. This table shows estimates of Equation 2 where Treat × Post is an indicator for regulated firms interacted with an indicator for years after 2006 and the dependent variable is log energy efficiency. Energy efficiency in this table is defined as the inverse of the energy share in variable input costs, and variable input is calculated from the ASIF in terms of sales cost. This table corresponds to Panel C of Table 3 but with an alternative definition of energy efficiency and corresponds to a pooled version of the regression displayed in Figure A.10. Standard errors clustered at the firm level are shown in parentheses with p-values below. * $p<0.1$, ** $p<0.05$, *** $p<0.01$.

Table A.19: Robustness of Effects on the Energy Efficiency of Related Firms

Variables	ln(Variable Input/Energy)			
Related × Post	-0.026	-0.033	-0.026	-0.008
	(0.078)	(0.080)	(0.088)	(0.088)
Observations	2,503	2,497	2,449	2,424
R^2	0.904	0.907	0.917	0.918
Firm FE	Y	Y	Y	Y
Year FE	Y	Y	Y	Y
Industry × Year FE		Y	Y	Y
Province × Year FE			Y	Y
Firm-level Controls				Y

Notes: Authors' calculations using data from the CESD and ASIF. This table shows estimates of Equation 2 where Related × Post is an indicator for related firms in the same 4-digit industry interacted with an indicator for years after 2006 and the dependent variable is log energy efficiency. Energy efficiency in this table is defined as the inverse of the energy share in variable input costs, and variable input is calculated from the ASIF in terms of sales cost. This table corresponds to Panel B of Table 5 but with an alternative definition of energy efficiency and corresponds to a pooled version of the regression displayed in Figure A.11. Standard errors clustered at the firm level are shown in parentheses with p-values below. * $p<0.1$, ** $p<0.05$, *** $p<0.01$.

Table A.20: Heterogeneous Spillover Effects by Local Pollution and Density

Variable	High to Low	Horizontal	Low to High
Related × Post	0.115**	0.101	0.224***
	(0.047)	(0.072)	(0.073)
Observations	10,256	3,740	3,457
R^2	0.895	0.883	0.897
Output Share	57.9%	13.9%	28.2%
Aggregate Effect	6.7%	1.4%	6.3%
Firm FE	Y	Y	Y
Year FE	Y	Y	Y
Industry × Year FE	Y	Y	Y
Province × Year FE	Y	Y	Y
Firm-level Controls	Y	Y	Y

Notes: Authors' calculations using data from the ASIF. This table show estimates of Equation 2 where Related × Post is an indicator for related firms in the same 4-digit industry interacted with an indicator for years after 2006 and the dependent variable is log firm output. The estimates correspond to Panel A of Table 4 but divide related firms into three groups according to their pollution exposure. Column (1) includes related firms whose city-level pollution exposure is less than (by more than 10%) that of their corresponding Top 1,000 firms; Column (2) includes related firms whose city-level pollution exposure is similar to (within 10%) that of their corresponding Top 1,000 firms; and Column (3) includes related firms whose city-level pollution exposure is more than (by more than 10%) that of their corresponding Top 1,000 firms. City-level pollution exposure is defined by city-level so_2 density × city population. This table shows that related firms in places with lower pollution exposure increased output by 11.5% and related firms in places with similar pollution exposure increased output by 10.1% while related firms in places with more pollution exposure increased output by 22.4% after the policy implementation. However, considering that a higher share of the related output (57.9%) was concentrated in less exposed areas, we see similar output increases in more and less exposed areas. See Section C for additional discussion. Standard errors clustered at the firm level are shown in parentheses with p-values below. * $p<0.1$, ** $p<0.05$, *** $p<0.01$.