

# Pass-through in a concentrated industry: empirical evidence and regulatory implications

Nathan H. Miller\*

Matthew Osborne\*\*

and

Gloria Sheu\*\*\*

*We estimate pass-through with 30 years of data from the portland cement industry. Robust econometric evidence supports that fuel cost changes are more than fully transmitted downstream in the form of price changes. This validates an implicit pass-through assumption made in recent academic research and regulatory analyses. We combine the econometric results with estimates of competitive conduct obtained from the literature to evaluate the incidence of market-based CO<sub>2</sub> regulation. Producers bear roughly 11% of the regulatory burden and could be compensated with 16% of the revenues obtained.*

## 1. Introduction

■ The distributional consequences of taxation in imperfectly competitive markets depend on pass-through and markups (Weyl and Fabinger, 2013; Atkin and Donaldson, 2015). This theoretical result poses a substantial challenge for applied research on incidence: reduced-form estimates of pass-through are insufficient if firms exercise market power, whereas structural models that allow for the recovery of markups often rely on tractable functional forms that predetermine pass-through. This issue is particularly salient for the study of emissions-intensive industries because production in these sectors often requires investments and fixed costs that necessitate high markups in equilibrium.

---

\* Georgetown University; [nhm27@georgetown.edu](mailto:nhm27@georgetown.edu).

\*\* University of Toronto; [matthew.osborne@utoronto.ca](mailto:matthew.osborne@utoronto.ca).

\*\*\* Department of Justice; [gloria.sheu@usdoj.gov](mailto:gloria.sheu@usdoj.gov).

We have benefited from conversations with David Atkin, John Asker, Ron Borkovsky, Andrew Ching, Keith Head, Mar Reguant, and Glen Weyl, as well as the seminar participants at Boston College, Department of Justice Antitrust Division, London School of Economics, University of British Columbia, UCLA, and University of California, Berkeley. We thank Sam Larson, Erika Lim, Conor Ryan, and Jiayi Zhang for research assistance. The views expressed herein are entirely those of the authors and should not be purported to reflect those of the US Department of Justice.

In this article, we estimate pass-through in the portland cement industry using reduced-form regression techniques. We combine the results with estimates of markups derived from an earlier study of the industry (Miller and Osborne, 2014) to evaluate the distributional consequences of market-based regulation that places a price on CO<sub>2</sub> emissions. The portland cement industry accounts for roughly 5% of global anthropogenic CO<sub>2</sub> emissions and also is a source of local pollutants such as particulate matter and mercury (Van Oss and Padovani, 2003). Market power arises due to spatial differentiation: cement is transported by truck to ready-mix concrete plants and large construction sites, and the associated costs typically account for a sizable portion of purchasers' total expenditures.

Our regression equation derives from a general class of oligopoly models. We show how regressors can be constructed in a manner that preserves the oligopoly interactions, even if only aggregated prices are observed. In our application, we rely on variation in region-specific average prices over the period 1980–2010. We calculate the fuel costs of each plant based on fossil fuel prices and kiln technology and estimate pass-through by regressing observed prices on fuel costs that are averaged to the region level. Unbiasedness is obtained under standard orthogonality assumptions that are defensible given the institutional details of the empirical setting. To provide one such detail, there are no viable substitutes for fossil fuel in the production process because inputs (e.g., limestone and heat) are used in fixed proportions. As such, fuel costs plausibly are uncorrelated with unobserved costs, especially once plant fixed effects absorb any plant-specific factors related to the kiln technology.

The primary econometric result is that market-wide cost changes are more than fully passed through to cement prices. The result is robust across a range of specifications and modelling choices, and the confidence intervals are sufficiently tight to reject that pass-through is substantially incomplete. Weyl and Fabinger (2013) demonstrate that, in a general symmetric model of oligopoly, for pass-through to exceed unity it is sufficient that marginal costs are constant, firms exercise market power, and demand is log-convex. The model provides the testable auxiliary prediction that competition reduces pass-through under the same conditions. We find support for this auxiliary prediction in the data, using measures of competition based on the number, proximity, and capacity of nearby plants. Given the presence of plant fixed effects, identification of this interactive effect rests on entry, exit, and fluctuations in the diesel price, the last of which affects transportation costs and the magnitude of localized market power.

We evaluate the incidence of market-based CO<sub>2</sub> regulation using the Weyl and Fabinger (2013) model of symmetric oligopoly. The effect of regulation on consumer surplus is determined by pass-through. The effect on producer surplus depends on pass-through and a conduct parameter that equals the multiplicative product of firm margins and the elasticity of market demand. Our econometric estimates inform pass-through but not the conduct parameter. By contrast, recently estimated structural models of the industry have bearing on the conduct parameter but are insufficiently flexible to inform pass-through. Thus, we calculate distributional effects for a range of pass-through that reflects the confidence intervals obtained in this article, and a range of conduct parameters that reflects confidence intervals obtained from a bootstrap of the Miller and Osborne (2014) structural model. At the middle of these distributions, the pass-through that we estimate implies that cement producers bear 11% of the regulatory burden and could be fully compensated with 16% of the revenues obtained from regulation.

This counterfactual analysis has limitations, and we highlight three here. First, our approach does not enable us to put a confidence bound on the harm to producers because there is no straightforward way to compute the statistical covariance between pass-through and conduct. Both theory and our reduced-form results suggest this covariance is positive for pass-through in excess of unity, and we discuss the implications of such a relationship qualitatively. Second, our approach does not inform the extent of heterogeneity that arises among producers and consumers. We rely on the symmetric model because it comports with our econometric estimates, which capture the average effect of fuel costs on prices. Finally, the results may not convey to other sectors. A new Working Paper finds that portland cement is one of the few US manufacturing sectors in which

pass-through exceeds unity; more commonly, pass-through is incomplete (Ganapati, Shapiro, and Walker, 2016).

In an extension, we evaluate recent regulations promulgated by the United States Environmental Protection Agency (EPA) to reduce emissions of hazardous air pollutants, including particulate matter, mercury, hydrocarbons, and hydrogen chloride. The EPA indicates that the monetized health benefits of regulation outweigh economic costs (EPA, 2009, 2010), the latter of which can be first order if firms exercise market power (e.g., Buchanon, 1969). Our analysis corroborates the simulation results developed by the EPA. The pass-through estimates imply average price increases of \$4.78 across 20 local markets, relative to a simulation average of \$4.66. Further, there is a high degree of correlation in the predictions across markets. We believe this is attributable to a fortuitous selection of functional forms in the EPA simulation model.

Our analysis complements the research of Fowlie, Reguant, and Ryan (2016) on the long-run effects of market-based CO<sub>2</sub> regulation. That study relies on a dynamic structural model in which payoffs are based on undifferentiated Nash-Cournot competition among cement plants facing a constant-elasticity market demand curve. Pass-through in this context is fully determined by the number of plants and the demand elasticity. We derive the pass-through rates implied by the model, over the range of elasticities by the authors, and show that they comport with our econometric estimates. Thus, our results support a previously untested modelling assumption that has first-order implications for welfare effects.

A small literature focuses more directly on the distributional impacts of market-based CO<sub>2</sub> regulation. Bovenberg, Goulder, and Gurney (2001) and Smith, Ross, and Montgomery (2002) analyze calibrated general equilibrium models of the US economy and determine that the free allocation of tradable emissions permits would substantially overcompensate firms. Burtraw and Palmer (2008) examine electricity generation specifically using a detailed industry model and find that electricity generators can be fully compensated with a small fraction of the total allowance value. Bovenberg, Goulder, and Jacobsen (2008) examine a number of related mechanism design issues using a calibrated general equilibrium model. Hepburn, Quah, and Ritz (2013) develop the theoretical result that market-based regulation is profit neutral if incumbents are freely allocated permits that cover a fraction of emissions not exceeding the Herfindahl index. Goulder (2013) provides a useful review. We contribute to the methodological diversity of this literature, even as our results reinforce that most of the regulatory burden is likely to fall downstream.<sup>1</sup>

Our research is one of a growing number of contributions that apply the “pass-through as a tool” paradigm of Weyl and Fabinger (2013) to empirical settings. Atkin and Donaldson (2015) use pass-through to account for markups in the estimation of intranational trade costs.<sup>2</sup> Cabral, Geruso, and Mahoney (2015) and Duggan, Starc, and Vabson (2014) find support for incomplete pass-through in the Medicare Advantage market, and the former article shows that pass-through tends to be somewhat higher in counties with more competitors. This interactive effect of competition is consistent with the general symmetric oligopoly model given that pass-through is incomplete, and does not conflict with our own results. Argarwal et al. (2014) estimate

<sup>1</sup> Firms may lobby for a favorable allocation of tradable permits even if they experience little harm. Indeed, regulation can be a windfall for firms if enough permits are allocated freely. The Portland Cement Association did not take a formal stance on the 2009 Waxman-Markey cap-and-trade bill, but we cannot rule out private communications and negotiations. The bill was going to provide 85% of the permits for free through 2014 and then phase into a full auction by 2024. Many of the free permits were designated for energy-intensive industrial sectors such as cement, steel, iron, and paper, so the outcome could be interpreted as consistent with an effective lobbying effort.

<sup>2</sup> Atkin and Donaldson (2015) assume that competition (and markups) are purely local, unobserved, and specific to the origin-destination pair. To implement, the authors estimate pass-through with subsample regressions on individual origin-destination pairs in a first stage. Pass-through is then substituted into a second-stage regression that recovers how distance affects trade costs. The dependent variable in the second stage is the pass-through adjusted price gap between the origin and destination, and the main independent variable is the log-distance between the origin and destination. By contrast, in our setting, competition is nonlocal and we use the distance between plants as an observed measure that shifts the degree of competition. We use this observed “competition-shifter” to estimate how pass-through varies with competition.

the effect of jet fuel prices on airline ticket prices and use this pass-through relationship to assess the consumer benefits of regulating hidden fees. Kremer and Snyder (2015) relate investments in preventative and treatment medicines to differences in the curvature of consumer values before and after diagnosis.

The broader empirical literature on pass-through is too large to summarize fully here. Research has exploited cost variation from a number of factors, including exchange rates (e.g., Campa and Goldberg, 2005; Gopinath et al., 2011), sales taxes (e.g., Barzel, 1976; Poterba, 1996; Besley and Rosen, 1998; Marion and Muehlegger, 2011; Conlon and Rao, 2016; Campos-Vazquez and Medina-Cortina, 2016), and input prices (e.g., Borenstein, Cameron, and Gilbert, 1997; Genesove and Mullin, 1998; Besanko, Dube, and Gupta, 2005; Nakamura and Zerom, 2010). Empirical support for pass-through in excess of unity is common, though far from ubiquitous, in this literature. Of particular relevance is Fabra and Reguant (2014), which finds that costs imposed by the emissions trading scheme of the European Union are almost fully passed-through to consumers in the form of higher electricity prices. Stolper (2016) adopts a version of our regression specification and finds that higher pass-through in wealthier areas makes diesel taxes progressive.

The article proceeds as follows. Section 2 provides the relevant institutional details of the portland cement industry and describes the available data. Section 3 sketches the symmetric oligopoly model of Weyl and Fabinger (2013). We show that pass-through can exceed unity under certain economic conditions, and that competition reduces pass-through in that case. Section 4 develops the regression model and discusses identification. It also provides methodological details about how we obtain conduct from the Miller and Osborne (2014) model and why it is difficult to place a confidence bound on producer surplus effects. Section 5 defines the variables used in the regressions. Section 6 presents the regression results and shows that the econometric estimates validate the implicit pass-through assumption of Fowlie, Reguant, and Ryan (2016). Section 7 develops implications for the market-based regulation of CO<sub>2</sub> and the EPA regulation of hazardous air pollutants. Section 8 concludes with a short discussion about possible directions for future research.

## 2. The portland cement industry

□ **Institutional details.** Portland cement is a finely ground dust that forms concrete when mixed with water and coarse aggregates such as sand and stone. Concrete, in turn, is an essential input to many construction and transportation projects. The production of cement involves feeding limestone and other raw materials into rotary kilns that reach peak temperatures of 1400°–1450° Celsius. Plants burn fossil fuels—mostly coal and petroleum coke—to produce these extreme kiln temperatures. Emissions of CO<sub>2</sub> range from 0.86 to 1.05 metric tonnes per metric tonne of cement, depending on the kiln technology. Of this, roughly 0.51 metric tonnes arise from the chemical conversion of calcium carbonate into lime and carbon dioxide. The combustion of fossil fuels accounts for most of the remainder.<sup>3</sup>

Capital investments over the last 40 years have increased the industry's capacity and productive efficiency. Table 1 provides snapshots of the industry over 1980–2010. During this period, a significant amount of plant exit coincides with a major technological shift, as older wet kilns and long dry kilns are replaced with more efficient modern dry kilns.<sup>4</sup> Total industry capacity

<sup>3</sup> The CO<sub>2</sub> emissions rates are 1.05, 0.98, 0.87, and 0.86 for wet, long dry, dry preheater, and dry precalciner kilns, respectively. Our calculations are consistent with the Cement CO<sub>2</sub> Protocol, developed by leading cement firms for the Cement Sustainability Initiative of the World Business Council for Sustainable Development. We scale up the impact of converting calcium carbonate to 0.525, in order to account for CO<sub>2</sub> emitted during the calcination of cement kiln dust. We add to this the CO<sub>2</sub> emitted from the burning of coal, based on an emissions factor of 0.095 metric tonnes per mBtu and the kiln energy requirements reported in a web Appendix. We then scale down total emissions by 5% to convert units of clinker to units of cement. Similar calculations underly the analysis in Fowlie, Reguant, and Ryan (2016).

<sup>4</sup> For wet kilns, the raw materials are wet-ground to form a slurry, but for dry kilns, the raw materials are dry-ground to form a powder. More fuel is required in the wet process to evaporate the added water. Modern dry kilns use exhaust gases

**TABLE 1** Plants and Kilns in the Cement Industry

	Number of Plants	Number of Kilns	Total Capacity	Capacity Share			
				Wet Kilns	Long Dry Kilns	Dry with Preheater	Dry with Precalciner
1980	142	319	77,100	49%	27%	16%	8%
1985	126	250	77,046	36%	24%	16%	24%
1990	109	208	72,883	32%	23%	19%	27%
1995	107	203	74,655	28%	22%	19%	30%
2000	107	196	82,758	24%	20%	17%	39%
2005	105	181	93,968	15%	14%	17%	54%
2010	101	153	103,482	8%	9%	14%	70%

Notes: Total capacity is in thousands of metric tonnes. All data are for the contiguous United States and are obtained from the PCA Plant Information Survey.

increases even as the number of plant and kilns falls. This variation is important in our empirical analysis for two reasons: first, it helps to identify pass-through, because changes in industry technology affect kiln efficiency and as a consequence plant-level fuel costs; second, it aids in the identification of the interaction between competition and pass-through, because plant exit creates variation in competitive conditions over time.

Cement manufacturers sell predominately to ready-mix concrete producers and large construction firms. Contracts are privately negotiated and relatively short term (often around one year in duration). They specify a free-on-board price at which cement can be obtained from the plant, along with discounts that reflect the ability of the customer to source cement from competing manufacturers. Although some cement manufacturers are vertically integrated into ready-mix concrete markets, Syverson and Hortaçsu (2007) show that this has little impact on plant- and market-level outcomes.

Figure 1 provides a map of the cement industry in 2010. Most cement is trucked directly from the plant to the customer, although some cement is transported by barge or rail first to distribution terminals and only then trucked to customers. Transportation accounts for a substantial portion of purchasers' total acquisition costs, because portland cement is inexpensive relative to its weight. Miller and Osborne (2014) estimate transportation costs to be \$0.46 per tonne-mile and determine that these costs create market power for spatially differentiated plants. Accordingly, the academic literature commonly models the industry using a number of geographically distinct local markets (e.g., Ryan, 2012; Fowlie, Reguant, and Ryan, 2016). Aside from these spatial considerations, cement is viewed as a commodity. Foreign cement enters the domestic market through a number of customs districts that we refer to in this article as ports, although exports are negligible.<sup>5</sup>

□ **Data sources.** We draw data from numerous sources. Chief among these is the *Minerals Yearbook*, an annual publication of the United States Geological Survey (USGS), which summarizes a census of portland cement plants.<sup>6</sup> The price data are aggregated to protect the confidentiality of census respondents, and reflect the average free-on-board price obtained by

---

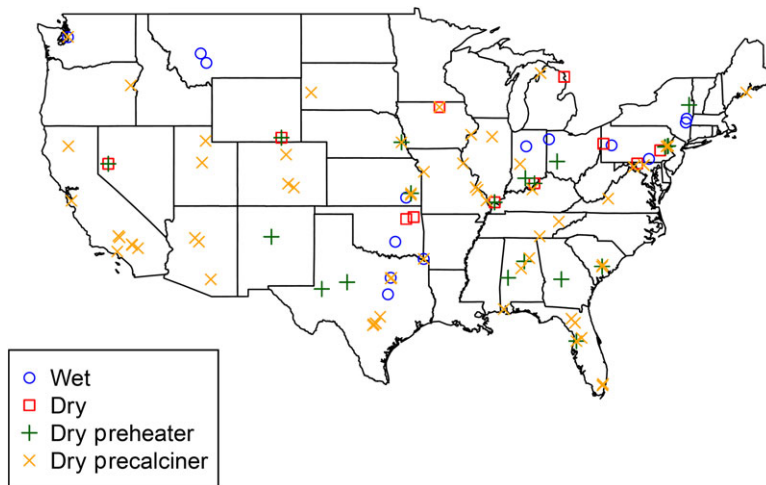
from the kiln to preheat the raw material used in cement production. This allows calcination, one of the major chemical reactions required in clinker production, to occur partially or fully outside the rotary kiln. The process is supplemented with an additional combustion chamber if a precalciner is present. There is no systematic relationship between the kiln technology and the primary fossil fuel that is used to fire the kiln. Adjustment costs limit the profitability of switching fuels in response to changing relative prices.

<sup>5</sup> Due to technological advances in the late 1970s, cement now can be shipped economically from Asia and Europe via ocean freighters, and then trucked to customers. Imports are highly procyclical and appear to fill the gap between demand and domestic capacity (e.g., Miller and Osborne, 2014).

<sup>6</sup> The census response rate is typically well over 90% (e.g., 95% in 2003), and USGS staff imputes missing values for the few nonrespondents based on historical and cross-sectional information.

FIGURE 1

## THE PORTLAND CEMENT INDUSTRY IN 2010



plants located in distinct geographic regions. The USGS frequently redraws boundaries to ensure that each region includes at least three independently owned plants. This “rule of three” prevents any one firm from backward engineering the business data of its competitors. Thus, the regions are not intended to approximate local markets in any economic sense. The *Minerals Yearbook* also contains aggregated production and consumption data, as well as the location of the customs districts through which foreign imports enter the domestic market. Our regression sample uses USGS data over 1980–2010, which yields 773 region-year observations.

Our second source of data is the *Plant Information Survey*, an annual publication of the Portland Cement Association (PCA), which provides information on the plants and kilns in the United States. We obtain the location, owner, and primary fuel of each plant, as well as the annual capacity of each rotary kiln and the type of technology employed. In total, there are 3494 plant-year observations over 1980–2010, of which 3445 are active and 49 are idle. We also make use of the PCA’s *U.S. and Canadian Portland Cement Labor-Energy Input Survey*, which is published intermittently and contains information on the energy requirements of clinker production and the energy content of fossil fuels burned in kilns. We have data for 1974–1979, 1990, 2000, and 2010.

We obtain data on the national average delivered bituminous coal price in the industrial sector over 1985–2010 from the annual *Coal Reports* of the Energy Information Agency (EIA). We backcast these prices to the period 1980–1984 using historical data on national average free-on-board prices of bituminous coal published in the 2008 *Annual Energy Review* of the EIA. We obtain national data on the prices of petroleum coke, natural gas, and distillate fuel oil, again for the industrial sector, from the State Energy Database System (SEDS) of the EIA.<sup>7</sup> We obtain data on the national average price of unleaded gasoline over 1980–2010 from the Bureau of Labor Statistics, in order to better model the spatial configuration of the industry. We convert this series to an index that equals one in 2000. Last, to help control for demand, we obtain county-level data

<sup>7</sup> The SEDS also includes data on coal prices, but no distinction is made between bituminous coal, sub-bituminous coal, lignite, and anthracite, despite the wide price differences that arise between those fuels. We also obtain state-level data on fossil fuel prices. There are many missing values at that level of reporting, and we impute these as described in a web Appendix. Using fuel costs variables based on state-level fossil fuel prices has virtually no effect on our results, so long as plant fixed effects are included in the specification. We use the national fuel prices in our baseline specifications because, when included together in regressions, fuel cost variables based on national fossil fuel prices dominate those based on state-level prices. This could be due to noise introduced by the imputation of missing values in the state-level data.



from the Census Bureau on construction employees and building permits. We provide details on data sources in a web Appendix.

### 3. Pass-through and market-based regulation

■ We first develop pass-through in the symmetric oligopoly model of Weyl and Fabinger (2013) and then discuss the relevance for market-based regulation. Let the oligopoly consist of  $n$  firms, each of which produces quantity  $q$  at cost  $c(q)$ . Firms receive the price  $p(q)$ , assuming symmetric quantities. Let  $Q = nq$  be the market quantity,  $\epsilon_D = \frac{p}{p'q}$  be the market elasticity of demand, and  $mc(q) \equiv c'(q)$  be the marginal cost. Market power is summarized by a conduct parameter,  $\theta = \frac{p-mc}{p} \epsilon^D$ , that equals the elasticity-adjusted Lerner index. This formulation remains quite general, nesting the homogeneous products Nash-Cournot model, the differentiated-products Nash-Bertrand model, and many others.<sup>8</sup> Last, let  $\epsilon_S = \frac{S'p}{Q}$  be the elasticity of the inverse marginal cost curve (“the supply function”), and let  $\epsilon_\theta = \frac{d\theta}{dq} \frac{q}{\theta}$  summarize how the conduct parameter changes with quantity. We focus on comparative statics around a single symmetric equilibrium, and acknowledge that market-based regulation could shift the market to a different equilibrium.

Output satisfies the following first-order conditions in equilibrium:

$$p(q) = mc(q) + \theta ms(q), \quad (1)$$

where  $ms = p'Q$  is the marginal surplus that consumers earn when quantity expands. Equation (1) is a generalized version of the markup equation that often appears in structural models of competition. An important point is that pass-through, which captures the response of price to a small increase in marginal cost, must be derived implicitly from equation (1), because price enters the right-hand side of the equation through its relationship with quantity. Weyl and Fabinger (2013) show that in this general model of symmetric oligopoly, pass-through can be derived as a function of conduct, the elasticity of conduct with respect to quantity, the elasticity of marginal surplus with respect to quantity,  $\epsilon_{ms} = \frac{ms}{ms'q}$ , and the demand and supply elasticities. Denoting pass-through as  $\rho$ , the function is:

$$\rho = \frac{1}{1 + \theta \epsilon_\theta + \frac{\epsilon_D - \theta}{\epsilon_S} + \frac{\theta}{\epsilon_{ms}}}. \quad (2)$$

An important determinant of pass-through is demand curvature, which can be measured by  $\frac{1}{\epsilon_{ms}}$ : this reciprocal is positive if demand is log-concave and negative if demand is log-convex. Log-concavity is sufficient for marginal revenue to be globally decreasing in quantity, and often is assumed in the theoretical literature. However, log-convexity can arise in a number of well-known demand systems, including the Almost Ideal Demand Systems (AIDS) of Deaton and Muellbauer (1980), some forms of Frechet demand, and the constant elasticity demand system.

In equation (2), the conduct parameter scales between monopoly ( $\theta = 1$ ) and marginal cost pricing ( $\theta = 0$ ). To push intuition further, consider that in the latter instance, pass-through is fully determined by the relative elasticities of demand and supply:

$$\lim_{\theta \rightarrow 0} \rho = \frac{1}{1 + \frac{\epsilon_D}{\epsilon_S}}. \quad (3)$$

This is the familiar result that in perfect competition, it is the inelastic side of the market that bears the burden of taxation. Pass-through converges to this limit *from above* if demand is log-convex because in that case,  $\frac{1}{\epsilon_{ms}} < 0$ . This relies on  $\epsilon_\theta$  being negative or zero, as is the case in standard

<sup>8</sup> The conduct parameter is equivalent to the Rothschild index (Rothschild, 1942), a measure of monopoly power based on the ratio of the industry elasticity to the firm-specific elasticity. It equals one with monopoly, zero with perfect competition,  $1/n$  with Nash-Cournot, and  $1 - D$  with differentiated-products Nash-Bertrand, where  $D$  is the aggregate diversion ratio defined in Shapiro (1996).

models.<sup>9</sup> Thus, for pass-through to exceed unity it is sufficient that marginal costs are constant, firms exercise market power, and demand is log-convex. (Mathematically, this corresponds to  $\frac{\epsilon_D}{\epsilon_S} = 0$ ,  $\theta > 0$ , and  $\frac{1}{\epsilon_{ms}} < 0$ .) Under these conditions, pass-through decreases as the conduct parameter moves toward zero.<sup>10</sup>

We comment briefly on the role of demand curvature in driving pass-through. Greater convexity in demand can be conceptualized as corresponding to greater heterogeneity in willingness-to-pay (WTP) among consumers. Thus, for instance, markets with log-convex demand have some consumers with very high WTP as well as many consumers with relatively low WTP. Cost increases then can cause large price increases because firms are induced to abandon the low-WTP consumers and price to the high-WTP consumers. Analogously, cost decreases result in large price decreases because the many low-WTP consumers become profitable. The converse analysis hold for concave demand curves: the greater is consumer homogeneity, the less firms will be inclined to pass-through cost changes.<sup>11</sup>

We model market-based regulation as a per-unit tax,  $t$ , that is levied on all firms. The following principles of incidence hold provided the tax is arbitrarily small:

$$\frac{dCS}{dt} = -\rho Q \quad (4)$$

$$\frac{dPS}{dt} = -(1 - \rho(1 - \theta))Q, \quad (5)$$

where  $CS$  and  $PS$  are consumer surplus and producer surplus, respectively. Equation (4) is obtained by applying the Envelope Theorem to consumers. Equation (5), initially derived in Atkin and Donaldson (2015), shows that pass-through moderates the loss of producer surplus but that, because higher prices generate fewer sales, this moderating effect diminishes with margins as summarized by the conduct parameter. In our counterfactual analysis, we examine changes in the implicit price of carbon emissions that are potentially large. As a result, we interpret our welfare findings as approximations. In principle, equations (4) and (5) could be adjusted using weighted-averages over relevant range, but because this range extends beyond the data, there is little empirical basis for the adjustment.

## 4. Methodologies

□ **Pass-through regression equation.** Our econometric objective is to obtain an estimate of how market-wide cost changes affect price in the cement industry. The regression equation that we take to the data expresses the average price charged by plants in USGS region  $m$  and year  $t$  as

$$\bar{p}_{mt} = \alpha_{mt}\bar{c}_{mt} + \bar{x}'_{mt}\gamma + \bar{\mu}_{mt} + \bar{\epsilon}_{mt}, \quad (6)$$

where  $\bar{c}_{jt}$  is average fuel costs,  $\bar{x}_{mt}$  is a vector of controls,  $\bar{\mu}_{mt}$  is a region-time effect that we define later, and  $\bar{\epsilon}_{mt}$  captures conditions unobserved by the econometrician. In some of our

<sup>9</sup> A number of nested models, including homogeneous-products Nash-Cournot competition, produce a  $\theta$  that is invariant to quantity, but the restriction does not hold generally. For example, in models of differentiated-products Nash-Bertrand competition and discrete-choice based demand,  $\theta$  decreases with quantity ( $\epsilon_\theta < 0$ ). This amplifies pass-through because higher prices soften competitive conduct.

<sup>10</sup> Pass-through also exceeds unity if  $\theta = 0$  and the industry marginal cost schedule decreases in output, in which case  $\epsilon^S < 0$ . That does not seem likely in our application. So long as firms have heterogeneous costs, the low-cost firms will be on the left of the industry marginal cost curve and high-cost firms will be on the right, and this suggests an upward-sloping industry marginal cost curve. This effect of heterogeneity could be dominated by downward-sloping plant-specific marginal cost curves, but that seems unlikely to us given the institutional details of the industry. Recent structural research assumes that the marginal costs of each plant are constant over a broad range, and then upward-sloping above some utilization threshold (e.g., Ryan, 2012; Miller and Osborne, 2014; Fowlie, Reguant, and Ryan, 2016).

<sup>11</sup> That pass-through can exceed unity does not depend on the symmetry of the model, and we refer interested readers to the Appendix for a short discussion of pass-through in asymmetric oligopoly.



regressions, we impose that the pass-through parameter is invariant across regions and years (i.e.,  $\alpha_{mt} = \alpha_0 \forall m, t$ ). The ordinary least squares (OLS) coefficient then is an unbiased estimate of the average effect of costs on prices if the standard orthogonality assumptions hold.

This regression equation can be derived from a broad class of oligopoly models. To demonstrate, we express the equilibrium prices of plant  $j$  in year  $t$  in the following linear form:

$$p_{jt} = \rho_{jjt}^* c_{jt} + \sum_{k \neq j} \rho_{jkt}^* c_{kt} + x'_{jt} \gamma + \sum_{k \neq j} x'_{kt} \gamma^* + \mu_j + \epsilon_{jt}. \quad (7)$$

The equilibrium price response of firm  $j$  to a market-wide change in costs is determined by the sum of the firm-specific pass-through coefficients:  $\rho_{jt} = \sum_k \rho_{jkt}^*$ . This equation is easily obtained in differentiated-products Nash-Bertrand models with linear demands, and is a linear approximation to equilibrium prices in many other models. We develop these connections in the Appendix using the model of Jaffe and Weyl (2013).<sup>12</sup>

The estimation of equation (7) is infeasible because there are more coefficients than observations. We make two restrictions to facilitate estimation. First, we let competitor costs affect equilibrium prices as follows:

$$\rho_{jkt} = \begin{cases} \beta g(z_{jkt}) & \text{if } g(z_{jkt}) > \bar{g} \\ 0 & \text{otherwise,} \end{cases} \quad (8)$$

where the function  $g(z_{jkt})$  provides the “closeness of competition” between any two plants  $j \neq k$  given observable data  $z_{jkt}$ . The restriction imposes that closeness is both observable and unaffected by the characteristics of other plants. In implementation, we use measures of distance and competitor capacity to construct  $g(z_{jkt})$ , consistent with transportation costs being the main source of differentiation in the industry.<sup>13</sup> This treatment is directly analogous to the assumption of Pinske, Slade, and Brett (2002) that the strategic complementarity of prices in gasoline markets decreases in the geographic distance.

Second, we allow the pass-through of firm-specific cost changes to diminish with competition, consistent with the theoretical results of ten Kate and Niels (2005) for the undifferentiated Nash-Cournot model and Zimmerman and Carlson (2010) for the differentiated-products Nash-Cournot and Nash-Bertrand models. We specify that each firm’s costs affect its equilibrium prices according to

$$\rho_{jjt} = \alpha_0 + \alpha_1 \sum_{k \neq j, g(z_{jkt}) > \bar{g}} g(z_{jkt}), \quad (9)$$

Combining the two restrictions, the net effect of competition on the pass-through of market-wide cost changes considered in Weyl and Fabinger (2013) is determined by the relative magnitudes of  $\alpha_1$  and  $\beta$ . The empirical model allows the data to determine whether this net effect is positive or negative. Thus, the restrictions solve the dimensionality problem while preserving flexibility in pass-through relationships.

Equations (7)–(9) provide the microfoundations of the regression equation. The linearity of the equilibrium pricing function facilitates aggregation to the region level, aligning the regressors with the observed price data. Suppose there exist  $m = 1 \dots M$  regions, and denote as  $\mathcal{J}_{mt}$  the set of plants that are in region  $m$  in period  $t$ . The USGS data provides the average price in a

<sup>12</sup> This pricing equation is reduced-form because it expresses equilibrium prices as a function of exogenous determinants. It differs in this sense from the standard pricing equations that define the first-order conditions for profit maximization (e.g., equation (1)) and that often are used to estimate the supply-side of structural models. In those first-order conditions, prices appear on both sides of the equation due to the relationship between prices and markups. As we argue in the third subsection of Section 4, without auxiliary information, the reduced-form approach does not allow for the recovery of markups or any structural parameters, and instead focuses on how exogenous factors affect equilibrium prices (taking into account all the channels through which the factors affect prices).

<sup>13</sup> The approach can be applied to markets with product differentiation provided that a reasonable Euclidean distance in attribute-space can be calculated (e.g., as in Langer and Miller, 2013).

region as  $\bar{p}_{mt} = \sum_{j \in \mathcal{J}_{mt}} \omega_{jmt} p_{jt}$ , where  $\omega_{jmt}$  is the fraction of the region's production accounted for by plant  $j$ . The same aggregation procedure can be applied to the regressors, and this obtains a region-level regression equation:

$$\begin{aligned} \bar{p}_{mt} = & \alpha_0 \sum_{j \in \mathcal{J}_{mt}} \omega_{jmt} c_{jt} + \alpha_1 \sum_{j \in \mathcal{J}_{mt}} \omega_{jmt} c_{jt} \sum_{k \neq j, g(z_{jkt}) > \bar{g}} g(z_{jkt}) \\ & + \beta \sum_{j \in \mathcal{J}_{mt}} \omega_{jmt} \sum_{k \neq j, g(z_{jkt}) > \bar{g}} c_{kt} g(z_{jkt}) \\ & + \sum_{j \in \mathcal{J}_{mt}} \omega_{jmt} x'_{jt} \gamma + \sum_{j \in \mathcal{J}_{mt}} \omega_{jmt} \sum_{k \neq j, g(z_{jkt}) > \bar{g}} x'_{kt} \gamma^* \\ & + \sum_{j \in \mathcal{J}_{mt}} \omega_{jmt} (\mu_j + \epsilon_{jt}). \end{aligned} \quad (10)$$

The pass-through coefficients are separately identifiable if heterogeneity in the competitive conditions exists among regions (this distinguishes  $\alpha_0$  and  $\alpha_1$ ) and if plants have a sufficient number of out-of-region competitors with different fuel costs (this distinguishes  $\alpha_1$  and  $\beta$ ). In our data, fuel costs tend to be highly correlated across plants, implying that the latter condition is unlikely to hold. As a result, we apply the normalization  $\beta = 0$  and allow the net effect of competition to load onto  $\alpha_1$ . We normalize  $\gamma^* = 0$  for the same reason. The equivalence of equations (6) and (10) is completed with the following definitions:

$$\begin{aligned} \alpha_{mt} &= \alpha_0 + \alpha_1 \sum_{j \in \mathcal{J}_{mt}} \omega_{jmt} \sum_{k \neq j, g(z_{jkt}) > \bar{g}} g(z_{jkt}) \\ \bar{c}_{mt} &= \sum_{j \in \mathcal{J}_{mt}} \omega_{jmt} c_{jt} \\ \bar{x}_{mt} &= \sum_{j \in \mathcal{J}_{mt}} \omega_{jmt} x_{jt} \\ \bar{\mu}_{mt} &= \sum_{j \in \mathcal{J}_{mt}} \omega_{jmt} \mu_j \\ \bar{\epsilon}_{mt} &= \sum_{j \in \mathcal{J}_{mt}} \omega_{jmt} \epsilon_{jt}. \end{aligned}$$

To proxy for the weights in aggregation, we assume that production within regions is proportional to capacity. This approach, necessitated by the lack of plant-level production data, is used by the EPA in its economic analysis of the industry (EPA, 2010). In the regression analysis, we weight the region-year observations by the number of plants so that the coefficients reflect the average plant-level effects (though this does not effect results).<sup>14</sup>

We wish to make two additional observations about the regression equation before proceeding. First, although the unit of observation is at the region level, competitive interactions that span the regional boundaries are incorporated. This is accomplished by defining all regressors at the plant level and then aggregating to the region level. Thus, regions need not comport with the local economic markets, and are better conceptualized as sets of plants loosely defined based on geographic criteria. Second, the restrictions we have placed on the empirical model enforce that pass-through is invariant to the magnitude of costs. This is not a general characteristic of

<sup>14</sup> Many of the plant fixed effects are collinear once aggregated to the region level. This is not always the case, however, because plants sometimes are observed in two or more regions within the sample period due to changes in region boundaries. We use the aggregated plant effects rather than region fixed effects in order to maintain a closer connection between the theory and empirical work.

oligopoly models, though a class of demand systems does generate constant pass-through (Bulow and Pfleiderer, 1983). To the extent that pass-through varies, our approach yields estimates of the average effect.

□ **Identification.** We estimate the empirical model with OLS. The error term in the model is a pricing residual that incorporates unobservable demand and cost conditions. Unbiasedness rests on orthogonality between fuel costs and the pricing residual. The institutional details support such an orthogonality assumption. That fuel costs could be correlated with unobserved costs is not obvious because the production process requires inputs (e.g., limestone and heat) in fixed proportions—there is no substitute for fossil fuel. Factor substitution causes more concern with Cobb-Douglas production functions.<sup>15</sup> Our regressions do not incorporate competitor costs, but this does not confound our estimates of market passthrough due to the high degree of collinearity mentioned above.<sup>16</sup> Fuel costs are plausibly uncorrelated with unobserved demand: bituminous coal and petroleum coke prices do not follow the procyclical pattern of cement consumption, and the cement industry accounts for only a small fraction of the fossil fuels consumed in the United States.

It seems possible that our competition measures are correlated with the pricing residual. Competitors could locate where unobserved demand is high (generating a positive relationship) or where unobserved costs are low (generating a negative relationship). Because the median kiln age at retirement is 37 years but contracts often are negotiated annually, such correlations would have greater impact on our estimates if the unobserved factors exhibit a high degree of autocorrelation. To allay concern, we employ (aggregated) plant fixed effects in many of our regressions. Identification of how competition affects pass-through then rests on entry, exit, and changes in the diesel price, the last of which affects the transportation costs that differentiate plants. Our estimates of pass-through are robust to the inclusion or exclusion of the plant fixed effects, but the interactive effect of competition on pass-through stabilizes across specifications only if plant fixed effects are included.

□ **Conduct and incidence.** This section describes how we construct estimates of harm for consumers and producers, and addresses statistical inference in the counterfactual analysis. Equation (4) establishes that the loss of consumer surplus depends on pass-through, and quantity. The corresponding sampling distribution is straightforward because quantity is observed and we can apply the estimated parameters from our region-level regression to put confidence bounds on pass-through. By contrast, equation (5) establishes that the loss of producer surplus depends on quantity, pass-through and conduct. This is more difficult because the reduced-form regressions do not support a point estimate on the conduct parameter.

We proceed by using the margins and the elasticities obtained from the structural model of Miller and Osborne (2014) to calculate an estimate of conduct. The structural model features differentiated-products Nash-Bertrand competition among plants. Consumers select plants according to county-specific nested logit demand systems, in which all cement plants and imports are within one nest and noncement products are within another nest. Differentiation arises from transportation costs and varies based on the locations of plants and counties. Plants set prices at the county level. The model is estimated with USGS and PCA data on Arizona, California, and Nevada (the “US Southwest”) over 1983–2003. Because the price data are observed at the region-year level, equilibrium plant-specific prices must be computed numerically, given the structural

<sup>15</sup> Consider a simple example in which the inputs are labor and capital. Under plausible parameterizations, wages increases result in greater labor and capital costs, creating a positive correlation between the two cost determinants.

<sup>16</sup> We estimate an augmented empirical model in the Appendix that accounts for competitor costs (i.e., does not impose the  $\beta = 0$  normalization), and show that the main results are robust. The formulation of the empirical model also is consistent with our focus on how market-wide cost changes affect prices in a model of symmetric oligopoly. In such a setting, costs are perfectly correlated (because  $c_{jt} = c_{kt} \forall j, k$ ), so estimation obtains the pass-through relationship of interest.

parameters. The model fits the data used in estimation well and also accurately predicts withheld data on cross-region shipments.

We derive a point estimate of conduct by computing equilibrium prices and calculating margins and the elasticity of market demand at the estimated structural parameters.<sup>17</sup> The quantity-weighted average margin, elasticity, and conduct parameter are 0.40, 0.92, and 0.33, respectfully. Similar margins and elasticities are obtained elsewhere in the literature. For instance, a recent EPA analysis calculated kiln-specific variable costs for each of 20 local markets; the costs imply an average margin of 43% when paired with market prices (EPA, 2009). Jans and Rosenbaum (1997) estimate a domestic elasticity of demand of 0.87, and the elasticity estimates of Fowlie, Reguant, and Ryan (2016) range between 0.89 and 2.03. Finally, Miller and Osborne (2014) also show that the estimated margins are consistent with margins that are published in cement producers' financial statements.

A drawback of combining reduced-form and structural estimates in this manner is that there is no straightforward way to compute the joint sampling distribution of pass-through and conduct, which would be needed to provide a formal confidence bound on the estimate of producer surplus loss. Consider that the structural model generates average pass-through of 0.89 and (because this is less than unity), a negative correlation between pass-through and conduct. By contrast, our reduced-form estimates of pass-through are above unity, and interaction terms support a positive correlation between pass-through and conduct. We view the reduced-form estimates as more reliable because the structural model imposes a particular demand system that restricts curvature and largely predetermines pass-through.<sup>18</sup>

Nevertheless, it is possible to compute a confidence bound on conduct alone using the same approach we use to compute a point estimate of conduct. With this confidence bound in hand, the magnitude of producer harm can be characterized for conduct and pass-through pairs for which each element of the pair is statistically likely. We compute a confidence bound on conduct using a bootstrap: we take 2000 draws from estimated asymptotic distribution of the structural parameters, and compute the conduct parameter at each draw. The symmetric 90% confidence interval for the conduct parameter is (0.25,0.42).

There is an alternative approach that infers conduct directly from pass-through, which is in the spirit of the exercise we perform in this article, and does not draw on estimates from existing work. To demonstrate how this approach works, we start with the symmetric oligopoly model of Weyl and Fabinger (2013) that is summarized in Section 3, and for simplicity of exposition, suppose that conduct and marginal costs are constant. Equation (2) then can be rearranged to provide conduct as a function of pass-through:

$$\theta = \left( \frac{1 - \rho}{\rho} \right) \epsilon_{ms}, \quad (11)$$

where again  $\epsilon_{ms}$  is the elasticity of marginal surplus with respect to quantity (recall that  $ms = p'Q$ ). Conduct can be inferred from pass-through given knowledge of the slope and curvature of demand. Econometric estimates of these objects can be obtained with a demand model that is second-order flexible if the data provide the requisite empirical variation. In a web Appendix, we show that there is not enough variation to estimate the curvature of demand with any reasonable degree of precision. The alternative approach of utilizing a demand system that can be calibrated from pass-through is not promising because the relationship between elasticities and pass-through is not robust to functional form assumptions (Bulow and Pfleiderer, 1983). Last, if we were to

<sup>17</sup> The relevant demand elasticity measures the change in the quantity of domestically produced cement with respect to the price of domestically produced cement. The structural estimates indicate that most substitution away from domestic cement goes to imported cement.

<sup>18</sup> A second difference between the reduced-form regressions and the structural model arises due to the samples used in estimation. In principle, the structural model could be reestimated with the broader data-set used here, but it is not clear to us whether such an endeavor is computationally feasible.

relax the assumptions of constant marginal cost and conduct, the exercise of recovering conduct would be more complicated.<sup>19</sup>

## 5. Variables and Summary Statistics

□ **Fuel costs and prices.** Table 2 provides mathematical definitions of the dependent variable and all the regressors, along with their means and standard deviations. We describe first the fuel cost variable, which we calculate based on the energy requirements of the plant's least efficient kiln and the price of the primary fuel:

$$\text{Plant Fuel Cost}_{jt} = \text{Primary Fuel Price}_{jt} \times \text{Energy Requirements}_{jt},$$

where the fuel price is in dollars per mBtu and the energy requirements are in mBtu per metric tonne of clinker. We use the least efficient kiln because it is most likely to produce the marginal output. We provide details on the calculation in a web Appendix, along with a discussion about potential sources of measurement error. The plant-level fuel costs are aggregated to the region level prior to estimation following equation (10).

Table 3 provides fuel costs at five-year intervals, by kiln technology and in unweighted national averages. The table also shows the national average price of portland cement. Time-series variation in fuel costs arises primarily due to changes in fossil fuel prices and the technological shift toward modern precalciner kilns. Cross-sectional variation across kiln technologies arises according to the heterogeneity in the energy requirements of production. Both fuel costs and prices decrease through the first two decades of the sample and then increase. Depending on the year and technology, average fuel costs account for between 7% and 20% of average revenues.

Figure 2 explores the empirical distributions of regional prices and fuel costs over the sample period of 1980–2010. Panels A and B show the univariate distributions. The price distribution is nearly symmetric around the mean of \$98.62 per metric tonne. The fuel cost distribution is tighter and left-centered. Panel C provides separate kernel density estimates for plants with wet and dry kilns. Panel D provides a scatterplot of the 773 region-year observations on prices and fuel costs. Observations with higher fuel costs also have higher prices: the correlation coefficient is 0.46, and a univariate regression of prices on fuel costs yields a coefficient of 1.28 that is statistically significant at the 1% level. This univariate regression coefficient ends up being close to the average pass-through that we obtain with the reduced-form regression analysis.

□ **Other variables.** We construct measures of domestic competition based on the location of plants, their capacity, and the magnitude of diesel prices (which scales transportation costs). The first measure, which we refer to as *Proximity of Rival Capacity*, is the count of competing plants within some distance threshold, weighted by capacity and inverse distance. It increases with the number, capacity, and proximity of competitors. The second measure, *Total Rival Capacity*, is total competitor capacity within some distance threshold. The third and fourth measures, *Proximity of Rivals* and *Number of Rivals*, are analogous but do not weight competitors by capacity. Each of these are calculated at the plant level and then aggregated to the region level prior to estimation. We also interact these measures with fuel costs, as in equation (10), in order to allow pass-through to vary with competition.

In the construction of these measures, we use a distance metric defined by the interaction of the diesel price index and the straight-line miles between plants. This approach reflects the

<sup>19</sup> To accomplish this exercise, one would first solve for  $\theta$  as a function of marginal surplus, observed prices, and costs, using the first-order condition in equation (1). One could substitute this formula for  $\theta$  into equation (2) to express pass-through in terms of observed prices, marginal costs, demand and supply elasticities, as well as marginal surplus and its derivative. Given estimates of the marginal surplus function derived from demand estimates, one could match estimated pass-through to predicted pass-through to estimate the parameters governing marginal cost, and derive conduct.

**TABLE 2** Definitions and Summary Statistics for Selected Variables

Regressor	Definition	Mean	Standard Deviation	Description
Price	$\sum_{j \in \mathcal{J}_m} \omega_{jmt} P_{jt}$	98.62	<i>Dependent Variable</i> (16.25)	The average cement price in the region.
Proximity of rival capacity	$\sum_{j \in \mathcal{J}_m} \omega_{jmt} \sum_{k \neq j, d_{jk} < \bar{d}} CAP_{kt} / d_{jkt}$	0.25	(0.23)	Competitor capacity, normalized by distance, totaled for each plant, and then aggregated to the region level.
Total rival capacity	$\sum_{j \in \mathcal{J}_m} \omega_{jmt} \sum_{d_{jk} < \bar{d}} CAP_{kt}$	19.67	(10.53)	Competitor capacity within the distance threshold, totaled for each plant, and then aggregated to the region level.
Proximity of rivals	$\sum_{j \in \mathcal{J}_m} \omega_{jmt} \sum_{k \neq j, d_{jk} < \bar{d}} 1 / d_{jkt}$	0.34	(0.29)	The count of competitors normalized by distance and aggregated to the region level.
Number of rivals	$\sum_{j \in \mathcal{J}_m} \omega_{jmt} \sum_{d_{jk} < \bar{d}} 1$	27.75	(15.34)	The count of competitors within the distance threshold, aggregated to the region level.
Construction employment	$\sum_{j \in \mathcal{J}_m} \omega_{jmt} \sum_{d_{kj} < \bar{d}} EMP_{at}$	835.27	(556.03)	Total construction employment in nearby counties, aggregated to the region level.
Building permits	$\sum_{j \in \mathcal{J}_m} \omega_{jmt} \sum_{d_{kj} < \bar{d}} PER_{at}$	216.35	(150.03)	Total building permits in nearby counties, aggregated to the region level.
Port proximity	$\sum_{j \in \mathcal{J}_m} \omega_{jmt} / \log(d_{jt}^{cd})$	0.27	(0.55)	The inverse log distance to the nearest customs district, through which foreign imports arrive, aggregated to the region level.
Fuel costs	$\sum_{j \in \mathcal{J}_m} \omega_{jmt} C_{jt}$	14.08	<i>Pass-Through Regressors</i> (5.79)	Fuel costs of the plant as defined in the text, aggregated to the region level.
Fuel Costs $\times$ Proximity of Rival Capacity	$\sum_{j \in \mathcal{J}_m} \omega_{jmt} C_{jt} \sum_{k \neq j, d_{jk} < \bar{d}} CAP_{kt} / d_{jkt}$	3.25	(3.02)	Fuel costs times the competitors capacity, normalized by distance, totaled for each plant, and aggregated to the region level.
Fuel Costs $\times$ Total Rival Capacity	$\sum_{j \in \mathcal{J}_m} \omega_{jmt} C_{jt} \sum_{k \neq j, d_{jk} < \bar{d}} CAP_{kt}$	255.65	(139.30)	Fuel costs times total nearby competitor capacity, totaled for each plant, and aggregated to the region level.
Fuel Costs $\times$ Proximity of Rivals	$\sum_{j \in \mathcal{J}_m} \omega_{jmt} C_{jt} \sum_{k \neq j, d_{jk} < \bar{d}} 1 / d_{jkt}$	4.54	(4.21)	Fuel costs times the count of competitors normalized by distance, aggregated to the region level.
Fuel Costs $\times$ Number of Rivals	$\sum_{j \in \mathcal{J}_m} \omega_{jmt} C_{jt} \sum_{k \neq j, d_{jk} < \bar{d}} 1$	373.40	(229.89)	Fuel costs times total nearby competitor capacity, aggregated to the region level.

Notes: The cement price is observed at the region-year level. For all other variables, aggregation to the region level is conducted using capacity shares as proxies for the weights  $\omega_{jmt}$ . In all equations,  $P_{jt}$  is the price of plant  $j$  in period  $t$ ,  $C_{jt}$  is the fuel cost of plant  $j$  in period  $t$ ,  $d_{jk}$  is the distance between plants  $j$  and  $k$  in period  $t$ ,  $d_{jt}^c$  is the distance between county  $a$  and plant  $j$  in period  $t$ ,  $d_{jt}^{cd}$  is the distance between plant  $j$  and the nearest customs district in period  $t$ ,  $PER_{at}$  and  $EMP_{at}$  are building permits and construction employment in county  $a$  in period  $t$ , respectively, and  $CAP_{kt}$  is the capacity of plant  $k$  in period  $t$ . Summary statistics are calculated from 773 region-year observations.



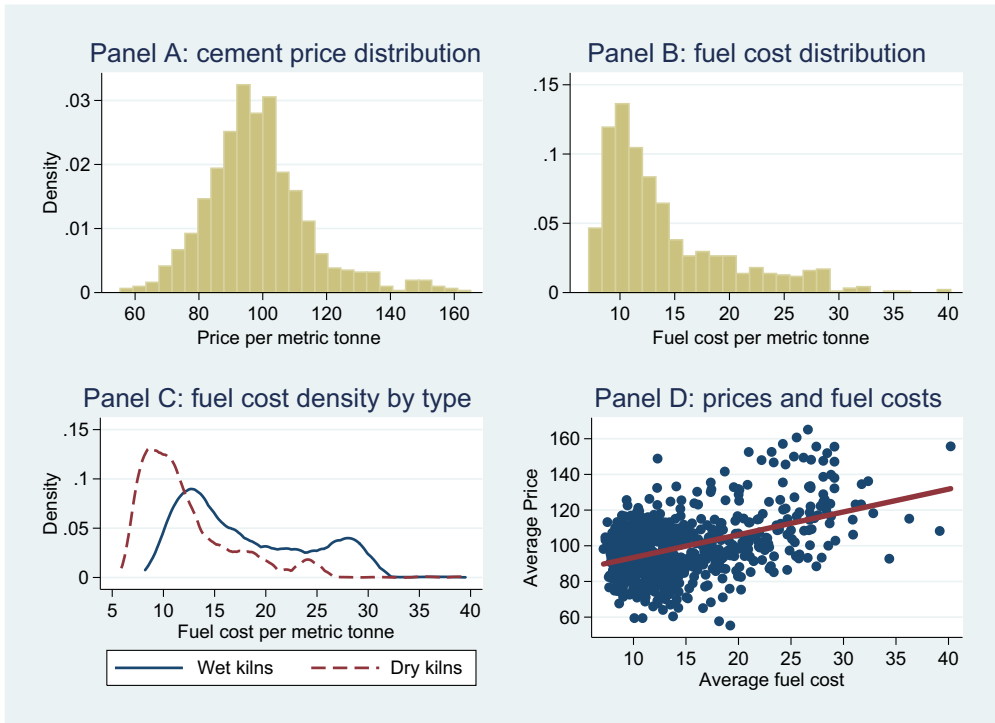
TABLE 3 Cement Prices and Fuel Costs

	Average Price	Average Fuel Costs			
		Wet Kilns	Long Dry Kilns	Dry with Preheater	Dry with Precalciner
1980	103.98	20.43	16.72	14.62	12.26
1985	81.61	15.75	13.17	10.01	9.60
1990	67.55	11.90	10.21	7.92	7.91
1995	73.83	9.45	7.90	6.70	6.26
2000	78.56	8.56	7.43	5.82	5.63
2005	80.51	11.12	9.52	7.56	7.39
2010	71.04	13.82	12.08	9.40	9.05

Notes: Cement prices and fuel costs are in real 2010 dollars per metric tonne.

FIGURE 2

## REGIONAL PRICES AND FUEL COSTS OVER 1980–2010



Notes: Panels A and B show the empirical distributions of cement price and fuel costs, and are based on 773 region-year observations. Panel C shows the kernel density of fuel costs, separately for plants with wet and dry kilns, and is based on 3445 plant-year observations. Panel D shows a scatterplot of regional cement prices and fuel costs, as well as a line of best fit, and is based on 773 region-year observations. All prices and fuel costs are in real 2010 dollars per metric tonne of cement.

predominant role of trucking in distribution.<sup>20</sup> Straight-line miles are highly correlated with both driving miles and driving time and, consistent with this, previously published empirical results on the industry are not sensitive to which of these measures is employed (e.g., Miller and

<sup>20</sup> A fraction of cement is shipped to terminals by train (6% in 2010) or barge (11% in 2010), and only then is trucked to customers. Some plants may be closer than our metric indicates if, for example, both are located on the same river system.

TABLE 4 The Average Effect of Fuel Costs on Prices

	(i)	(ii)	(iii)	(iv)	(v)	(vi)	(vii)	(viii)
<i>Pass-through Regressor</i>								
Fuel costs	1.03 (0.16)	1.11 (0.16)	1.30 (0.16)	1.37 (0.18)	1.47 (0.27)	1.58 (0.26)	1.63 (0.25)	1.65 (0.27)
<i>Control Variables for Domestic Competition</i>								
Proximity of rival capacity	-13.68 (2.39)	-8.46 (2.81)		-7.38 (6.72)	-5.89 (9.72)	4.07 (9.96)		-16.84 (23.89)
Total rival capacity ( $d < 400$ )	-0.97 (0.10)	-0.58 (0.17)		0.48 (0.26)	-1.31 (0.20)	-0.68 (0.22)		-0.12 (0.35)
Total rival capacity ( $d < 300$ )		-0.39 (0.33)				-0.83 (0.32)		
Total rival capacity ( $d < 200$ )		-1.24 (0.38)				-1.95 (0.46)		
Proximity of rivals			-11.09 (1.93)	-4.80 (5.72)			-8.35 (8.07)	-22.36 (20.89)
Number of rivals ( $d < 400$ )			-0.69 (0.06)	-0.99 (0.18)			-0.89 (0.12)	-0.78 (0.25)
<i>Other Control Variables</i>								
Construction employment	-0.004 (0.002)	0.003 (0.003)	-0.005 (0.002)	-0.006 (0.002)	0.024 (0.004)	0.032 (0.004)	0.020 (0.004)	0.020 (0.004)
Building permits	0.046 (0.009)	0.044 (0.009)	0.054 (0.009)	0.056 (0.009)	0.017 (0.010)	0.027 (0.011)	0.026 (0.010)	0.026 (0.010)
Port proximity	2.34 (1.02)	2.52 (0.97)	2.26 (1.08)	2.28 (1.08)	-5.93 (3.21)	-2.96 (3.79)	-4.87 (2.93)	-4.15 (3.23)
<i>Fixed Effects</i>								
Plant fixed effects	No	No	No	No	Yes	Yes	Yes	Yes

Notes: The table reports the results of OLS regressions. The sample includes 773 region-year observations over 1980–2010. The dependent variable is the cement price. Distance ( $d$ ) is measured in miles times a diesel price index. All regressions also include fixed effects for the kiln technology of the plant. Observations are weighted by the number of plants within the region. Standard errors are calculated using a Newey-West correction for first-order autocorrelation within regions.

Osborne, 2014). The baseline distance threshold is 400. This is motivated by prior findings that 80%–90% of portland cement is trucked less than 200 miles (Miller and Osborne, 2014), so that plants separated by more than 400 miles are unlikely to compete for many customers. We obtain similar results with alternative thresholds, and in some regressions we employ multiple variables constructed with different thresholds to allow for a more nonparametric treatment.

We control for demand conditions using county-level data on building permits and construction employment. The USGS provides consumption data at the state (not region) level, and when aggregated to the state level, building permits and construction employment together explain nearly 90% of the variation in cement consumption. To construct the controls, we calculate the total building permits and construction employment in counties within the distance threshold of each plant, and then aggregate to the region level. We similarly control for port proximity based on the plants' inverse log distances to the nearest port; we use log distance to reduce skewness in this variable.

## 6. Empirical evidence on pass-through

□ **Main regression results.** Table 4 summarizes a first set of regressions in which *Fuel Costs* is the sole pass-through regressor. The *Fuel Costs* coefficient thus represents the average effect of fuel costs on prices. The regressions differ in the specification of the control variables and fixed effects. Columns (i)–(iv) control for domestic competition using different combinations of variables. Columns (v)–(viii) examine the same specifications but also include plant fixed effects.

TABLE 5 The Effect of Competition on Pass-through

	(i)	(ii)	(iii)	(iv)	(v)	(vi)
<i>Pass-through Regressors</i>						
Fuel costs	2.38 (0.28)	2.05 (0.36)	2.48 (0.27)	2.15 (0.37)	2.60 (0.30)	2.76 (0.31)
Fuel Costs × Proximity of Rival Capacity	-4.45 (0.84)				-4.17 (0.88)	
Fuel Costs × Total Rival Capacity ( $d < 400$ )		-0.42 (0.16)			-0.03 (0.01)	
Fuel Costs × Proximity of Rivals			-3.05 (0.47)			-2.88 (0.45)
Fuel Costs × Number of Rivals ( $d < 400$ )				-0.30 (0.01)		-0.20 (0.10)
<i>Derived Statistics</i>						
Median Pass-through	1.64	1.37	1.79	1.46	1.30	1.51

Notes: The table reports the results of OLS regressions. The sample includes 773 region-year observations over 1980–2010. The dependent variable is the cement price. All regressions include the same control variables as column (viii) of Table 4, as well as technology and plant fixed effects. Observations are weighted by the number of plants within the region. The derived statistics are calculated by applying the regression coefficients to the 3445 plant-year observations. Standard errors are calculated using a Newey-West correction for first-order autocorrelation within regions.

All standard errors and confidence intervals are calculated using a Newey-West correction for first-degree autocorrelation among observations from the same region. Breusch-Godfrey tests provide no statistical support for higher degrees of autocorrelation.

The *Fuel Cost* regression coefficient ranges from 1.03 in column (i) to 1.65 in column (viii). The point estimates are therefore consistent with pass-through that exceeds unity. The precision of the estimates also is notable: the magnitude of the coefficients tend to be nearly an order of magnitude larger than their standard error. In some of the regressions, this produces a symmetric 95% confidence interval that excludes unity on the lower end (columns (iv), (vi), (vii), and (viii)). In the other regressions, pass-through that is substantially incomplete still can be rejected. The *Fuel Cost* coefficient tends to be somewhat larger if plant fixed effects are incorporated, and if the control variables are constructed based on competitor counts rather than competitor capacity.

The control variables have coefficients that are consistent with expectations. The coefficients on the controls for domestic competition typically are negative; the only statistically significant exception arises in column (iv), which excludes plant fixed effects. Columns (ii) and (vi) provide a nonparametric treatment of the distance metric. The results imply that the effect of competitor capacity on prices increases with the proximity of that capacity. This is consistent transportation costs providing localized market power, and with prices being constrained by nearby competitors.<sup>21</sup> Port proximity, which proxies for the competitive impact of imported cement, also has a negative effect on prices if plant fixed effects are included in the specification. Finally, the construction employment and building permits variables tend to be associated with higher prices.<sup>22</sup>

Table 5 summarizes a second set of regressions that examine whether competition affects pass-through. We motivate these regressions based on the auxiliary prediction of the Weyl and Fabinger (2013) model that competition should lessen pass-through if, as we estimate, pass-through exceeds unity. Columns (i)–(vi) use different measures of domestic competition and

<sup>21</sup> The *Total Rival Capacity* regressors in columns (ii) and (vi) are cumulative. Thus, for example, in column (vi) the total effect of capacity within a distance threshold of 200 equals  $-0.68 - 0.83 - 1.95 = -3.46$ .

<sup>22</sup> The construction employment coefficient is negative in some specifications that exclude plant fixed effects. The net effect of these demand shifters nonetheless is positive. In alternative regressions (not shown), we use a linear combination of construction employment and building permits to control for demand conditions. The weights in the linear combination are determined by regressing observed state-level consumption on (suitably aggregated) versions of construction employment and building permits, following Miller and Osborne (2014). The linear combination consistently has a positive effect on prices when it replaces construction employment and building permits in the regressions.

consistently supports that competition lessens pass-through. The median pass-through that arises with these regressions ranges over 1.37–1.79. Next, we use multiple distance metrics to capture the interactive effect of competition, based on competitor capacity (column (v)) and competitor counts (column (vi)). Each of the interactions is negative and statistically significant, and the resulting median pass-through remains well above unity. The symmetric 95% confidence intervals exclude unity in columns (i), (iii), (iv), and (vi). The results are consistent with the auxiliary prediction of the model.

We have subjected these regression results to a battery of robustness checks and do not believe that they are the product of particular sample selection or functional form choices. In addition to areas of robustness mentioned elsewhere in the article and Appendices, the results prove robust to (i) the use of feasible generalized least squares as a correction for autocorrelation; (ii) the exclusion of particularly influential observations, as determined by Cook's  $D$  statistic; and (iii) the incorporation of additional control variables constructed with a variety of distance thresholds. Tests for structural breaks in the data provide modest support for somewhat higher pass-through over the most recent decade in the sample.

□ **Validation exercise.** Our regression results allow for an evaluation of an implicit pass-through assumption that is made in recent research on the portland cement industry (e.g., Ryan, 2012; Fowlie, Reguant, and Ryan, 2016). Those articles estimate a structural oligopoly model relying on the same data sources employed here, and then use simulation to examine the effects of market-based regulation of CO<sub>2</sub> and other environmental policies. The structural model incorporates dynamics and, to facilitate tractable estimation, state-space payoffs are specified as arising from homogeneous-products Nash-Cournot competition among firms in local markets. ten Kate and Niels (2005) derive pass-through in the Nash-Cournot setting as

$$\rho = \frac{N}{N + 1 - \phi}, \quad (12)$$

where  $N$  is the number of firms and  $\phi$  is a measure of demand curvature that is positive with convex demand, negative with concave demand, and zero with linear demand. Pass-through converges to unity as the number of firms grow large, either from above or below.<sup>23</sup>

The structural models use a constant-elasticity assumption that imposes convexity on the demand curve. Because this in turn determines pass-through, the constant-elasticity assumption matters for the simulated economic outcomes. As a validation exercise, we calculate the pass-through implied by the model, for the local markets delineated by the EPA and used in Fowlie, Reguant, and Ryan (2016), and over a range of demand elasticities considered in that article. Table 6 provides the results for selected markets. (Calculations for all 20 EPA markets are available from the authors upon request.) The similarity between the theoretical predictions and our empirical estimates is apparent: pass-through somewhat exceeds unity, and competition has a damping effect. Thus, our regression results support the validity of the structural models.

## 7. Regulatory implications

□ **Market-based regulation of CO<sub>2</sub>.** Table 7 summarizes the welfare implications of market-based regulation. Panel A provides the change in producer surplus (in millions) per dollar of carbon

<sup>23</sup> The curvature term is  $\phi = -(Q \frac{\partial^2 P}{\partial Q^2}) / (\frac{\partial P}{\partial Q})$ . This derivation of Nash-Cournot pass-through requires constant marginal costs, but firms need not be symmetric. The structural models of Ryan (2012) and Fowlie, Reguant, and Ryan (2016) assume that marginal costs are constant up to some threshold capacity utilization level, beyond which they begin to increase. The formula, nonetheless, should be roughly accurate because plants are found to seldom produce above the utilization threshold. A major emphasis of the ten Kate and Niels (2005) article is that the pass-through of a firm-specific cost change is quite different from that of a market-wide cost change. The relevant formula for the firm-specific pass-through is  $\frac{1}{N+1-\phi}$ . Thus, firm-specific pass-through converges to zero as the number of firms grows large. It is theoretically possible for this to exceed unity, though only with a very convex demand curve.

**TABLE 6 Industry Pass-through in Selected EPA Markets**

	N	Theoretical Predictions		
		$\epsilon^D = 1.0$	$\epsilon^D = 1.5$	$\epsilon^D = 2.0$
Atlanta	6	1.20	1.13	1.09
Birmingham	5	1.25	1.15	1.11
Chicago	4	1.33	1.20	1.14
Cincinnati	3	1.50	1.29	1.20
Detroit	2	2.00	1.50	1.33

Notes: Theoretical predictions are derived from a model of Cournot competition among firms with constant but heterogeneous marginal costs and a constant-elasticity market demand schedule. We denote the number of firms with active plants in the EPA market in 2010 as  $N$  and the market elasticity as  $\epsilon^D$ .

**TABLE 7 Impacts of Market-Based Regulation**

Panel A: Change in Producer Surplus

Conduct	Pass-through				
	1.00	1.20	1.30	1.40	1.60
0.25	-16.97	-6.78	-1.70	3.39	13.58
0.30	-20.37	-10.86	-6.11	-1.36	8.15
0.35	-23.76	-14.94	-10.52	-6.11	2.72
0.40	-27.16	-19.01	-14.94	-10.86	-2.72
0.45	-30.55	-23.08	-19.35	-15.62	-8.15

Panel B: Change in Consumer Surplus

$\Delta CS$	Pass-through				
	1.00	1.20	1.30	1.40	1.60
$\Delta CS$	-67.90	-81.47	-88.26	-95.05	-108.63

Notes: All numbers are in millions of real 2010 dollars per dollar of carbon tax. Calculations are based on a general model of symmetric oligopoly, and use the 2011 industry output of 67.90 million metric tonnes. We use the ratio of 0.88 metric tonnes of CO<sub>2</sub> per metric tonne of cement to convert from an output tax to a carbon tax.

price. Panel B provides the change in consumer surplus. Calculations are shown for pass-through ranging from 1.00 to 1.60 and conduct ranging from 0.25 to 0.45, reflecting, respectively, the statistical variance of the reduced-form pass-through regressions and the bootstrap of the Miller and Osborne (2014) results.<sup>24</sup> We provide results in this manner because we are unable to put a confidence interval on the change in producer surplus due to the difficulty of recovering the covariance between conduct and pass-through (as discussed in Section 4).

Evaluating at the middle of estimated distributions, the loss of producer surplus is \$10.52 million per dollar of carbon price with pass-through of 1.30 and a conduct parameter of 0.35, and the loss of consumer surplus is \$88.26 million. These numbers indicate that consumers would bear about 89% of the burden of regulation. Official estimates of the social cost of carbon range from \$12 to \$129 per metric tonne for the year 2020, depending on the social discount rate (Working Group on Social Cost of Carbon, 2013). With a \$40 price on carbon, the producer surplus loss scales to \$421 million and the consumer surplus loss scales to \$3.5 billion. This can be compared to industry revenues of roughly \$7 billion in 2012. The fraction of revenues needed to fully compensate producers equals  $1 - \rho(1 - \theta)$ . Again evaluated at the middle of

<sup>24</sup> The 95% confidence interval on pass-through from specification (iv) of Table 4, which we use as our baseline, is [1.03, 1.73], and the confidence interval on conduct is [0.25, 0.43].

the estimated distributions, producers could be fully compensated with 15.5% of the revenues obtained from market-based regulation.

At least three important caveats apply to this counterfactual analysis. First, our approach for producer surplus does not account for the statistical covariance between pass-through and conduct. Still, it is not necessary to remain entirely agnostic because theory indicates that if pass-through exceeds unity, then it decreases as conduct parameter gets small. Thus, we view the combinations along the diagonal of Table 7 (i.e., low conduct and low pass-through, or high conduct and high pass-through) as being more likely to reflect actual market conditions.<sup>25</sup> Second, our estimates do not inform how consumer surplus loss is distributed downstream. Disentangling these impacts among ready-mix concrete plants, construction firms, and end users would require additional data and is beyond the scope of this research. Finally, our analysis in this section incorporates that cement purchasers could turn to unregulated imports after the imposition of market-based regulation. In regulatory parlance, such substitution is known as “leakage,” and typically an effort is made to design regulation in a manner that limits leakage.<sup>26</sup> To the extent that these efforts are successful, the burden of regulation would shift downstream to a greater degree than we calculate.

□ **NESHAP amendments.** We turn now to an economic analysis of recent revisions to the National Emissions Standards for Hazardous Air Pollutants (NESHAP) promulgated by the EPA. The revisions reduce the legally permissible emissions of hazardous air pollutants (HAPs) including particulate matter, mercury, hydrocarbons, and hydrogen chloride. EPA analysis indicates that monetized health benefits, which it predicts exceed \$7–\$18 billion, far outweigh economic costs (EPA, 2009, 2010). We revisit the price predictions of the EPA using our pass-through estimates. The EPA relies on a Cournot model of competition to simulate the effect of regulation in each of 20 local markets based on conditions in 2005. The model incorporates a constant-elasticity market demand curve and, for markets that are adjacent to a customs office, a constant-elasticity import supply curve. It is calibrated using methodologies that we detail in a web Appendix.

We replicate the EPA modelling results up to the restriction that compliance costs are public only at the market-average level. We update the analysis to 2010, the most recent year of our sample, and compare the price predictions to an alternative based on our pass-through estimates. Although the EPA approach is grounded in modelling techniques and functional forms that are standard in the literature of industrial organization (e.g., Fowlie, Reguant, and Ryan, 2016), the drawback is that pass-through is fully determined by functional forms and the first-order properties of the system. Relying on empirical estimates of pass-through relaxes these assumptions and allows the data to inform predictions more directly. We use the pass-through estimates from column (iv) of Table 4. Scaling pass-through up or down across the range of our estimates would have a commensurate effects on the prediction.

Figure 3 provides a scatterplot of market-specific predictions from the EPA’s Cournot model (on the vertical axis) and the predictions from our pass-through estimates (on the horizontal axis). Across the 20 local markets, the Cournot model yields average price increases of \$4.66 per metric tonne and the pass-through calculations yield average increases of \$4.78. The predictions are highly correlated, with a univariate correlation statistic of 0.88.<sup>27</sup> The similarity between the two

<sup>25</sup> Notice that producer surplus increases with some combinations of high pass-through and low conduct parameters (e.g.,  $\rho = 1.60$  and  $\theta = 0.25$ ). This has long been recognized as a theoretical possibility (Kimmel, 1992), but one that cannot be true globally, as that would imply infinite consumer surplus.

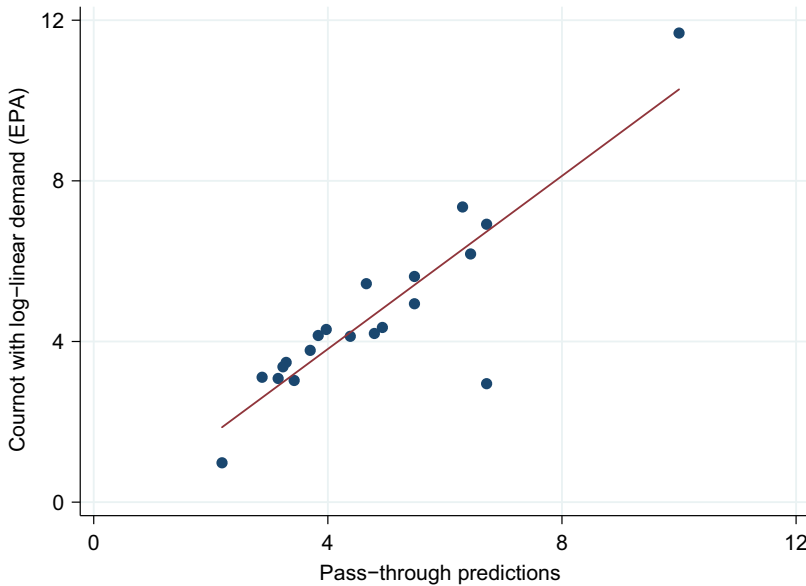
<sup>26</sup> The first-best solution to leakage is a border tax adjustment (BTA) that raises the effective price of unregulated imports. However, BTAs may violate World Trade Organization (WTO) prohibitions on trade restrictions because by design, they apply differentially to certain countries. Thus, some existing emissions trading systems instead utilize a production-based updating of permit allocations that compensate regulated firms for profit losses related to leakage. The 2009 Waxman-Markey bill proposed to apply production-based updating to “trade-vulnerable” industries, including the portland cement industry.

<sup>27</sup> The exceptions are Pittsburgh, for which the EPA underpredicts by \$3.76 relative to the pass-through calculation, and Cincinnati, for which the EPA overpredicts by \$1.68 relative to the pass-through calculation.



FIGURE 3

## PRICE EFFECTS OF NESHAP AMENDMENTS FOR PORTLAND CEMENT



Notes: Each dot represents the price predictions based on (i) the EPA model of Cournot competition between firms facing a constant-elasticity demand curve, and (ii) our estimates of pass-through. Also shown is a line of best fit.

methodologies arises because the pass-through that is implicit in the EPA model is close to our econometric estimates.

## 8. Conclusion

Recent theoretical advances highlight the usefulness of extending empirical pass-through research to imperfectly competitive markets (e.g., Weyl and Fabinger, 2013; Fabinger and Weyl, 2015). In this article, we develop an empirical model that incorporates oligopoly interactions and is theoretically capable of identifying both firm-specific and market pass-through. We take the model to data on the portland cement industry and find robust econometric evidence that market pass-through exceeds unity. The results have direct bearing on distributional effects of market-based environmental regulation. In particular, we calculate that the burden of cap-and-trade programs to limit CO<sub>2</sub> emissions falls predominately downstream, and that cement producers could be fully compensated with a small fraction of the government revenues obtained.

We conclude with a brief discussion of two limitations that we encountered in this project, keeping in mind that these limitations provide opportunity for future research. First, our data on the portland cement industry do not allow for the identification of firm-specific pass-through. This is due to the decision of the USGS to aggregate prices in the *Minerals Yearbook* (which protects confidentiality of business data). Although our empirical model is theoretically capable of disentangling the firm-specific pass-through rates, this requires a greater number of plants having out-of-region competitors with different fuel costs than we observe in the data. As a result, we have focused the counterfactual analyses on regulatory questions for which estimates of market pass-through are sufficient. Future studies that succeed in estimating firm-specific pass-through rates could address a range of other interesting topics, in environmental economics and elsewhere.

A second limitation is that the welfare formulas of Weyl and Fabinger (2013) require information on both pass-through and a conduct parameter. Reduced-form studies of pass-through

(including ours) typically obtain estimates only of the former. We sidestep the problem by bringing information to bear on the conduct parameter from the structural results of Miller and Osborne (2014), an approach that is possible because portland cement is so widely studied in the field of industrial organization. It would be conceptually advantageous to estimate pass-through and conduct jointly, in the context of a single structural model. It is possible, for example, that pass-through variation could be exploited to pin down a demand curvature parameter that otherwise would be difficult to identify empirically. In the context of portland cement, this would require more flexible models of demand than have been used in recently published structural models.

**Appendix**

□ **Model of asymmetric oligopoly.** In this Appendix, we provide a theoretical treatment of pass-through in asymmetric oligopoly, using the framework of Jaffe and Weyl (2013). We distinguish between responses to firm-specific cost shocks (“firm-specific pass-through”) and responses to market-wide cost shocks (“market pass-through”). We then discuss how omitting the costs of competitors from a reduced-form regression affects the interpretation of coefficients, following MacKay et al. (2014). Finally, we estimate an augmented empirical model that accounts explicitly for competitor costs, and find that our main results are robust.

Consider an oligopoly of firms, each of which produces one or more products and sets a single price per product. Let prices, quantities, and marginal costs of firm *i* be given by the vectors *P<sub>i</sub>*, *Q<sub>i</sub>*, and *MC<sub>i</sub>(P)*, respectively, where *P* is a vector of all firms’ prices. Each firm may conjecture that changes in its prices induce changes in competitors’ prices. This allows the model to nest the Nash-Bertrand and Nash-Cournot models, among others.<sup>28</sup> Finally, assume that each firm has well-behaved, twice-differentiable demand and cost functions. The first-order conditions that characterize equilibrium are given by:

$$f_i(P) \equiv - \left[ \frac{dQ_i(P)}{dP_i} \right]^{-1} Q_i(P) - P_i + MC_i(P) = 0 \quad \forall i \in I. \tag{A1}$$

Let *f(P)* = [*f<sub>1</sub>*(*P*) *f<sub>2</sub>*(*P*) . . .]’ denote the stacked first-order conditions. The imposition of quantity taxes, represented by a vector *t*, results in a new equilibrium characterized by *f(P) + t = 0*. An application of the Implicit Function Theorem yields the pass-through matrix:

$$\rho^F = - \left( \frac{\partial f(P)}{\partial P} \right)^{-1}. \tag{A2}$$

As in Section 3, pass-through depends on the elasticities and curvatures of the demand, as well as on the slope of the marginal cost function. The key difference is that equation (A2) provides firm-specific pass-through whereas equation (2) provides market pass-through.

To fix ideas, consider an oligopoly of three single-product firms in differentiated-products Nash-Bertrand competition. Each firm has a margin of 0.50 and a 30% market share (let a nonstrategic outside good capture the remaining share). The demand system is logit and marginal costs are constant. Based on the calibration technique of Miller et al. (forthcoming), pass-through is given by

$$\rho^F = \begin{bmatrix} 0.728 & 0.107 & 0.107 \\ 0.107 & 0.728 & 0.107 \\ 0.107 & 0.107 & 0.728 \end{bmatrix} \quad \text{and} \quad \rho = \begin{bmatrix} 0.942 \\ 0.942 \\ 0.942 \end{bmatrix}. \tag{A3}$$

Each diagonal element in  $\rho^F$  shows how a firm changes its price in response to a change in its own marginal cost, and each off-diagonal element shows the response of a firm to a change in a competitor’s marginal cost. These latter effects are indirect and arise if prices are strategic complements or strategic substitutes, in the sense of Bulow, Geanakoplos, and Klemperer (1985). If all marginal costs go up by the same magnitude—as in the Weyl and Fabinger (2013) models—then the effect on prices can be obtained by summing across the columns of  $\rho^F$ , which obtains the vector  $\rho$  of market pass-through.

Although the relationship between pass-through and demand curvature is more opaque in the asymmetric case (e.g., compare equations (2) and (A2)), it is still the case that pass-through tends to increase with the curvature of the demand system. Miller et al. (forthcoming) develop Monte Carlo evidence based on hundreds of four-firm oligopolies with randomly drawn market shares and margins. Competition is differentiated-products Nash-Bertrand. Market pass-through is always less than unity with the log-concave linear and logit demand systems. It often exceeds unity with the almost ideal demand system, and always exceeds unity with the constant-elasticity demand system.

<sup>28</sup> The Nash-Cournot model obtains from conjectures that competitors change their price such that their quantity remains constant.

TABLE A1 Augmented Regression Results

	(i)	(ii)
<i>Pass-through Regressors</i>		
Fuel costs	2.41 (0.27)	1.40 (0.19)
Fuel Costs × Proximity of Rival Capacity	−2.39 (1.40)	−4.86 (1.04)
Rival Fuel Costs × Proximity of Rival Capacity	−0.67 (2.35)	4.89 (1.24)
<i>Specification Details</i>		
Controls variables	Yes	Yes
Plant fixed effects	Yes	No
Kiln fixed effects	Yes	Yes
<i>Derived Market Pass-through Statistics</i>		
Median	1.61	1.33

Notes: The sample includes 773 region-year observations over 1980–2010. The dependent variable is the cement price. Standard errors are calculated using a Newey-West correction for first-order autocorrelation within regions.

It follows from equation (A2) that a linear approximation to equilibrium prices takes the form provided in equation (7). The role of competitor costs is notable. To develop this further, consider a simplified equation:

$$p_j = \rho_{jj}^F c_j + \sum_{k \neq j} \rho_{jk}^F c_k + \epsilon_j, \quad (\text{A4})$$

where we have allowed the error term to absorb all demand-side considerations. The population parameters are given by equation (A2) in the general case, or by equation (A3) in the specific numerical example. Suppose that the econometrician ignores competitor costs in the regression, that is, that the equation taken to the data is

$$p_j = \alpha_j c_j + \epsilon_j^*, \quad (\text{A5})$$

where  $\epsilon_j^* = \epsilon_j + \sum_{k \neq j} \rho_{jk}^F c_k$ . The regression coefficients  $\hat{\alpha}_j$  are unbiased estimates of firm-specific pass-through if marginal costs are uncorrelated across firms, unbiased estimates of market pass-through if costs are perfectly correlated, and biased estimates of both firm-specific and market-wide pass-through if costs are imperfectly correlated.<sup>29</sup>

Our application most closely resembles the second case. To see this, consider two regressors constructed according to equation (10): *Fuel Costs × Proximity of Rival Capacity*, which enters multiplied by the parameter  $\alpha_i$  and also appears in the main regression model; and *Rival Fuel Costs × Proximity of Rival Capacity*, which enters multiplied by the parameter  $\beta$  but does not appear in the main regression model. The correlation coefficient between these two regressors is 0.995. Although cost heterogeneity exists at the plant level, there are too few plants having out-of-region competitors with different costs to create useful variation at the region level. With that level of correlation, a regression that excludes competitor costs obtains unbiased estimates of market pass-through.

Table A1 summarizes the results from a regression that includes both interactive regressors. The specification in the first column includes plant fixed effects and is analogous to column (viii) in the main regression table. The median market pass-through rate is quite similar to that from the main results (1.61 versus 1.65). The second column omits plant fixed effects and is analogous to column (iv) in the main results table. The median market pass-through rate is again similar (1.33 versus 1.37). This latter regression also resembles the regressions that appeared in the working drafts of this article. The standard errors for the interactive variables in this Appendix table are understated due to biases that arise with collinearity (e.g., Mela and Kopalle, 2002). Still, these results confirm that excluding competitor costs from the main regressions does not distort market pass-through estimates.

## References

- ARGARWAL, S., CHOMSISENGPHET, S., MAHONEY, N., AND STROEBEL, J. “A Simple Framework for Estimating Consumer Benefits from Regulating Hidden Fees.” *Journal of Legal Studies*, Vol. 43(S2) (2014), pp. S239–S252.
- ATKIN, D. AND DONALDSON, D. “Who’s Getting Globalized? The Size and Nature of Intranational Trade Costs.” 2015.
- BARZEL, Y. “An Alternative Approach to the Analysis of Taxation.” *Journal of Political Economy*, Vol. 84(6) (1976), pp. 1177–1197.

<sup>29</sup> The regression coefficients  $\hat{\alpha}_j$  are unbiased estimates of both firm-specific and market-wide pass-through in the special case that prices are neither strategic complements nor strategic substitutes, because then  $\rho_{jk}^F = 0 \quad \forall j \neq k$ .

- BESANKO, D., DUBE, J.-P., AND GUPTA, S. "Own-Brand and Cross-Brand Retail Pass-Through." *Marketing Science*, Vol. 1(1) (2005), pp. 123–137.
- BESLEY, T.J. AND ROSEN, H. "Sales Taxes and Prices: An Empirical Analysis." *National Tax Journal*, Vol. 52(2) (1998), pp. 157–178.
- BORENSTEIN, S., CAMERON, C., AND GILBERT, R. "Do Gasoline Prices Respond Asymmetrically to Crude Oil Price Changes?" *Quarterly Journal of Economics*, Vol. 112(1) (1997), pp. 305–339.
- BOVENBERG, A.L., GOULDER, L., AND GURNEY, D.J. "Neutralizing the Adverse Industry Impact of CO<sub>2</sub> Abatement Policies: What Does It Cost?" In C. Carraro and G. Metcalf, eds., *Behavioral and Distributional Effects of Environmental Policy*. Chicago: University of Chicago Press, 2001.
- BOVENBERG, A.L., GOULDER, L.H., AND JACOBSEN, M.R. "Cost of Alternative Environmental Policy Instruments in the Presence of Industry Compensation Requirements." *Journal of Public Economics*, Vol. 92 (2008), pp. 1236–1253.
- BUCHANON, J.M. "External Diseconomies, Corrective Taxes, and Market Structure." *American Economic Review*, Vol. 59(1) (1969), pp. 174–177.
- BULOW, J.I., GEANAKOPOLOS, J.D., AND KLEMPERER, P.D. "Multimarket Oligopoly: Strategic Substitutes and Complements." *Journal of Political Economy*, Vol. 93(3) (1985), pp. 488–511.
- BULOW, J.I. AND PFLIEDERER, P. "A Note on the Effect of Cost Changes on Prices." *Journal of Political Economy*, Vol. 91(1) (1983), pp. 182–185.
- BURTRAW, D. AND PALMER, K. "Compensation Rules for Climate Policy in the Electricity Sector." *Journal of Policy Analysis and Management*, Vol. 27(4) (2008), pp. 819–847.
- CABRAL, M., GERUSO, M., AND MAHONEY, N. "Does Privatized Health Insurance Benefit Patients or Producers? Evidence from Medicare Advantage." Working Paper, 2015. [https://papers.ssrn.com/sol3/papers.cfm?abstract\\_id=2489999](https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2489999)
- CAMPA, J.M. AND GOLDBERG, L.S. "Exchange Rate Pass-through into Import Prices." *Review of Economics and Statistics*, Vol. 87(4) (2005), pp. 679–690.
- CAMPOS-VAZQUEZ, R.M. AND MEDINA-CORTINA, E.M. "Pass-through and Competition: The Impact of Soft Drink Taxes Using Mexican Supermarket Stores." 2016.
- CONLON, C.T. AND RAO, N.S. "Wholesale Prices, Retail Prices, and the Lumpy Pass-through of Alcohol Taxes." 2016.
- DEATON, A. AND MUELLBAUER, J. "An Almost Ideal Demand System." *The American Economic Review*, Vol. 70(3) (1980), pp. 312–326.
- DUGGAN, M., STARC, A., AND VABSON, B. "Who Benefits When the Government Pays More? Pass-through in the Medicare Advantage program." Working Paper, 2014.
- EPA. "Regulatory Impact Analysis: National Emission Standards for Hazardous Air Pollutants from the Portland Cement Manufacturing Industry." 2009.
- . "Regulatory Impact Analysis: Amendments to the National Emission Standards for Hazardous Air Pollutants (NESHAP) and New Source Performance Standards (NSPS) for the Portland Cement Manufacturing Industry." 2010.
- FABINGER, M. AND WEYL, E.G. "A Tractable Approach to Pass-through Patterns with Applications to International Trade." 2015.
- FABRA, N. AND REGUANT, M. "Pass-through of Emissions Costs in Electricity Markets." *American Economic Review*, Vol. 104(9) (2014), pp. 2872–2899.
- FOWLIE, M., REGUANT, M., AND RYAN, S.P. "Market-Based Emissions Regulation and Industry Dynamics." *Journal of Political Economy*, Vol. 124(1) (2016), pp. 249–302.
- GANAPATI, S., SHAPIRO, J.S., AND WALKER, R. "Energy Prices, Pass-through, and Incidence in U.S. Manufacturing." 2016.
- GENESOVE, D. AND MULLIN, W.P. "Testing Static Oligopoly Models: Conduct and Cost in the Sugar Industry, 1980–1914." *RAND Journal of Economics*, Vol. 29(2) (1998), pp. 355–377.
- GOPINATH, G., GOURINCHAS, P.-O., HSIEH, C.-T., AND LI, N. "International Prices, Costs, and Markup Differences." *American Economic Review*, Vol. 101 (2011), pp. 1–40.
- GOULDER, L.H. "Markets for Pollution Allowances: What Are the (New) Lessons?" *Journal of Economic Perspectives*, Vol. 27(1) (2013), pp. 87–102.
- HEPBURN, C., QUAH, J.K.-H., AND RITZ, R.A. "Emissions Trading with Profit Neutral Permit Allocations." *Journal of Public Economics*, Vol. 98 (2013), pp. 85–99.
- JAFFE, S. AND WEYL, E.G. "The First Order Approach to Merger Analysis." *American Economic Journal: Microeconomics*, Vol. 5(4) (2013), pp. 188–218.
- JANS, I. AND ROSENBAUM, D. "Multimarket Contact and Pricing: Evidence from the U.S. Cement Industry." *International Journal of Industrial Organization*, Vol. 15 (1997), pp. 391–412.
- KIMMEL, S. "Effects of Cost Changes on Oligopolists' Profits." *Journal of Industrial Economics*, Vol. 40 (1992), pp. 441–449.
- KREMER, M. AND SNYDER, C.M. "Preventives versus Treatments." *Quarterly Journal of Economics*, Vol. 130(3) (2015), pp. 1167–1239.
- LANGER, A. AND MILLER, N.H. "Automakers' Short-Run Responses to Changing Gasoline Prices." *Review of Economics and Statistics*, Vol. 95(4) (2013), pp. 1198–1211.
- MACKAY, A., MILLER, N.H., REMER, M., AND SHEU, G. "Bias in Reduced-Form Estimates of Pass-through." *Economics Letters*, Vol. 123(2) (2014), pp. 200–202.

- MARION, J. AND MUEHLEGGGER, E. "Fuel Tax Incidence and Supply Conditions." *Journal of Public Economics*, Vol. 95 (2011), pp. 1202–1212.
- MELA, C.F. AND KOPALLE, P.K. "The Impact of Collinearity on Regression Analysis: The Asymmetric Effect of Negative and Positive Correlations." *Applied Economics*, Vol. 34 (2002), pp. 667–677.
- MILLER, N.H. AND OSBORNE, M. "Spatial Differentiation and Price Discrimination in the Cement Industry: Evidence from a Structural Model." *RAND Journal of Economics*, Vol. 45(2) (2014), pp. 221–247.
- MILLER, N.H., REMER, M., RYAN, C., AND SHEU, G. "Pass-through and the Price Effects of Mergers." *Journal of Industrial Economics*, (forthcoming).
- NAKAMURA, E. AND ZEROM, D. "Accounting for Incomplete Pass-through." *Review of Economic Studies*, Vol. 77(3) (2010), pp. 1192–1230.
- PINSKE, J., SLADE, M.E., AND BRETT, C. "Spatial Price Competition: A Semiparametric Approach." *Econometrica*, Vol. 70(3) (2002), pp. 1111–1153.
- POTERBA, J.M. "Retail Price Reactions to Changes in State and Local Sales Taxes." *National Tax Journal*, Vol. 49(2) (1996), pp. 165–176.
- ROTHSCHILD, K.W. "The Degree of Monopoly." *Economica*, Vol. 9 (1942), pp. 24–39.
- RYAN, S. "The Costs of Environmental Regulation in a Concentrated Industry." *Econometrica*, Vol. 80(3) (2012), pp. 1019–1062.
- SHAPIRO, C. "Mergers with Differentiated Products." *Antitrust*, Vol. 10(2) (1996), pp. 23–30.
- SMITH, A.E., ROSS, M.E., AND MONTGOMERY, W.D. "Implications of Trading Implementation Design for Equity-Efficiency Tradeoffs in Carbon Permit Allocations." 2002.
- STOLPER, S. "Who Bears the Burden of Energy Taxes? The Critical Role of Pass-through." 2016.
- SYVERSON, C. AND HORTAÇSU, A. "Cementing Relationships: Vertical Integration, Foreclosure, Productivity, and Prices." *Journal of Political Economy*, Vol. 115 (2007), pp. 250–301.
- TEN KATE, A. AND NIELS, G. "To What Extent are Cost Savings Passed on to Consumers? An Oligopoly Approach." *European Journal of Law and Economics*, Vol. 20 (2005), pp. 323–337.
- VAN OSS, H.G. AND PADOVANI, A. "Cement Manufacture and the Environment, Part II: Environmental Challenges and Opportunities." *Journal of Industrial Ecology*, Vol. 7(1) (2003), pp. 93–126.
- WEYL, E.G. AND FABINGER, M. "Pass-through as an Economic Tool." *Journal of Political Economy*, Vol. 121(2) (2013), pp. 528–583.
- Working Group on Social Cost of Carbon. "Technical Support Document: Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis under Executive Order 12866." Technical Report, United States Government, 2013.
- ZIMMERMAN, P.R. AND CARLSON, J.A. "Competition and Cost Pass-through in Differentiated Oligopolies." MPRA Paper no. 25931, 2010.