Rethinking Trade Exposure: The Incidence of Environmental Charges in the Nitrogenous Fertilizer Industry

James Bushnell, Jacob Humber

Abstract: The imposition of environmental regulations to domestic manufacturing traditionally creates concerns over the impacts of those regulations on international competition and downstream product prices. The US nitrogen fertilizer industry has been considered by conventional metrics to be one of the most vulnerable to such effects. Since 2010 the industry has undergone increased concentration of producers and a dramatic reduction in natural gas prices. Our research establishes that the pass-through of changes in prices to domestic natural gas declined from 80% prior to 2010 to effectively zero through 2014. One implication of this change in pricing dynamics is that the imposition of greenhouse gas (GHG) regulations on producers of nitrogen fertilizers would have little impact on fertilizer prices. Within the context of a GHG cap-and-trade program, the allocation of emissions allowances would likely result in a transfer to fertilizer producers on the order of hundreds of millions of dollars with no impact on fertilizer prices, emissions, or quantity consumed.

JEL Codes: H23, Q17, Q52

Keywords: Cap and trade, Incidence of regulation, Trade exposure

THE TRADE IMPACTS of local environmental regulations have long been of concern and interest. These concerns are closely related to those of jurisdictional limits.[1] When emissions charges do not "reach" all relevant sources, as with charges related to greenhouse gasses, then the leakage of emissions to unregulated jurisdictions not only causes economic harm but can dilute, perhaps substantially, the benefits of the regulation. Policy concerns with the trade impacts of regulations revolve around three re-

James Bushnell is at the Department of Economics, University of California, Davis (jbbushnell@ucdavis.edu). Jacob Humber is at the Department of Agricultural and Resource Economics, University of California, Davis (humber@primal.ucdavis.edu). This work was supported by the National Institute of Food and Agriculture, US Department of Agriculture, under Agreement no. 2012-67023-30236.

1. Bushnell, Peterman, and Wolfram (2008), Fowlie (2009), Fischer and Fox (2012).

Received September 28, 2015; Accepted March 22, 2017; Published online July 19, 2017.

JAERE, volume 4, number 3. 2333-5955/2017/0403-0006$10.00 http://dx.doi.org/10.1086/692506

lated but distinct perspectives. From an environmental perspective, the concern stems from the prospect of emissions leakage, where emissions-intensive industries relocate to unregulated areas but maintain their output levels and emissions. To the extent the damages from those emissions are still felt locally (as with greenhouse gasses) leakage is a serious environmental concern. From a macro-economic perspective, the concern is that leakage can lead to a loss in economic activity and employment, as well as limit the environmental gains of a regulation. Finally, local firms most directly affected by environmental regulations also fear that trade exposure will erode profitability either by directly impacting sales or by raising input costs of firms downstream of regulated industries.

Such concerns have been a major issue in the adoption and design of cap-and-trade markets for greenhouse gasses. As carbon pricing has been adopted piecemeal by individual regions, countries, and US states, each jurisdiction has in turn had to confront the prospect of increased local carbon costs affecting trade flows. Each jurisdiction has considered a similar set of policy tools, including allowance allocation and border tariffs, for addressing the problem. In addition to the question of how to protect vulnerable domestic industries, the other challenge has been to identify which industries merit such protection. Over the course of the last decade, a standard metric has evolved for classifying industries as energy intensive and trade exposed (EITE) and thereby deserving of special consideration. The specific metric varies by jurisdiction, but in each case they combine a measure of industry-level carbon intensity with a measure of "trade-share" (a ratio of trade flows over domestic consumption). While potential weaknesses with this metric have been identified (CARB, 2010, appendix K) it has nonetheless become a standardized approach whose application continues to expand.[2]

In this paper we study the question of trade exposure to environmental charges in the context of the nitrogenous fertilizer industry. Nitrogen-based fertilizers are a significant contributor to greenhouse gasses both upstream in its production and downstream in its application through the emissions of nitrous oxide (N_2O). This industry is one of the most carbon-intensive sectors to be covered under carbon-trading regimes in Europe and California, as well as the US national carbon-trading system proposed under the American Clean Energy and Security Act (ACES, HR 2454, also known as Waxman-Markey) legislation of 2009. As such the industry easily qualified for mitigating measures under standard EITE metrics applied or proposed in those cap-and-trade programs. Since the industry is also a source of a critical input for the agricultural sector, there has in addition been strong policy interest in the impact of these regulations on the costs of agricultural production (USDA 2009).

2. For example, Washington and Oregon are both initiating regulatory processes to cap carbon emissions in their states and have initially proposed adopting variants of the standard EITE measures.

During the last 10 years period, the US nitrogen industry has also undergone a substantial transformation. Domestic production of nitrogenous fertilizer had declined steadily through the early 2000s due largely to higher local costs of the key input, natural gas. With the onset of the fracking boom in natural gas during the latter part of the first decade of the 2000s, this situation stabilized and US producers found themselves instead with a growing production cost advantage relative to offshore sources. Within the United States, the industry also underwent a period of consolidation in the latter part of the first decade of the 2000s, culminating in a merger of two leading producers in 2010. As a result of the combination of cost advantages and a consolidation of the market structure, the industry has enjoyed particularly large margins since 2010. Despite the much-noted decline in the prices of domestic natural gas, fertilizer prices have remained high and more closely respond to international gas prices and demand-related drivers such as corn prices than to local cost drivers since 2010.

We focus much of our analysis on the potential incidence, or pass-through, of a hypothetical carbon charge to fertilizer prices. We examine the pass-through of prices of domestic natural gas, a key input to nitrogenous fertilizer, to fertilizer prices. As we demonstrate in this paper, the relationship between input costs and fertilizer prices fundamentally shifted around 2010. An industry that had been highly sensitive to input costs became much less so after 2010.

One implication of these changes to the industry is that the impacts of the proposed greenhouse gas regulation on trade flow and domestic prices would be extremely muted. This in turn implies that the abatement from reductions in production and consumption of fertilizers induced by such an emissions trading scheme would be minimal, particularly relative to what was assumed by policy analysis at the time HR 2454 was under consideration. Abatement resulting from emissions trading would thus be pushed into other sectors covered under a cap-and-trade scheme.

This finding highlights a sharp contrast to the fact that standard EITE measures continue to identify the industry as highly vulnerable and deserving of protective support. Our results imply that incentives that would be provided under EITE policies would be nearly completely unnecessary in terms of its stated goal of protecting local producers, while at the same time constituting a substantial windfall to those same producers. The results also starkly illustrate the shortcomings of the EITE measures, particularly its reliance on a static measure of trade shares.

1. ENVIRONMENTAL REGULATION AND TRADE EXPOSURE

There are several tools that have been proposed and implemented to attempt to mitigate the impacts of environmental regulations on trade (Frankel and Aldy 2008). One is the implementation of border tax adjustments (BTAs) that would place an environmental charge on goods as they enter the country. The border tax would level the playing field with importers and eliminate the incentive for local producers to relocate in order to avoid paying the fee. However, the most commonly invoked mechanism to address trade exposure has been the use of allowance allocation as an implicit subsidy for domestic production. Under output-based updating, each firm receives an allocation of emissions permits that is proportional to its total production. In the fertilizer context, for example, this means each firm receives an allocation that is proportional to the tons of product produced within the regulatory jurisdiction. The effects of output-based updating have been a subject of much research.[3] In general, it is believed that output-based updating is effective in mitigating leakage, as firms are rewarded (in the form of permits) for domestic production.

Output-based updating is also widely believed to result in lower product prices than alternative forms of allocation. While one strain of the academic literature has focused on the detrimental efficiency effects of such a price impact, it has an appeal to policy makers. Despite the political appeal of this product price effect, these "lower" prices can lead to inefficient overconsumption as the externality cost of the pollution is not adequately reflected in product prices.[4] Output-based allocation comes at considerable opportunity cost to public expenses, as allowance revenue that could otherwise be used as public funds is given freely to targeted industries. There has been considerable focus on the general equilibrium benefits from using the revenues from environmental regulations to offset existing tax distortions (see Goulder et al. 1999; Fullerton and Metcalf 2001), and it is important to recognize that any form of free allocation prevents the use of allowance revenues for more efficient purposes.

One paper that combines many of these considerations is Fowlie, Reguant, and Ryan (2016), which examines the prospective impacts of environmental charges on the cement industry. That industry is carbon intensive, subject to both local market power and in some places competition from overseas imports. Fowlie et al. demonstrate that for this industry, an output-based updating mechanism dominates a border tax, because the pro-competitive impacts of output-based updating outweigh any concerns over suppression of the external costs in retail prices.

While we address a similar question to Fowlie et al., we take a different methodological approach. Unlike cement or many other manufacturing industries, marginal cost in the nitrogen industry is dominated by a single input, natural gas. Where Fowlie et al. apply structurally estimated cost and market parameters to simulations of hypothetical emissions charges, we utilize the observed variation of a key input factor, natural gas, on fertilizer prices. While the more detailed picture of production costs allow Fowlie et al. to simulate the dynamic responses to regulations, we are less reliant upon functional form assumptions that can dictate the curvature of residual demand and play an important role in predicting the incidence of a hypothetical emissions charge. By using natural

3. See Jensen and Rasmussen (2000) and Fischer (2003, 2011).

4. See Palmer, Burtraw, and Kahn (2006) for a discussion of the various impacts of updating.

gas costs as a proxy for that environmental charge, we can directly estimate the impact of change in input costs from an environmental charge.[5]

1.1. Trade Exposure and the Nitrogen Industry

In this paper we focus on the greenhouse gas implications of nitrogen production and utilization. Significant greenhouse gasses are emitted in the production of ammonia and other nitrogenous fertilizers, but even larger amounts are attributed to the conversion of nitrogen fertilizer to nitrous oxide (N_2O), a potent greenhouse gas with a global warming potential of nearly 300 times that of carbon dioxide. Globally, the production and application of fertilizers are estimated to constitute 2.5% of annual greenhouse gas (GHG) emissions (International Fertilizer Association 2009). The US EPA estimates that fertilizer contributes about 1.5% of US annual GHG emissions, with about 10 million metric tons (MMT) CO_2e coming from ammonia production, another 15 MMT coming from other nitrogen-based industrial processes, and about 60 MMT CO_2e from N_2O emissions attributed to the application of synthetic fertilizer.[6] This is coming from an overall agricultural N consumption of just under 13 million nutrient-tons.

While fertilizer may not be the largest source of GHG emissions, it is one of the most carbon-intensive industries. The 2009 American Clean Energy and Security Act (HR 2454) would have established a GHG cap over a broad set of greenhouse gas sources, including the production of nitrogenous fertilizers. One of many controversial aspects of HR 2454 was its potential impact on the costs and competitiveness of GHG-intensive US industries. According to an interagency study that included the US EPA and Department of Energy, nitrogenous fertilizer manufacturing would have been the second most GHG intensive industry covered under the law, with both direct and indirect GHG costs amounting to 18.5% of 2007 revenues (US EPA, EIA, and Treasury 2009). In other words, this analysis implies that absent other provisions, and under full pass-through, a \$20/ton CO_2 price would have raised nitrogen fertilizer prices by nearly 20%.

In the highly sensitive environment in which HR 2454 was developed, the prospect of mitigating price impacts to key constituencies, such as the agricultural sector, was an important negotiating tool. One implication of the output-based allocation approach to mitigating leakage is that product prices will not rise with the costs of the GHG regulation. Indeed, a USDA analysis of HR 2454 (USDA 2009) emphasized the fact that

5. One shortcoming of our approach relative to Fowlie et al. is that the impact of any dynamic responses we can measure is limited to our sample, which lasts about 5 years after the decline of US natural gas prices.

6. "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990 to 2013." United States Environmental Protection Agency. April 2015. These figures include the N_2O emissions only attributed to synthetic fertilizers.

output-based allocation greatly mitigated any potential price increases of fertilizer. While the study estimated that "in the absence of EITE provisions, higher fertilizer costs could lead to an average annual increase in crop production expenses of $1.4 Billion," its primary estimate, which incorporates the EITE provisions, estimated an annual increase of less than $100 million (USDA 2009, 7). The ACES act, as well as similar EITE legislation within the European Union, Australia, and California does not, however, directly impact the agricultural sector. Emissions directly generated within this sector, either through nitrogen fertilizer application or other endeavors, are not covered under any of the iterations of the aforementioned EITE legislation.

The ACES legislation developed a framework for defining EITE industries that has also been adapted by several other jurisdictions around the world.[7] The metric combines dual thresholds for both trade exposure and energy (or carbon) intensity. Energy intensity is measured by dividing sector energy costs by sector revenues. Trade exposure is measured in slightly different ways in different jurisdictions, but in general divides a static measure of gross trade flow (value of imports + exports) by a measure of domestic consumption (e.g., value of shipments plus imports). Although critics such as Fowlie (2012) have noted the weakness of a static measure of trade flow, it continues to be the standard metric for defining trade-exposed industries. Although HR 2454 did not become law, variants of metric have been put into practice in the European Union, Australia, and California and have been proposed for carbon-pricing schemes in Washington and parts of Canada.[8]

The nitrogen fertilizer industry is consistently found to be highly energy intensive and trade exposed in all the jurisdictions listed above, including in the United States at the time HR 2454 was under consideration. Although we describe in this paper how the competitive position of the US industry has dramatically shifted since 2010, such a distinction is not captured by the standard EITE metric. Figure 1 depicts the status of the nitrogen industry in each year from 2006 to 2014. The industry's position in the trade exposure dimension does shift between 2006 and 2008 but remains well above the threshold for qualifying for EITE treatment. In the period 2008–16, trade exposure fluctuates and energy costs decline but again remain beyond the threshold levels defined in HR 2454.

1.2. Emissions Charges and Pass-Through

In section 3, we explore the hypothetical impacts of HR 2454 on fertilizer prices in the context of both pre- and post-2010 market conditions. As described above, this industry was identified as highly trade exposed by the metric proposed for HR 2454, as it

7. Fowlie (2012) describes both the policy process and welfare implications of the approach that was adopted.

8. Stavins, Borck, and Schatzki (2014), Canada Ecofiscal Commission (2015), and European Commission (2016).

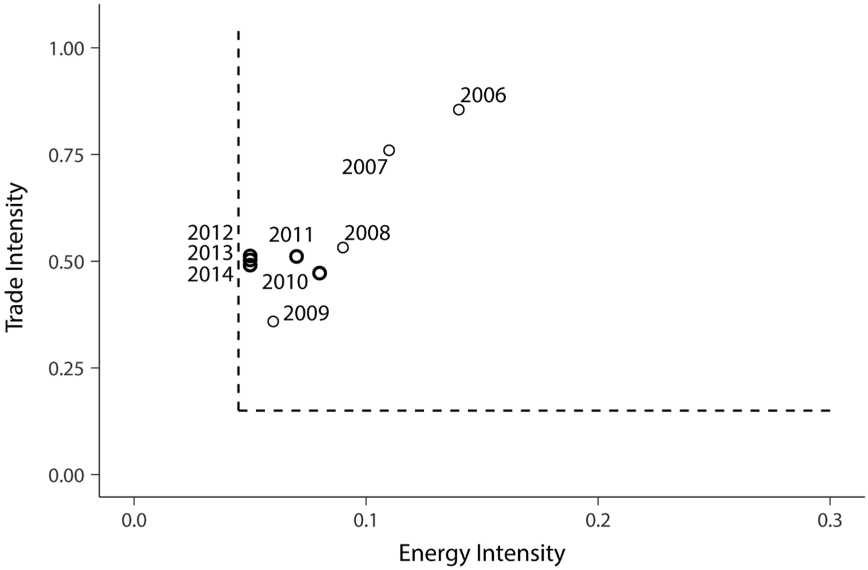

Figure 1. Energy intensity and trade exposure of the nitrogenous fertilizer industry. This figure depicts the energy intensity and trade exposure of the nitrogenous fertilizer industry as defined by HR 2454 using annual data from 2006 through 2014. The dashed lines represent the thresholds for qualifying for EITE treatment. Trade exposure is defined as the combined value of exports and imports divided by the value of domestic production and imports. Energy intensity is defined as energy expenditure divided by value of output.

would also be under similar metrics currently in use in other jurisdictions including Australia, Europe, and California. We contrast this EITE metric with an alternative measure of the impact of a hypothetical carbon charge, namely, the pass-through of input costs to wholesale fertilizer prices.

Pass-through of cost shocks has been an area of general interest to economists. The interactions of cost shocks and product prices can be quite complex and are largely dependent upon characteristics of the demand function.[9] Empirically, measures of pass-through of currency exchange rates have been used to diagnose market frictions (Goldberg and Hellerstein 2013) and assess the incidence of energy policies (Marion and Muehlegger 2011; Knittel, Meiselman, and Stock 2015).

The actual and potential pass-through of environmental charges is also an area of focus in the literature. In a closely related paper, Fabra and Reguant (2014) study the pass-through of European carbon prices in the electricity industry in Spain. They

9. Weyl and Fabinger (2013) derive a general framework for modeling the incidence of taxes under imperfect competition.

find allowance prices fully passed through to electricity prices and therefore electricity producers fully internalize the compliance cost. However, in many cases such as ours, the question of interest is the potential impact of a carbon price that has not yet been applied. Variation in other input costs has been used as a proxy for environmental costs in these cases. Miller, Osborne, and Sheu (2017) use variation in fuel costs to examine the incidence of market-based CO_2 regulations within the Portland cement industry. Cullen and Mansur (2014) use variation in natural gas prices to examine the impact of a hypothetical carbon price applied to the US electric sector. Ganapati, Shapiro, and Walker (2016) motivate their study of the incidence of energy prices on the manufacturing sector as predictive of the impacts of a US carbon price on that sector. Marion and Muehlegger (2011) find that the pass-through of both oil price shocks and of tax rates were statistically indistinguishable, providing support for the assumption that energy inputs are a useful proxy for a carbon price. Of course pass-through rates of either inputs or taxes can vary over time and with market structure, and we find that these rates did dramatically change for the fertilizer industry around 2010, implying the impacts of carbon prices would have dramatically changed during this period also.

2. THE NITROGENOUS FERTILIZER INDUSTRY

Nitrogenous fertilizers utilize nitrogen, one of three primary nutrients essential for plant growth. The foundational product in the industry is anhydrous ammonia (AA), the largest volume chemical produced from hydrocarbon feedstocks and a key intermediate product in the production of fertilizers such as urea and ammonium nitrate. Ammonia is also used in several industrial applications, but about 90% of global 2010 consumption went directly or indirectly to fertilizer applications (ChemSystems 2013). In the United States, fertilizer manufacturing overall generates roughly $30 billion in annual revenues and is closely linked to the agricultural sector. During the first decade of the 2000s the industry's growth followed that of the corn industry, which was in turn strongly influenced by biofuel policy and demand.

Outside of China, the key input to ammonia production is natural gas.[10] Natural gas costs comprise over 80% of production costs of AA (Kim et al. 2002). As most other costs are fixed, one would expect marginal costs to be dominated by natural gas prices. While natural gas is a key driver for the ammonia industry, the reverse is not necessarily the case. Only about one-third of natural gas is consumed by the industrial sector—the largest share is dedicated to electricity generation—and ammonia production constitutes about one-fourth of industrial sector demand. Ammonia is a globally traded product, but the costs of transporting it are considerable relative to the value of the product. As a volatile liquid chemical with applications in the manufacture of explosives as well as agricul-

10. Coal is the primary feedstock for ammonia in China, making Chinese ammonia more GHG intensive than that produced in most other regions of the world.

ture, both technical transport costs and regulatory barriers are high. WenYuan (2009) estimates that overseas transport from the Middle East or Black Sea regions represents 50% of the cost of ammonia shipped to the US Gulf coast. While nearly 40% of US ammonia consumption is met through imports (fig. 2), the vast majority of these imports come from either Canada or Trinidad and Tobago. The bulk of the remaining, modest share is met through imports from the Middle East, Russia, and Ukraine. Urea, an increasingly popular nitrogen fertilizer product that is derived from ammonia, is a more stable easily transported solid and is accordingly more widely traded on global markets.

During the early 2000s the US nitrogen industry suffered during periods of relatively high US natural gas prices, which peaked in 2006. High demand from a strong agricultural sector kept US producers marginally profitable, but there was a large shift of production to Trinidad and Tobago during the early 2000s. Importantly much of this investment was by the same firms. The large players in the industry maintained their dominance, but in a fashion that shifted production offshore to the Caribbean. The industry also went through a period of consolidation culminating in the merger of two of the largest producers, CF Industries and Terra Industries, in 2010.

These conditions have reversed since the onset of the US fracking boom in the natural gas industry. With US natural gas consumers enjoying relatively low prices on a

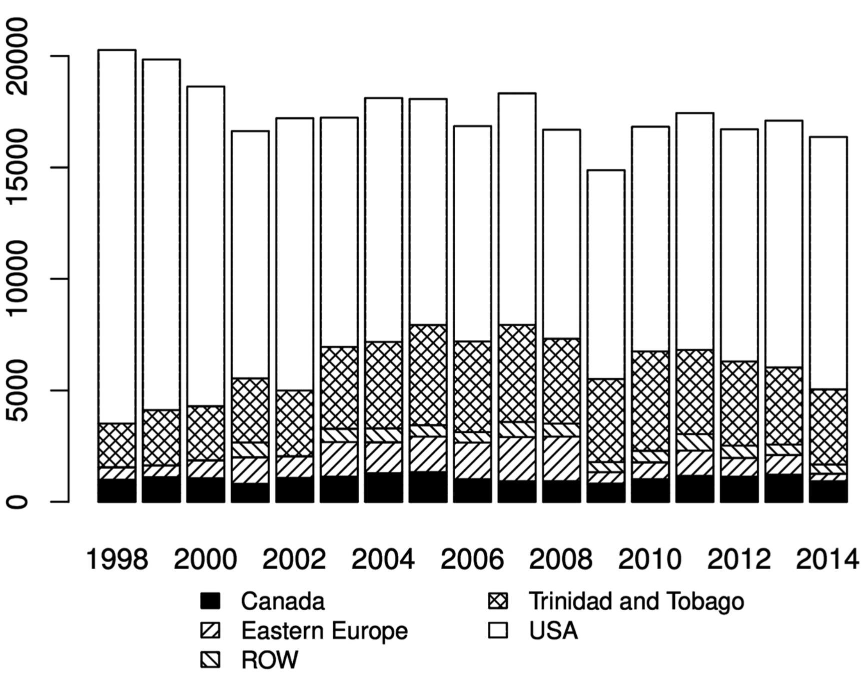

Figure 2. Sources of US consumption of ammonia

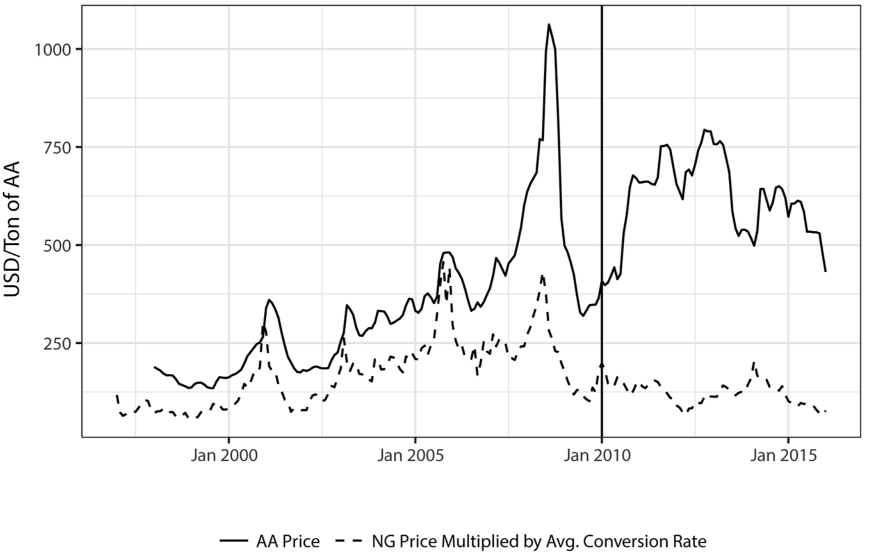

Figure 3. North American wholesale ammonia and natural gas prices. This figure depicts anhydrous ammonia prices as well as natural gas prices scaled by the industry level natural gas to anhydrous ammonia conversion rate of 34 MMBTU per ton of anhydrous ammonia. The vertical line represents January 2010, a point of time in which domestic natural gas and anhydrous ammonia prices decouple.

global scale, industries reliant on natural gas have enjoyed a growing cost advantage in global markets (Hausman and Kellogg 2015). Wholesale ammonia prices in North America did not decline nearly as dramatically as production costs. Figure 3 plots an approximate index of gas input costs against an index of the US wholesale ammonia price.[11] Prior to 2010 the most notable activity in market prices surrounds the period of the commodity boom from roughly 2006 to 2008. While overall margins grew during this period, this partly reflects a tightening of ammonia production capacity in the United States. After 2010, the separation between ammonia and domestic natural gas prices becomes pronounced as the decline in gas prices is to a large extent not passed through to wholesale ammonia. Overall, it is clear that domestic margins have grown dramatically since 2009. One implication of this is that domestic prices have become increasingly decoupled from domestic production costs, as we document below.

11. For this calculation we utilize an industry standard conversion rate of 34 MMBTU of natural gas per 1 ton of ammonia. Actual conversion rates at individual facilities vary somewhat but according to an International Fertilizer Association study, conversion rates fall within a range of 32–40 MMBTU/ton (IFA 2009).

3. DATA AND ANALYSIS

Our approach to examining the prospective impacts of upstream GHG-based charges on nitrogenous fertilizer production is to utilize variation in the key cost driver to nitrogen fertilizer production, natural gas, as a proxy for the impact of an environmental charge. As noted above, natural gas can account for 80% of the marginal cost of production of ammonia depending upon natural gas prices. As such, in a perfectly competitive market one would expect to see long-run pass-through rates in this range unless the industry were capacity constrained. Increases in horizontal concentration and therefore market power, which coincided with the fracking boom, can also be expected to lower pass-through rates.

We explore the pass-through of domestic natural gas prices to nitrogenous fertilizer prices using several specifications. In doing so we rely primarily on two price series, domestic natural gas spot prices and wholesale anhydrous ammonia prices.

3.1. The Anhydrous Ammonia Market

Wholesale prices of anhydrous ammonia are obtained from Green Markets, a third party data provider of nitrogen, potassium, and phosphorus fertilizer prices. Green Markets obtains all price data by surveying numerous buyers (retailers) and sellers (wholesalers) of various fertilizers. Prices are collected on a weekly basis and originate from within the United States as well as internationally. All prices within this analysis are aggregated to a monthly frequency by taking an unweighted average of weekly prices within a given month. A monthly periodicity of price data is chosen because it is the most amenable for examining both the short- and long-run pass-through relationship between natural gas and anhydrous ammonia prices. An annual periodicity would prevent the estimation of short-run pass-through and dramatically reduce the number of observations. In contrast, an analysis at a weekly periodicity is limited by the fact that fertilizer prices within our data set are relatively static from week to week. Additionally a weekly analysis would be computationally burdensome, requiring 52 lags to capture annual pass-through relationships.

Figure 4 depicts three anhydrous ammonia price series at major points within the international supply chain of anhydrous ammonia: the Black Sea port, the US Tampa port, and the US Corn Belt.[12] The price of the anhydrous ammonia at the port in the Black Sea reflects the price of fertilizer sold by Eastern European countries. Countries like Russia and the Ukraine are exporters of anhydrous ammonia and provide anhydrous ammonia and other nitrogenous fertilizers to Western Europe, China, India, and to a lesser extent the United States. The Tampa port within the United States, in contrast, represents a major point of entry of nitrogen fertilizer into the country. Finally, the US Corn Belt consumes the vast amount of anhydrous ammonia for agricultural purposes and therefore represents a major end-point user within the fertilizer supply chain.

12. The Corn Belt comprises Ohio, Indiana, Illinois, Iowa, Missouri, and Nebraska.

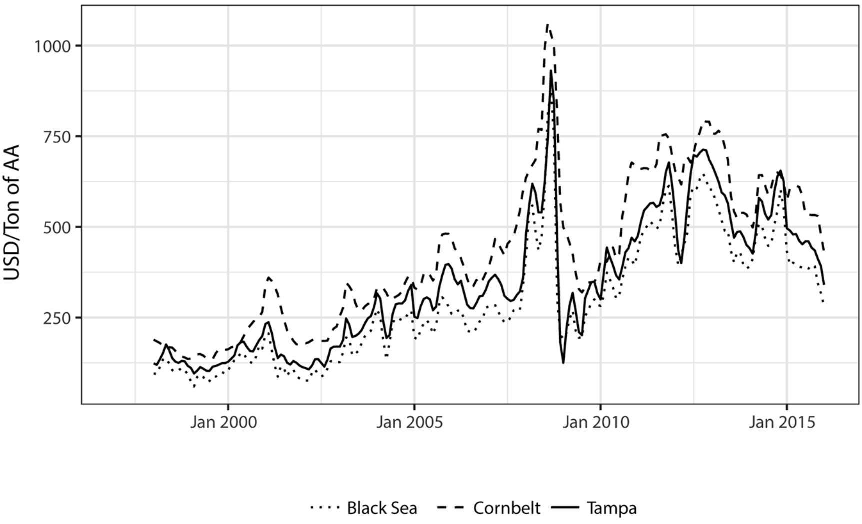

Figure 4. Prices of anhydrous ammonia in different markets

The tight co-movement of anhydrous ammonia prices in figure 4 suggests that the regional fertilizer markets are integrated and comprise a single global market. Tables A1, B1, and B2 in appendixes A and B corroborate this notion and find strong evidence of a long-run relationship between the various aforementioned anhydrous ammonia price series as all series are $I(1)$ and pairwise cointegrated. For the following analysis we utilize price quotes of anhydrous ammonia from the US Corn Belt. Not surprisingly, our results are robust to the use of other fertilizer prices.

Monthly natural gas prices are obtained from the Energy Information Administration and reflect the spot price of natural gas at the Henry Hub (HH).[13] Figure 3 depicts the relationship between the anhydrous ammonia prices as well as the natural gas prices scaled by the industry level natural gas to anhydrous ammonia conversion rate. Leading up until 2010, there is a strong relationship between natural gas and anhydrous ammonia prices. This relationship appears to decouple after 2010 and foreshadows our finding that after the fracking boom, the pass-through of domestic natural gas prices to anhydrous ammonia prices dramatically decreased.

Finally, the summary statistics of the two time series under consideration, natural gas and anhydrous ammonia prices are depicted in table 1. Given the potential structural break in the relationship between natural gas and anhydrous ammonia prices at the onset of the fracking boom we report summary statistics both before and after

13. The Henry Hub is a gas distribution hub in Louisiana where futures contracts for natural gas are priced. Appendix tables A1 and B1 depict that natural gas prices also follow a stochastic trend.

Table 1. Summary Statistics

Statistic	N	Mean	SD	Min	Max
Full sample:					
AA	217	430.130	208.938	135.000	1,062.500
NG	217	4.689	2.272	1.720	13.420
Before January 2010:					
AA	144	335.90	183.73	135.00	1,062.50
NG	144	5.23	2.56	1.72	13.42
After January 2010:					
AA	73	616.01	105.51	397.50	794.00
NG	73	3.63	.88	1.93	6.00

Note. This table depicts the summary statistics of anhydrous ammonia and natural gas prices. Specifically, these prices represent the price of anhydrous ammonia sold within the US Corn Belt and the price of natural gas sold at the Henry Hub. The units of measure for each are metric tons and 1 million British thermal units respectively. AA = anhydrous ammonia; NG = natural gas.

2010. Relative to the period of time leading up to 2010, natural gas prices decrease while anhydrous ammonia prices increase.

3.2. Pass-Through Regressions

Before analyzing a potential change in the domestic natural gas to anhydrous ammonia price pass-through rate, we first analyze pass-through rates for the entire sample, January 1998 until January 2016. The literature on pass-through utilizes numerous pass-through estimators. The most common one is the distributed lag specification adopted within Goldberg and Campa (2010), Gopinath and Itskhoki (2010), Nakamura and Zerom (2010), and Knittel et al. (2015) and is specified below.

$$\Delta \log(AA_t) = \alpha + \sum_{l=0}^{L} \beta_l \Delta \log(HH_{t-l}) + \sum_{j=1}^{3} \rho_j S_j + \epsilon_t \,. \tag{1}$$

Above, AA_t represents nitrogen fertilizer prices. The cost measure, HH_t, is represented by natural gas prices at the Henry Hub. Seasonal fixed effects, S_j are also included within the pass-through equation. The pass-through rate is therefore calculated as $\beta_{PT} = \sum_{l=1}^{L} \beta_l$.

Utilizing monthly data, we estimate the short-, medium-, and long-term pass-through rates that correspond to $L = 3, 6, 12$ in table 2. The results from the log-log specification can be directly interpreted as percentage changes.[14] For example, in table 2 when

14. It is not the goal of this paper to estimate the best model of anhydrous ammonia prices and therefore we do not utilize traditional lag selection techniques. Such techniques seek to obtain a model that balances goodness of fit and the number of model parameters. In the current context, obtaining such a balance is not desirable. Specifically, it is possible that a given lag se-

Table 2. Pass-Through Rates in Logs: HH on AA

	L = 3	L = 6	L = 12
HH	.5***	.6***	.68***
	(.33, .67)	(.38, .83)	(.42, .93)
Adjusted R^2	.26	.28	.28
N	217	217	217

Note. This table reports parameter estimates and 95% confidence intervals for the pass-through rate of natural gas to anhydrous ammonia prices. The sample size is 217 and reflects the entire sample, spanning from January 1998 until January 2016. The table reports pass-through estimates for lag lengths of 3, 6, and 12 months. All specifications include season fixed effects. Standard errors are obtained with the Newey-West estimator; the lag length for this estimator is selected in accordance with Newey and West (1994). A log transformation is applied to all price series within the pass-through specification. HH = Henry Hub; AA = anhydrous ammonia.

* $p \leq .1$.

** $p \leq .05$.

*** $p \leq .01$.

$L = 12$, a 1% change in natural gas prices elicits a .68% change in anhydrous price. The succeeding analysis presents evidence that a break occurs between anhydrous ammonia and natural gas prices around 2010 and therefore the pass-through rates in table 2 represent a data weighted average of two very different natural gas to anhydrous ammonia pass-through rates, that is, pass-through rates before and after 2010. With this in mind, the interpretation of pass-through rates in the context of an environmental charge is reserved for section 3.4.

The aforementioned pass-through specification can also be estimated in levels. It is worth discussing the difference between the log-log and levels specification. Specifically, the log-log specification represents a pass-through elasticity whereas the level-specification can be interpreted as a dollar-to-dollar pass-through rate. One concern for the log-log specification is that if total marginal costs are not accounted for, the pass-through will be incomplete, as discussed in Gopinath and Itskhoki (2010). In the current context, however, this concern is assuaged by the fact that natural gas prices comprise the vast majority of the marginal cost of production. In appendix B, we estimate a levels specification and confirm that it is qualitatively similar to the log-log specification.

3.3. Structural Break

Our assertion hypothesis throughout this paper is that as US and world natural gas prices decoupled and the US industry became more concentrated, US fertilizer prices

lection technique will preclude the inclusion of additional lags which do not substantially improve model fit but do impact pass-through rates.

became less responsive to US natural gas prices. To test this hypothesis we test the pass-through regressions in section 3.2 for a structural break in the natural gas to anhydrous pass-through relationship. In doing so, we treat the structural break as unknown and estimate the most likely break in the data spanning our sample, January 1998 until January 2016. This allows us to find the most likely date at which the natural gas to anhydrous ammonia pass-through relationship changed. In section 3.4 we utilize the findings from this test to choose the correct date to partition our pass-through regressions and analyze pass-through rates before and after the identified structural break. Additionally, treating the break as unknown allows us to confirm that the structural break did coincide with industry changes such as the fracking boom and the increased concentration of producers.

We test for the presence of a single unknown partial structural break in which only the pass-through parameters are allowed to vary over time,

$$\begin{aligned}\Delta \log(AA_t) = \alpha + \sum_{l=0}^{L}\beta_l \Delta \log(HH_{t-l}) \\ + \sum_{l=0}^{L}\phi_l I(t \geq T)\Delta \log(HH_{t-l}) + \sum_{j=1}^{3}\rho_j S_j + \epsilon_t,\end{aligned} \tag{2}$$

where $I(\cdot)$ represents an indicator function that takes on a zero before the structural break, T, and a one otherwise. To estimate T we follow the testing procedure proposed by Andrews (1993). First we roll a Wald statistic over the data. In doing so we utilize the Newey-West estimator to accommodate the presence of serial correlation within the specification. We also trim the first and last 15% of the sample, removing it from testing. Such a trimming is common across the structural break literature and is shown to perform well (Bai and Perron 2006), especially in the context of serial correlation. Next, the supremum of the set of Wald statistics generated in the previous step is compared to critical values derived by Andrews (1993) and later updated by Andrews (2003) and if statistically significant the corresponding T is selected as the most likely break.

Tables 3 and 4 present both the maximum Wald statistic utilizing Andrews's (2003) critical values for the pass-through model estimated in both logs and levels. The estimated break points across the log-log and levels specifications mirror one another. Additionally, the results support our expectation that events such as the fracking boom and increased industry concentration coincided with the structural break in the natural gas to anhydrous ammonia pass-through rate.

3.4. Partitioning of Pass-Through Regressions

Given the evidence of a structural break within the natural gas to anhydrous ammonia pass-through rate, we now estimate the log-log pass-through specification before and after January 2010. The date of January 2010 roughly represents a mid-point between all the identified break points in table 3 and is chosen to ensure that all pass-through

Table 3. Date of Structural Break for Log-Log Specification: HH and AA

	L = 3	L = 6	L = 12
Test statistic	43.68***	73.56***	1805.69***
Date	October 2009	February 2010	September 2010

Note. This table reports the test statistics derived from performing a test of an unknown structural break in the pass-through rate of natural gas to anhydrous ammonia prices. The testing procedure implemented is proposed by Andrews (1993). Critical values are obtained from Andrews (2003). The long-run variance utilized within this testing procedure is obtained with the Newey-West estimator. The test is performed for the pass-through specification with 3, 6, and 12 lags. A log transformation is applied to both anhydrous ammonia and natural gas prices within the pass-through specification. HH = Henry Hub; AA = anhydrous ammonia.

* $p \leq .1$.

** $p \leq .05$.

*** $p \leq .01$.

specifications are estimated on the same sample and therefore are directly comparable. The results for the distributed lag approach in logs are presented in table 5. The table reveals that pass-through rates of natural gas to anhydrous ammonia before and after January 2010 differ substantially. After January 2010 the pass-through rate of natural gas to anhydrous ammonia is both smaller and statistically insignificant. Insofar as these pass-through rates represent a proxy of an environmental charge, this implies that the efficacy of such a charge would not pass through downstream after 2010, and consequently it is not necessary that this industry receive allowances in accordance with output-based updating. The results for the levels pass-through specification generate qualitatively similar results which are reported in appendix B.

3.5. Robustness

In this section we check the robustness of our pass-through results to different specifications. We begin by exploring potential covariates that may explain anhydrous am-

Table 4. Date of Structural Break for Levels Specification: HH and AA

	L = 3	L = 6	L = 12
Test statistic	15.54***	47.71***	1811.27***
Date	October 2009	January 2010	May 2010

Note. This table reports the test statistics derived from performing a test of an unknown structural break in the pass-through rate of natural gas to anhydrous ammonia prices. The testing procedure implemented is proposed by Andrews (1993). Critical values are obtained from Andrews (2003). The long-run variance utilized within this testing procedure is obtained with the Newey-West estimator. The test is performed for the pass-through specification with 3, 6, and 12 lags. Both the anhydrous ammonia and natural gas prices enter the pass-through specification in levels. HH = Henry Hub; AA = anhydrous ammonia.

* $p \leq .1$.

** $p \leq .05$.

*** $p \leq .01$.

Table 5. Pass-Through Rates in Logs Before and After 2010: HH on AA

	L = 3		L = 6		L = 12	
	Pre-2010	Post-2010	Pre-2010	Post-2010	Pre-2010	Post-2010
HH	.63***	.11	.77***	−.01	.81***	−.06
	(.47, .79)	(−.12, .34)	(.55, .98)	(−.43, .42)	(.62, 1.01)	(−.84, .71)
Adjusted R^2	.45	.03	.48	.03	.47	−.14
N	144	73	144	73	144	73

Note. This table reports parameter estimates and 95% confidence intervals for the pass-through rate of natural gas to anhydrous ammonia prices. The table contains pass-through estimates before and after January 2010. The table reports pass-through estimates for lag lengths of 3, 6, and 12 months. All specifications include season fixed effects. Standard errors are obtained with the Newey-West estimator; the lag length for this estimator is selected in accordance with Newey and West (1994). A log transformation is applied to all price series within the pass-through specification. HH = Henry Hub; AA = anhydrous ammonia.

* $p \leq .1$.

** $p \leq .05$.

*** $p \leq .01$.

monia prices. In particular we examine the implications of including international natural gas prices as well as the price of corn within the pass-through specifications. Figure 5 depicts both of these price series alongside anhydrous ammonia prices as well as US natural gas prices.

It is plausible that international natural gas prices and not US natural gas prices are the key driver of anhydrous ammonia prices before and after January 2010. To test this proposition we use front month future contracts of natural gas traded on the Intercontinental Exchange (ICE) based in the United Kingdom to represent the international natural gas price. Figure 5 depicts both the Henry Hub and ICE price and shows that starting in 2010 HH natural gas prices diverged from ICE natural gas prices.

It is important to remember that the main exporters of anhydrous ammonia include countries within the Eastern European and Near East regions. The natural gas companies within these regions are both highly concentrated and in some cases vertically integrated with fertilizer producers. As a result of this, the ICE natural gas price likely represents an upper bound on the natural gas price that fertilizer producers face within these regions. That said, the ICE price series is a reasonable proxy for natural gas prices within these regions insofar as it represents the opportunity cost of selling natural gas to Western Europe.

Table 6 depicts both the short- and medium-run pass-through rates of Henry Hub and Intercontinental Exchange natural gas prices to anhydrous ammonia prices.[15] The

15. Due to a small sample size after 2010 it is not feasible to estimate the long-run pass-through specifications, i.e., the specification with 12 lags.

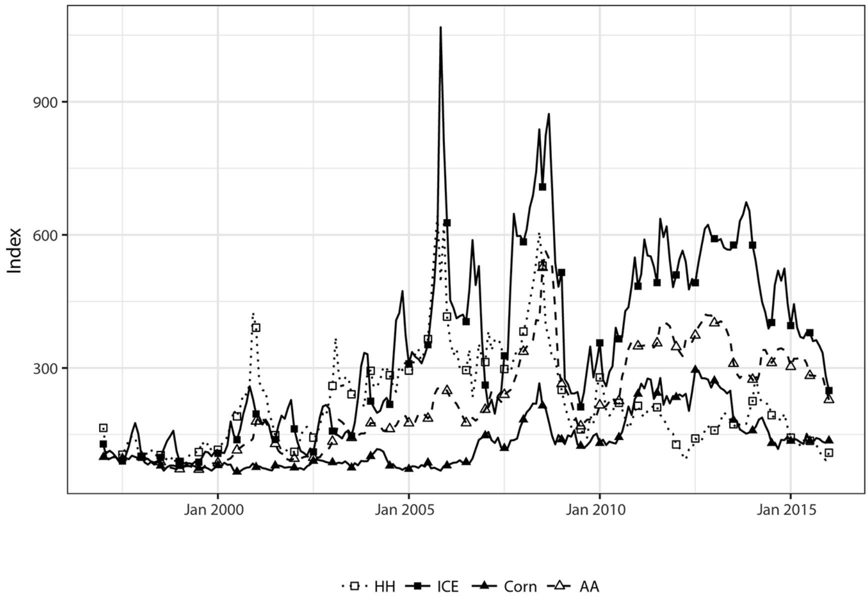

Figure 5. Price series for the robustness analysis. Prices for anhydrous ammonia (AA), nearby US corn futures, and natural gas at the Henry Hub (HH) and Intercontinental Exchange (ICE) span 1998 until 2015, where Janurary 1998 = 100.

reported estimates generate two noteworthy results. First, the pass-through rates of international natural gas prices to anhydrous ammonia prices are only statistically significant at the 10% level for the short-run pass-through after 2010. Despite this lack of statistical significance, the pass-through rates after 2010 are large in magnitude. These results suggest, first, that as ammonia prices decoupled from US gas prices, the pass-through of international gas prices remained and perhaps increased. In appendix C, we further explore the relationship between anhydrous ammonia and international natural gas prices and find evidence in line with these conclusions. Second, the magnitude of the pass-through from Henry Hub natural gas prices to anhydrous ammonia prices is similar to those results in table 5, which suggests that domestic natural gas prices represented the key cost driver of anhydrous ammonia prices before 2010, but not after that date.

Along with international natural gas prices, food prices also increased substantially at the onset of 2010. To explore the potential effects of these increases on anhydrous ammonia prices we include corn prices within our pass-through specifications. We select corn prices as an additional covariate in our model as corn is a nitrogen-intensive crop consuming 46% of all nitrogen fertilizer used for agricultural purposes within the United States in 2015. The corn spot price is represented by front month corn future

Table 6. Pass-Through Rates in Logs: HH and ICE on AA

	L = 3		L = 6	
	Pre-2010	Post-2010	Pre-2010	Post-2010
HH	.57***	.1	.66***	−.03
	(.46, .69)	(−.17, .37)	(.49, .83)	(−.48, .42)
ICE	.17	.37*	.2**	.49
	(−.04, .38)	(−.02, .76)	(.01, .4)	(−.1, 1.08)
Adjusted R^2	.47	.07	.49	.03
N	144	73	144	73

Note. This table reports parameter estimates and 95% confidence intervals for the pass-through rate of domestic natural gas and international natural gas to anhydrous ammonia prices. The table contains pass-through estimates before and after January 2010. The table reports pass-through estimates for lag lengths of 3 and 6 months. All specifications include season fixed effects. Standard errors are obtained with the Newey-West estimator; the lag length for this estimator is selected in accordance with Newey and West (1994). A log transformation is applied to all price series within the pass-through specification. HH = Henry Hub; ICE = Intercontinental Exchange; AA = anhydrous ammonia.

* $p \leq .1$.

** $p \leq .05$.

*** $p \leq .01$.

prices from the Chicago Board of Trade and therefore represents a proxy of the corn spot price. The estimation results after controlling for international and US natural gas prices as well as corn prices are presented in table 7. Interestingly, the pass-through rate of corn to anhydrous ammonia prices is both large and statistically significant after 2010. These findings are corroborated by Humber (2016), which focuses exclusively on modeling the change in the relationship between anhydrous ammonia prices and corn prices, US natural gas prices and international natural gas prices. As we will discuss in the following section, this finding is suggestive of two possible explanations: industry concentration and capacity constraints.

The validity of natural gas as a proxy for compliance cost is potentially hindered by the fact that natural gas prices have decreased since 2010; however, allowance prices would have increased, from zero, at the onset of a cap-and-trade system. To ensure that natural gas prices represent a reasonable proxy for allowance prices it is necessary that the response of anhydrous ammonia prices to increases and decreases of natural gas prices is symmetric. Table 8 generalizes the specification in table 7 to accommodate both positive and negative natural gas price shocks for the medium run pass-through specification, that is, the specification with six lags. Following the literature on asymmetric price transmission, Borenstein, Cameron, and Gilbert (1997), a positive increase in natural gas is defined as $\Delta HH_t^+ = \max\{0, \Delta HH_t\}$ and a negative increase is defined as $\Delta HH_t^- = \min\{0, \Delta HH_t\}$. Unfortunately a lack of observations after 2010 precludes the estimation of the positive and negative price changes within the same

Table 7. Pass-Through in Logs: HH, ICE, and Corn on AA

	L = 3		L = 6	
	Pre-2010	Post-2010	Pre-2010	Post-2010
HH	.55***	.01	.61***	.16
	(.44, .65)	(−.25, .26)	(.45, .77)	(−.18, .49)
ICE	.18**	.28	.22***	.14
	(.01, .34)	(−.07, .63)	(.04, .4)	(−.55, .83)
Corn	.15	.41**	.25	.64*
	(−.12, .41)	(.05, .77)	(−.11, .61)	(−.02, 1.29)
Adjusted R^2	.49	.24	.54	.17
N	144	73	144	73

Note. This table reports parameter estimates and 95% confidence intervals for the pass-through rate of domestic natural gas, international natural gas, and corn prices to anhydrous ammonia prices. The table contains pass-through estimates before and after January 2010. The table reports pass-through estimates for lag lengths of 3 and 6 months. All specifications include season fixed effects. Standard errors are obtained with the Newey-West estimator; the lag length for this estimator is selected in accordance with Newey and West (1994). A log transformation is applied to all price series within the pass-through specification. HH = Henry Hub; ICE = Intercontinental Exchange; AA = anhydrous ammonia.

* $p \leq .1$.

** $p \leq .05$.

*** $p \leq .01$.

model. Table 8 confirms that anhydrous ammonia prices respond to positive and negative change in natural gas prices in a similar manner before and after 2010. More importantly, table 8 corroborates the above finding that after 2010, the pass-through of natural gas prices to anhydrous ammonia prices is statistically insignificant.

3.6. Discussion

The analysis in the previous section documents that domestic ammonia prices have become largely decoupled from the marginal cost of production. An immediate corollary to this finding is that any tax that increases (at least modestly) the domestic marginal cost of production would have very little impact on domestic ammonia and fertilizer prices. It is worth considering the market conditions that might produce this result, as it helps to inform the contrast between this industry and others, such as the Portland cement industry, for which output-based updating is believed to be effective.

Two market conditions that would be consistent with a finding of limited pass-through are the presence of binding capacity constraints on domestic production and an increase in market power by domestic suppliers. In both cases, domestic prices would be set by higher cost imported ammonia. Our central question regarding the efficacy of an emissions charge and necessity for output-based allocation does not depend upon which of these two conditions is more reflective of the industry today. Further, it is im-

Table 8. Asymmetric Pass-Through in Logs: HH on AA

	L = 6		L = 6	
	Pre-2010	Pre-2010	Post-2010	Post-2010
Positive HH	.7***		.34	
	(.32, 1.09)		(−.25, 1)	
Negative HH		.87***		.14
		(.59, 1.15)		(−.53, .81)
ICE	.34***	.34***	.2	.12
	(.15, .52)	(0, .39)	(−.35, .75)	(−.82, 1.06)
Corn	.29	.29	.45	.75**
	(−.09, .67)	(−.03, .85)	(−.14, 1.04)	(.03, 1.47)
Adjusted R^2	.51	.48	.12	.17
N	144	144	73	73

Note. This specification only includes six lags. This table reports parameter estimates and 95% confidence intervals for the pass-through rate of both positive and negative natural gas price shocks to anhydrous ammonia prices. Additionally, the pass-through of international natural gas prices and corn prices to anhydrous ammonia prices is reported. The table contains pass-through estimates before and after January 2010. The table reports pass-through estimates for lag lengths of 6 months. All specifications include season fixed effects. Standard errors are obtained with the Newey-West estimator; the lag length for this estimator is selected in accordance with Newey and West (1994). A log transformation is applied to all price series within the pass-through specification. HH = Henry Hub; ICE = Intercontinental Exchange; AA = anhydrous ammonia.

* $p \leq .1$.
** $p \leq .05$.
*** $p \leq .01$.

portant to note that these two conditions are not mutually exclusive. When domestic production capacity is relatively tight, but not completely exhausted, relatively modest withholding of output can lead to sharp price increases, thereby enhancing the potential market power of producers with remaining slack capacity.

We have assembled estimates of country-level utilization rates from a collection of sources.[16] Table 9 summarizes the annual capacity and production of North American ammonia facilities, including Canada, Trinidad and Tobago, and the United States. Recall that all three of these markets feature many of the same producers, each with production in several countries. Utilization rates peaked during the commodity boom when US natural gas prices were near their highest historical levels. Since the fracking boom began in 2009, there is no discernible trend in utilization rates except in Trinidad

16. Canadian and Trinidad and Tobago production totals come from each country's energy statistics offices. Production for the United States comes from the Department of Commerce and the International Fertilizer Association. Production capacity values come from the International Fertilizer Development Association (IFDC), which collects data on production capacity worldwide.

Table 9. Ammonia Capacity and Utilization in the North American Region

	United States		Canada		Trinidad and Tobago		Total North America		
Year	Cap.	Prod.	Cap.	Prod.	Cap.	Prod.	Cap.	Prod.	Util.
2006	10,601	9,136	5,181	4,623	5,413	5,155	21,195	18,914	.892
2007	10,693	9,787	5,256	4,431	5,413	5,219	21,362	19,437	.910
2008	10,920	9,702	5,256	4,729	5,432	4,974	21,608	19,405	.898
2009	11,187	9,507	5,261	4,161	6,085	5,417	22,533	19,085	.847
2010	11,330	10,255	5,431	4,432	6,085	6,082	22,846	20,769	.909
2011	11,606	10,633	5,431	4,764	6,085	5,636	23,122	21,033	.910
2012	12,131	10,414	5,497	4,725	6,085	5,416	23,713	20,555	.867
2013	12,131	11,064	5,497	4,881	6,085	5,135	23,713	21,080	.889

Note. Capacity and production in metric tons.

and Tobago, where they have declined. While utilization has not grown dramatically within the United States, this is at least in part due to the expansion of capacity since 2010. A second source of information comes from the US EPA, which has reported the greenhouse gas emissions of major US stationary sources since 2010. Again we see no discernible trend in emissions, and under the assumption that emissions rates (which remain unregulated) remained constant, this implies that output has not dramatically increased at US facilities despite the significant cost advantages they enjoy.

These approximately measured utilization rates, approaching 90% of nameplate capacity, could easily imply full, or near full, utilization. On the other hand, the utilization rates are similar during a period of 2006–8 when, as demonstrated above, pass-through of natural gas prices was much more responsive.

One remaining question relevant to emissions charges and trade policy is the production response within the United States from changes in input costs. The evidence above demonstrates that product prices have decoupled from domestic natural gas prices but does not address the question of local production. To address this question directly we regress US nitrogen fertilizer production on domestic natural gas prices in table 10. Production data are relatively sparse and are only available on a quarterly basis from the Department of Commerce (DOC) prior to 2011 and from the International Fertilizer Association (IFA) after 2007. Given the data limitations, it is necessary that we combine these disparate data sets to ensure a single continuous time series of anhydrous ammonia production. This is not ideal; however, it is justified insofar as the two data sources contain similar production figures during the periods in which they overlap.[17]

17. The average ratio of production reported by the IFA to the production reported by the DOC is 1.012, suggesting that IFA production is 1% larger in the overlapping sample.

Table 10. Leakage Regression: Natural Gas Prices on Fertilizer Production

	Production of AA (1,000 MT)	
	Pre-2010	Post-2010
HH	−183.735***	26.028
	(28.104)	(38.078)
Constant	3,882.856***	2,565.819***
	(162.420)	(149.632)
Adjusted R^2	.470	−.031
N	48	19

Note. This table reports parameter estimates and standard errors for two regressions of quarterly anhydrous ammonia production regressed on quarterly natural gas prices, at the Henry Hub, both before and after January 2010. HH = Henry Hub; AA = anhydrous ammonia.

* $p \leq .1$.

** $p \leq .05$.

*** $p \leq .01$.

In table 10 we report the results of regressing natural gas price on DOC nitrogen fertilizer production data prior to 2010 and IFA nitrogen fertilizer production after 2010. Before 2010, a strong negative relationship existed between natural gas prices and anhydrous ammonia production, as is expected. In contrast, the coefficient estimates associated with natural gas prices are not statistically significant.[18] Given the limitations of the data, we do not place too much emphasis on the specific values, but these results do indicate that at least qualitatively the changes in price pass-through were also reflected in domestic production. These results therefore support the conclusion that output-based updating would have had little impact in the post-2010 period.

Taken together, tables 9 and 10 highlight related but distinct trends in the relationship between ammonia and domestic natural gas prices. While it is true that US output has expanded roughly 10% between 2006 and 2013, the short-term relationship between US gas prices and ammonia production is much less pronounced. Natural gas prices in the United States reached their nadir in 2012, when US ammonia production was only 3% higher than during the height of the commodity boom in 2007. While US output has climbed in recent years, so has the US natural gas price. This contributes to the findings in table 10 that domestic natural gas prices and ammonia output have decoupled post-2010. As we discuss in section 4, the fluctuations in domestic natural gas prices post-2010 have been in the range of what a carbon fee would have imposed, leading us to conclude that those fluctuations represent a decent proxy for the impact of a carbon fee.

18. When we generalize the specification to include a lag of natural gas prices similar results are obtained.

4. EVALUATION OF POLICY OPTIONS

The fact that the nitrogen fertilizer industry since 2010 has demonstrated very little pass-through of local cost shocks—either due to market power, capacity constraints, or both—has several implications for the efficacy of carbon pricing or other environmental charges. First, a carbon tax or cap-and-trade obligation such as proposed under HR 2454 would have minimal impact on domestic fertilizer prices. Second, our analysis indicates such a charge would also have had little impact on North American production, although at very high levels it could induce some shift of production within North America. Third, because the carbon costs would not have been passed through anyway, output-based updating would also have had almost no impact on downstream fertilizer prices.

In this section we calculate, roughly, the impact alternative regulatory approaches would have had on GHG emissions and ammonia consumption. We use the year 2012, for which all the needed data are available, as a benchmark year for this analysis. Taking the prevailing wholesale prices and quantities for ammonia, emissions intensity of both production and downstream use of ammonia, and values for the elasticity of demand for ammonia, we calculate the implied changes in prices, quantities, and emissions that would have prevailed under either with output-based updating, a border tax, or no adjustments for trade exposure. For this analysis we focus on ammonia, following the logic that ammonia is the key input to all downstream nitrogen-based fertilizers so that emissions associated with producing N fertilizers are ultimately sourced in the production of ammonia.

Data on ammonia and other fertilizer production quantities were taken from the International Fertilizer Association, which reports quarterly production, imports, and exports of various fertilizer products for most major producing countries. As described above, prices for ammonia come from Green Markets data.

There are multiple sources for the emissions of the ammonia or nitrogen industry, all of which measure slightly different things. For the direct emissions we follow Fowlie, Requant, and Ryan (2016) and use the European Union's value for emissions intensity that is used for their output-based allocations under Europe's carbon-trading program. In the EU allowances are allocated to the ammonia industry according to a benchmark emissions level of 1.619 tons CO_2e per metric ton of ammonia (or 1.47 per short ton).[19] This value is slightly higher than the 1.2 tons CO_2e per ton used by the EPA in their 2015 inventory of GHG emissions in the United States (US EPA 2015), but the US inventory value excludes emissions associated with fuel combustion and only includes chemical process emissions.

19. European Commission Decision of April 27, 2011, determining transitional Union-wide rules for harmonized free allocation of emission allowances pursuant to Article 10a of Directive 2003/87/EC of the European Parliament and of the Council. http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32011D0278&from=EN.

There are two additional types of indirect emissions to consider. The first is the emissions associated with electricity consumption at the production facilities and the second is the downstream emissions associated with both the production of derivative nitrogen fertilizer products and the emissions associated with the use of fertilizer in agriculture and urea in industrial applications. For the former we utilize the US Interagency Report, which attributed roughly 4% (or .06 tons CO_2/ton of ammonia) of emissions from the sector to the electricity consumed in production. For the latter we utilize the EPA Inventory, which assigns roughly 10 MMT of CO_2e to the production of nitrogen fertilizer derivatives, about another 5 to the industrial usage of urea, and 60 MMT to the agricultural land-use emissions stemming from synthetic fertilizers. This totals 75 MMT of total downstream emissions. To derive a downstream emissions rate, we need to divide total emissions by total consumption of 12.8 million nutrient-tons (USDA Economic Research Service), which includes both domestically produced and imported fertilizers (ammonia and urea). We then convert this back to units of ammonia tons by multiplying this (tons CO_2e/N) rate by 0.82, the nitrogen percentage of ammonia. The result is a downstream emissions rate of 4.81 tons CO_2e per ton of ammonia. All together we attribute 6.342 tons of CO_2e (1.47 upstream, .06 indirect electricity, and 4.81 downstream) to the production and consumption of 1 ton of ammonia.

As members of an emissions-intensive trade-exposed industry, US fertilizer manufacturers would have been eligible to receive allowances equal to 100% of the average emissions in their industry, adjusted for output levels. Therefore manufacturers would have, on average, received subsidies equivalent to 100% of their compliance cost through 2025. After 2025, the allocations were scheduled to phase out at a pace somewhat at the discretion of the president (US EIA, EPA, and Treasury 2009, 34). Therefore one can reasonably quantify the subsidy received in aggregate by the industry by taking its total emissions multiplied by the assumed allowance price.

A significant body of literature exists that estimates the own price elasticity of nitrogen fertilizer within the US agricultural sector. The majority of this research suggests that the own-price demand of elasticity is inelastic and ranges from −.2 to −.9 (see Burrell [1989] for a literature review as well as Denbaly and Vroomen [1993] and Hansen [2004] for more recent contributions). For this reason we examine elasticities ranging from −0.2 to −1.0 as these demand elasticities correspond roughly to the prevailing literature.

Table 11 summarizes our calculations for the ammonia industry. For three demand elasticity values (−0.2, −0.5, and −1) we also calculate the impact of emissions charges of $20 per ton. The impact of other carbon prices would be a multiple of those presented here, for example, all these values would be doubled for a carbon price of $40 per ton. The rows labeled “Post-2010” assume either output-based allocation and/or our estimated post-2010 pass-through rate. In either case, the impact on US prices would be effectively zero and the output-based allocation would not change anything with respect

Table 11. Impacts of Alternative Competitiveness Policies

			$20/ton CO_2		
	Δ Price	Allowance/Tax Value	Elas. −.2	Elas. −.5	Elas. −1
	Change in Consumption (1,000 Tons)				
Post-2010	.00	345	.00	.00	.00
AA border tax	30.63	0	−153.45	−383.63	−767.26
Lifecycle tax	126.83	0	−635.36	−1588.39	−3176.78
	Change in Emissions (MMT)				
Post-2010	.00	345	.00	.00	.00
AA border tax	30.63	0	−.97	−2.43	−4.87
Lifecycle tax	126.83	0	−4.03	−10.07	−20.15

Note. This table calculates the magnitude of price, quantity, and emissions changes from a $20 per ton carbon charge. The rows marked post-2010 assume full output-based updating and therefore no pass-through of carbon costs. The other rows assume a domestic and border charge applied to either the upstream or full upstream and downstream emissions associated with ammonia production and consumption. In both cases full pass-through of carbon charges is assumed. At $40 per ton of carbon, all of the values in this table would be doubled. AA = anhydrous ammonia.

to US prices. The allocation values we list are the estimated allocation to ammonia producers, but not to other downstream nitrogen producers. The rows labeled "Border tax" assume that both domestic and imported ammonia is charged a carbon price evaluated at 1.53 tons CO_2e per ton of AA. In other words AA is taxed at the combined direct and indirect emissions associated with its production. For the border tax scenario we assume that no allocations are made to the industry as their trade exposure is addressed via the border tax. Last, we consider a "lifecycle" border tax that would incorporate not just the production emissions but also the downstream emissions associated with ammonia production. In other words, the lifecycle tax would be an upstream charge, akin to a carbon tax on gasoline, on the emissions associated with ammonia usage as well as ammonia production. In the case of both border taxes we assume the near-complete pass-through experienced in the industry before the US gas market separated from the rest of the world in 2010.

As we have argued in previous sections, one implication of these calculations is that under current market conditions output-based allocation to ammonia producers would distribute between about $350 million to producers and have no effect on upstream or downstream production. Under the conditions that maintained prior to 2010, this allocation would have effectively shielded downstream consumers from emissions costs. However if a border tax were instead applied, shifting upward the residual demand faced by North American producers, then price increases on the order of $30 per metric ton (second column of table 11) would reduce downstream consumption, resulting in a reduction of 2 million tons of CO_2e (mostly in the form of N_2O emissions) if we assume an elasticity in the middle range of –0.5. Under the lifecycle tax, the full 6.3 tons of CO_2e per ton of ammonia would be charged to sellers of ammonia, raising prices by 15%–25% or hundreds of dollars per ton. We again assume this is applied to both domestic and imported ammonia and fully passed through to consumers.

Emissions leakage under each scenario would be minimal, by design. Both the output-based updating and the border taxes would insulate domestic producers from the competitive effects of carbon pricing. Even without updating, our earlier results imply little leakage, as long as the carbon charge were relatively modest. Using the above numbers, the marginal production cost impact of a \$20–\$40/ton CO_2e charge would be roughly equivalent to a \$1–\$2 MMBTU change in natural gas prices. Such variation is seen within our sample post-2010, with no discernible impact on domestic production levels. With a higher carbon price, or a charge of the magnitude of the lifecycle tax, it is quite possible that US producers, without a border adjustment would no longer be the low cost producers, resulting in pass-through and/or leakage.

5. CONCLUSIONS

In industries where input costs can be volatile both over time and geography, the estimation of trade exposure using domestic market shares can be particularly problematic. It is useful to consider the situation of three prominent energy-intensive and trade-exposed industries: cement manufacturing, petroleum refining, and nitrogenous fertilizer. All three of these industries receive output-based allocations of allowances in the EU and in California under their respective cap-and-trade programs and would have received comparable support under the American Climate and Energy Security Act.

While all are capital intensive industries, the dramatic changes in the market structure and input markets in the nitrogen industry provide an interesting contrast to the relatively stable cement industry. As we document in this paper, input costs have dramatically shifted the geographic competitive landscape in the nitrogen industry, but without a comparable transformation in either domestic production or of wholesale or retail prices. Given the highly capital intensive nature of the industry, it could be that we are in the process of a decades-long adjustment. However, it is also possible that the specter of more dramatic shifts in the geographic landscape of the industry can forestall a full adjustment to current input price conditions. Producers in the California gasoline market consistently enjoy higher local prices than neighboring states, yet the price disparities have not been sufficient to draw sufficient imports to equalize prices or expand local production enough to eliminate imports. Like the US nitrogen industry, California gasoline refining has grown increasingly concentrated, and it is not implausible that a degree of local market power is helping to maintain these conditions. In either case, we see in the nitrogen industry today a situation where domestic producers enjoy an extremely favorable competitive position but continue to import product at levels that conventional measures would label as "trade exposed."

The implications for environmental policy, particularly climate policy, are that input cost conditions, and likely market structure, need to be weighed carefully in assessing the trade exposure of an industry. Using domestic natural gas price variation as a proxy for an emissions charge, we find an extremely weak relationship between input cost shocks, product prices, and output in the industry after 2009. Unlike the conventional conclusion that output-based updating would be effective in both changing local producer behavior and in mitigating downstream price increases, we find that the regulation, with or without updating, would have almost no effect on the domestic nitrogen industry. We do not directly consider the opportunities for process abatement, so there could be some abatement from producers as a result of the incentives provided by a carbon price, even under output-based updating. Such an incentive would exist with or without updating, however, and in both cases the opportunities for effecting downstream emissions, which are more than three times larger than the production emissions, are lost. It is possible that these findings will not persist in the long run. Through either expansion in industry capacity or a return to what is considered to be "new normal" international gas prices, a regime akin to that which existed before 2010 may return. Such a transition, however, will likely be slow to materialize; in the 6 years succeeding the fracking boom such a transition has yet to occur within the industry. Therefore, even if a decades-long process erodes the current margins in US nitrogen markets, 10 years of allowance allocation would imply transfers on the order of $5 billion dollars to the industry before such an adjustment took root. Our findings therefore suggest that the commonly adopted EITE metrics may lack the ability to adequately regulate industries, such as the nitrogen fertilizer industry, in which uncertainty surrounds both input costs and market structure.

The merits of a border tax are more difficult to interpret. If US fertilizer prices are being artificially inflated by the market power of domestic producers, it is possible that this market power is already raising prices by more than would be justified by the environmental externalities. If the US market is instead capacity constrained, over time the dynamic inefficiencies identified by Fowlie et al. (2016) could play a role in limiting US capacity expansion. One last consideration is the global equilibrium effects of changes to the US agricultural industry. Research by Elobeid et al. (2013) indicates that a 10% increase in US fertilizer costs would result in shifts to global agricultural that, although reducing US N_2O emissions would produce a net increase of emissions globally.

With regard to output-based updating, however, our results indicate that there is almost no public purpose to currently awarding allowances to the US fertilizer industry if a national carbon price were applied to this industry. Like the petroleum industry in California, it appears that the nitrogen industry has been enjoying sizable and durable margins stemming from a combination of advantageous local production costs and relatively high transportation costs. Based on the response of these industries to input cost shocks, it appears that GHG regulation, and therefore any offsetting allowance allocation, would have little to no effect on their output levels or downstream product prices.

APPENDIX A

Time Series Analysis of the Anhydrous Ammonia Market

In this section we test for a pairwise cointegrating relationship between anhydrous ammonia prices at the Black Sea port, Tampa port, and within the US Corn Belt. This is accomplished by first testing for the presence of a stochastic trend in anhydrous ammonia prices. Tables A1 and B1 depict the results of an augmented Dickey Fuller (ADF) test (Dickey and Fuller 1979), and Zivot and Andrews (ZA) test (Zivot and Andrews 1992). Both tests suggest that the various anhydrous ammonia price series follow I(1) processes. The ZA test allows for the presence of an unknown structural break within a time series and is necessary insofar as the 2007–8 food price crisis and the 2010 fracking boom represent potential structural breaks. Table B2 reports the results of Johansen's cointegration test, Johansen (1991), for each pairwise combination of nitrogen fertilizer prices mentioned above. All price series are cointegrated. This fact suggests that these numerous fertilizer markets are linked within one global nitrogen fertilizer market.

Table A1. Augmented Dickey Fuller Test Statistics

	Log	Log Difference
AA: Corn Belt	−1.89	−6.96***
AA: Black Sea	−2.49	−11.51***
AA: Tampa	−2.95	−12.82***
NG	−2.36	−9.08***

Note. The Akaike information criterion is used for lag selection. Linear trends are included in within the test. AA = anhydrous ammonia; NG = natural gas.

* $p \leq .1$.

** $p \leq .05$.

*** $p \leq .01$.

APPENDIX B

Pass-Through Estimates in Levels

As a supplement to the log-log specification in table 2 we estimate equation (1) in levels and report the results in table B3. We normalize all results within table B3 by the industry-level conversion rate, 34 MMBTU of natural gas per ton of anhydrous ammonia. The results can therefore be interrupted as a dollar to dollar pass-through rate. These results imply a pass-through rate of greater than 100%, as a one dollar increase in natural gas prices is associated with a more than a one dollar increase in anhydrous ammonia prices. While theoretically possible, pass-through rates exceeding 100% are rarely observed in practice. The cause of these seemingly implausible results is the significant spike in anhydrous ammonia prices that coincided with the 2007–8 food price crisis. Figure 3 clearly depicts that both natural gas and anhydrous ammonia prices spike during this period of time; however, it is clear that relative to natural gas prices, anhydrous ammonia prices are much higher. This period of time represents an outlier that strongly impacts the results.

Table B1. Zivot Andrews Test Statistics

	Log	Log Difference
AA: Corn Belt	−4.64	−6.7***
AA: Black Sea	−4.65	−10.19***
AA: Tampa	−4.88	−10.42***
NG	−4.27	−7.83***

Note. The Akaike information criterion is used for lag selection. Linear trends are included in within the test. AA = anhydrous ammonia; NG = natural gas.

* $p \leq .1$.

** $p \leq .05$.

*** $p \leq .01$.

Table B2. Johnanson Maximal Eigenvalue Statistics: AA prices

	Corn Belt and Tampa	Corn Belt and Black Sea	Tampa and Black Sea
$r = 0$	29.04**	30.24**	34.48**
$r \leq 1$	2.82	3.17	2.42

Note. The Akaike information criterion is used for lag selection. AA = anhydrous ammonia.

* $p \leq .1$.

** $p \leq .05$.

*** $p \leq .01$.

This outlier is driven, in part, by a confluence of different market phenomena that are unaccounted for in our simple pass-through specification. During the food price crisis of 2007–8 the price of nitrogen-intensive crops, such as corn and wheat, increased dramatically. Such a large increase in crop prices stimulated nitrogen fertilizer demand and nitrogen fertilizer prices increased as plants became capacity constrained. The already tight nitrogen fertilizer market was further affected by a quick succession of supply-side events beginning with China raising nitrogen fertilizer export duties by 100% on April 17, 2008.[20] Unexpected plant outages in Australia[21] on August 2008 as well as planned outages in Indonesia[22] and Russia in September of the same year further constrained the industry. The simultaneous occurrence of increased fertilizer demand as well as the aforementioned supply-side events put upward pressure on anhydrous ammonia prices, which is not accounted for within the pass-through specification. As a result, these large increases in nitrogen fertilizer prices are incorrectly attributed to relatively modest fluctuations in natural gas prices during this brief period of unrest. In an attempt to model these events, in table B4, we include slope dummy variables for the period of April 2008 until April 2009. It is worth noting that the log-log specification is less affected by the presence of these events within 2008 as the log transformation of the time series stabilizes its variance (table B5). For this reason we prefer the log-log specification.

Table B6 reports the levels specification estimated on the pre- and post-2010 sample. The results are similar to those generated by the log specification; mostly notably, the pass-through rates after 2010 are statistically insignificant.

---

20. http://www.icis.com/resources/news/2008/04/17/9116767/china-hikes-ferts-export-tax-100-/.

21. http://www.icis.com/resources/news/2008/06/06/9130221/burrup-brings-ammonia-shutdown-forward/.

22. http://www.icis.com/resources/news/2008/09/24/9158530/indonesia-plant-shutdowns-tighten-ammonia-supply/.

Table B3. Pass-Through Rates in Levels: HH on AA

	L = 3	L = 6	L = 12
HH	1.17***	1.55***	1.46***
	(.6, 1.74)	(.77, 2.33)	(.75, 2.18)
Adjusted R^2	.21	.26	.24
N	217	217	217

Note. This table reports parameter estimates and 95% confidence intervals for the pass-through rate of domestic natural gas. The sample size is 217 and reflects the entire sample, spanning from January 1998 until January 2016. The table reports pass-through estimates for lag lengths of 3, 6, and 12 months. All specifications include season fixed effects. Standard errors are obtained with the Newey-West estimator; the lag length for this estimator is selected in accordance with Newey and West (1994). All prices enter the model in levels and anhydrous ammonia prices are normalized by the industry-level natural gas to anydrous ammonia conversion rate, 34 MMBTU per ton of ammonia. HH = Henry Hub; AA = anhydrous ammonia.

* $p \leq .1$.

** $p \leq .05$.

*** $p \leq .01$.

Table B4. Pass-Through Rates in Levels with Interaction Term: HH on AA

	L = 3	L = 6	L = 12
HH	.92***	1.06***	.93***
	(.54, 1.29)	(.5, 1.62)	(.41, 1.46)
Interaction	.71***	.89***	−.03
Term	(.42, 1)	(.49, 1.29)	(−.42, .36)
Adjusted R^2	.24	.45	.52
N	217	217	217

Note. This table reports parameter estimates and 95% confidence intervals for the pass-through rate of domestic natural gas. The sample size is 217 and reflects the entire sample, spanning from January 1998 until January 2016. The table reports pass-through estimates for lag lengths of 3, 6, and 12 months. All specifications include season fixed effects. Standard errors are obtained with the Newey-West estimator; the lag length for this estimator is selected in accordance with Newey and West (1994). All prices enter the model in levels and anhydrous ammonia prices are normalized by the industry-level natural gas to anydrous ammonia conversion rate, 34 MMBTU per ton of ammonia. The dummy variable takes on one for April 2008 until April 2009 and zero otherwise. HH = Henry Hub; AA = anhydrous ammonia.

* $p \leq .1$.

** $p \leq .05$.

*** $p \leq .01$.

Table B5. Pass-Through Rates in Logs with Interaction Term: HH on AA

	L = 3	L = 6	L = 12
HH	.47***	.53***	.58***
	(.31, .64)	(.31, .75)	(.31, .86)
Interaction	.07*	.12***	−.02
Term	(0, .14)	(.03, .21)	(−.16, .12)
Adjusted R^2	.27	.31	.38
N	217	217	217

Note. This table reports parameter estimates and 95% confidence intervals for the pass-through rate of domestic natural gas. The sample size is 217 and reflects the entire sample, spanning from January 1998 until January 2016. The table reports pass-through estimates for lag lengths of 3, 6, and 12 months. All specifications include season fixed effects. Standard errors are obtained with the Newey-West estimator; the lag length for this estimator is selected in accordance with Newey and West (1994). A log transformation is applied to all price series within the pass-through specification. The dummy variable takes on a one for April 2008 until April 2009 and zero otherwise. HH = Henry Hub; AA = anhydrous ammonia.

* $p \leq .1$.

** $p \leq .05$.

*** $p \leq .01$.

Table B6. Pass-Through Rates in Levels Before and After 2010: HH on AA

	L = 3		L = 6		L = 12	
	Pre-2010	Post-2010	Pre-2010	Post-2010	Pre-2010	Post-2010
HH	1.06***	.38	1.18***	−.1	.96***	−.46
	(.53, 1.59)	(−.67, 1.44)	(.63, 1.72)	(−1.98, 1.79)	(.6, 1.31)	(−3.94, 3.03)
Interaction	.32*		.74***		.14	
Term	(−.02, .66)		(.37, 1.12)		(−.42, .7)	
Adjusted R^2	.3	.04	.37	.05	.34	−.11
N	144	73	144	73	144	73

Note. This table reports parameter estimates and 95% confidence intervals for the pass-through rate of domestic natural gas. The table contains pass-through estimates before and after January 2010. The table reports pass-through estimates for lag lengths of 3, 6, and 12 months. All specifications include season fixed effects. Standard errors are obtained with the Newey-West estimator; the lag length for this estimator is selected in accordance with Newey and West (1994). All prices enter the model in levels and anhydrous ammonia prices are normalized by the industry-level natural gas to anydrous ammonia conversion rate, 34 MMBTU per ton of ammonia. The dummy variable takes on a one for April 2008 until April 2009 and zero otherwise. HH = Henry Hub; AA = anhydrous ammonia.

* $p \leq .1$.

** $p \leq .05$.

*** $p \leq .01$.

APPENDIX C

Pass-Throught Rate of International Natural Gas Prices to Anhydrous Ammonia Prices

As a supplement to the analysis in section 3.5, we consider a pass-through specification comprising solely international natural gas and anhydrous ammonia prices. The results, depicted in table C1, corroborate the findings in section 3.5. After 2010, the pass-through rates are statistically insignificant; however, the rates are similar in magnitude to the pass-through rates before 2010.

Finally, we consider anhydrous ammonia prices originating from the Tampa spot market discussed in section 3.1. These prices represent the price of anhydrous ammonia at a port of entry into the United States and therefore may be linked more closely to international natural gas prices than anhydrous ammonia prices within the Corn Belt. The findings in table C2 provide further evidence that the pass-through rates of international natural gas prices to anhydrous ammonia are less affected by events occurring in 2010 than pass-through rates obtained with US natural gas prices.

Table C1. Pass-Through: ICE on AA

	L = 3		L = 6		L = 12	
	Pre-2010	Post-2010	Pre-2010	Post-2010	Pre-2010	Post-2010
ICE	.39***	.3	.52***	.48*	.38*	.27
	(.09, .68)	(−.23, .83)	(.16, .87)	(−.09, 1.05)	(−.01, .77)	(−.35, .89)
Adjusted R^2	.19	−.02	.2	.04	.25	0
N	144	73	144	73	144	73

Note. This table reports parameter estimates and 95% confidence intervals for the pass-through rate of natural gas to anhydrous ammonia prices at the Tampa port. The table contains pass-through estimates before and after January 2010. The table reports pass-through estimates for lag lengths of 3, 6, and 12 months. All specifications include season fixed effects. Standard errors are obtained with the Newey-West estimator; the lag length for this estimator is selected in accordance with Newey and West (1994). A log transformation is applied to all price series within the pass-through specification. ICE = Intercontinental Exchange; AA = anhydrous ammonia.

* $p \leq .1$.

** $p \leq .05$.

*** $p \leq .01$.

Table C2. Pass-Through: ICE on AA at Tampa

	L = 3		L = 6		L = 12	
	Pre-2010	Post-2010	Pre-2010	Post-2010	Pre-2010	Post-2010
ICE	.54**	.5*	.41	.65**	.15	.57
	(.06, 1.01)	(−.07, 1.08)	(−.11, .94)	(.08, 1.22)	(−.3, .6)	(−.26, 1.39)
Adjusted R^2	.09	.11	.08	.15	.08	−.02
N	144	73	144	73	144	73

Note. This table reports parameter estimates and 95% confidence intervals for the pass-through rate of natural gas prices from the Intercontinental Exchange to anhydrous ammonia prices at the Tampa port. The table contains pass-through estimates before and after January 2010. The table reports pass-through estimates for lag lengths of 3, 6, and 12 months. All specifications include season fixed effects. Standard errors are obtained with the Newey-West estimator; the lag length for this estimator is selected in accordance with Newey and West (1994). A log transformation is applied to all price series within the pass-through specification. ICE = Intercontinental Exchange; AA = anhydrous ammonia.

* $p \leq .1$.

** $p \leq .05$.

*** $p \leq .01$.

Table C3. Pass-Through: ICE and Corn on AA

	L = 3		L = 6	
ICE	.34***	.32	.46***	.41
	(.13, .56)	(−.19, .83)	(.22, .7)	(−.66, 1.47)
Corn	.36**	.48**	.6***	.66**
	(.02, .69)	(.07, .88)	(.13, 1.07)	(.09, 1.22)
Adjusted R^2	.22	.12	.28	.15
N	143	45	137	36

Note. This table reports parameter estimates and 95% confidence intervals for the pass-through rate of natural gas prices from the Intercontinental Exchange to anhydrous ammonia prices at the Tampa port. The table contains pass-through estimates before and after January 2010. The table reports pass-through estimates for lag lengths of 3, 6, and 12 months. All specifications include season fixed effects. Standard errors are obtained with the Newey-West estimator; the lag length for this estimator is selected in accordance with Newey and West (1994). A log transformation is applied to all price series within the pass-through specification. ICE = Intercontinental Exchange; AA = anhydrous ammonia.

* $p \leq .1$.

** $p \leq .05$.

*** $p \leq .01$.

REFERENCES

Andrews, Donald W. K. 1993. Tests for parameter instability and structural change with unknown change point. *Econometrica* 61 (4): 821–56.

———. 2003. Tests for parameter instability and structural change with unknown change point: A corrigendum. *Econometrica* 71 (1): 395–97.

Bai, Jushan, and Pierre Perron, 2006. Multiple structural change models: A simulation analysis. In *Econometric theory and practice: Frontiers of analysis and applied research*, ed. Dean Corbae, Steven N. Durlauf, and Bruce E. Hansen. Cambridge: Cambridge University Press.

Borenstein, Severin, A. Colin Cameron, and Richard Gilbert. 1997. Do gasoline prices respond asymmetrically to crude oil price changes? *Quarterly Journal of Economics* 112 (1): 305–39.

Burrell, Alison, 1989. The demand for fertiliser in the United Kingdom. *Journal of Agricultural Economics* 40 (1): 1–20.

Bushnell, James, Carla Peterman, and Catherine Wolfram. 2008. Local solutions to global problems: Climate change policies and regulatory jurisdiction. *Review of Environmental Economics and Policy* 2 (2): 175–93.

Canada Ecofiscal Commission. 2015. Provincial carbon pricing and competitiveness pressures. https://www.ecofiscal.ca/reports/provincial-carbon-pricing-competitiveness-pressures/.

CARB (California Air Resources Board). 2010. Proposed regulation to implement a cap and trade program. https://www.arb.ca.gov/regact/2010/capandtrade10/capandtrade10.htm.

ChemSystems. 2013. Ammonia and urea: Strategic business analysis. Program prospectus.

Cullen, Joseph A., and Erin T. Mansur. 2014. Inferring carbon abatement costs in electricity markets: A revealed preference approach using the shale revolution. NBER Working Papers 20795, National Bureau of Economic Research, Cambridge, MA.

Denbaly, Mark, and Harry Vroomen. 1993. Dynamic fertilizer nutrient demands for corn: A cointegrated and error-correcting system. *American Journal of Agricultural Economics* 75 (1): 203–9.

Dickey, David A., and Wayne A. Fuller, 1979. Distribution of the estimators for autoregressive time series with a unit root. *Journal of the American Statistical Association* 74 (366a): 427–31.

Elobeid, Amani, Miguel Carriquiry, Jerome Dumortier, Francisco Rosas, Kranti Mulik, Jacinto F. Fabiosa, Dermot J. Hayes, and Bruce A. Babcock. 2013. Biofuel expansion, fertilizer use, and GHG emissions: Unintended consequences of mitigation policies. *Economics Research International* 2012 (1): 1–12.

European Commission. 2016. Impact assessment determining a list of sectors and subsectors which are deemed to be exposed to a significant risk of carbon leakage for the period 2015–2019. http://ec.europa.eu/clima/policies/ets/allowances/leakage/.

Fabra, Natalia, and Mar Reguant. 2014. Pass-through of emissions costs in electricity markets. *American Economic Review* 104 (9): 2872–99.

Fischer, Carolyn. 2003. Output-based allocation of environmental policy revenues and imperfect competition. RFF Discussion Papers 02-60, Resources for the Future, Washington, DC.

———. 2011. Market power and output-based refunding of environmental policy revenues. *Resource and Energy Economics* 33 (1): 212–30.

Fischer, Carolyn, and Alan K. Fox. 2012. Comparing policies to combat emissions leakage: Border carbon adjustments versus rebates. *Journal of Environmental Economics and Management* 64 (2): 199–216.

Fowlie, Meredith. 2009. Incomplete environmental regulation, imperfect competition, and emissions leakage. *American Economic Journal: Economic Policy* 1 (2): 72–112.

———. 2012. Updating the allocation of greenhouse gas emissions permits in a federal cap-and-trade program. In *The design and implementation of U.S. climate policy*, ed. Don Fullerton and Catherine Wolfram. Chicago: University of Chicago Press.

Fowlie, Meredith, Mar Reguant, and Stephen Ryan. 2016. Market-based emissions regulation and industry dynamics. *Journal of Political Economy* 124 (1): 249–302.

Frankel, Jeffrey A., and Joseph E. Aldy. 2008. Addressing the leakage/competitiveness issue in climate change policy proposals [with comment]. *Brookings Trade Forum* no. 1, 69–91.

Fullerton, Don, and Gilbert E. Metcalf. 2001. Environmental controls, scarcity rents, and pre-existing distortions. *Journal of Public Economics* 80 (2): 249–67.

Ganapati, Sharat, Joseph S. Shapiro, and Reed Walker. 2016. Energy prices, pass-through, and incidence in US manufacturing. NBER Working Papers 22281, National Bureau of Economic Research, Cambridge, MA.

Goldberg, Linda S., and Jos Manuel Campa. 2010. The sensitivity of the CPI to exchange rates: Distribution margins, imported inputs, and trade exposure. *Review of Economics and Statistics* 92 (2): 392–407.

Goldberg, Pinelopi Koujianou, and Rebecca Hellerstein. 2013. A structural approach to identifying the sources of local currency price stability. *Review of Economic Studies* 80 (1): 175–210.

Gopinath, Gita, and Oleg Itskhoki. 2010. Frequency of price adjustment and pass-through. *Quarterly Journal of Economics* 125 (2): 675–727.

Goulder, Lawrence H., Ian W. H. Parry, Roberton C. Williams III, and Dallas Burtraw. 1999. The cost-effectiveness of alternative instruments for environmental protection in a second-best setting. *Journal of Public Economics* 72 (3): 329–60.

Hansen, Lars Garn. 2004. Nitrogen fertilizer demand from Danish crop farms: Regulatory implications of heterogeneity. *Canadian Journal of Agricultural Economics* 52 (3): 313–31.

Hausman, Catherine, and Ryan Kellogg, 2015. Welfare and distributional implications of shale gas. NBER Working Papers 21115, National Bureau of Economic Research, Cambridge, MA.

Humber, Jacob. 2016. The implications of climate change policy in the United States nitrogen fertilizer industry. Ph. thesis, University of California, Davis, Department of Agricultural and Resource Economics.

IFA. 2009. Energy efficiency and CO_2 emissions in ammonia production. International Fertilizer Association, Paris.

Jensen, Jesper, and Tobias N. Rasmussen. 2000. Allocation of CO_2 emissions permits: A general equilibrium analysis of policy instruments. *Journal of Environmental Economics and Management* 40 (2): 111–36.

Johansen, Soren. 1991. Estimation and hypothesis testing of cointegration vectors in Gaussian vector autoregressive models. *Econometrica* 59 (6): 1551–80.

Kim, C. S., C. Hallahan, H. Taylor, and G. Schluter. 2002. Market power and cost-efficiency effects of the market concentration in the U.S. nitrogen fertilizer industry. Paper prepared for the 2002 annual meeting of the American Agricultural Economics Assoication, Long Beach, CA.

Knittel, Christopher R., Ben S. Meiselman, and James H. Stock. 2015. The pass-through of RIN prices to wholesale and retail fuels under the renewable fuel standard. NBER Working Papers 21343, National Bureau of Economic Research, Cambridge, MA.

Marion, Justin, and Erich Muehlegger. 2011. Fuel tax incidence and supply conditions. *Journal of Public Economics* 95 (9): 1202–12.

Miller, Nathan H., Matthew Osborne, and Gloria Sheu. 2017. Pass-through in a concentrated industry: Empirical evidence and regulatory implications. *RAND Journal of Economics* 48 (1): 69–93.

Nakamura, Emi, and Dawit Zerom. 2010. Accounting for incomplete pass-through. *Review of Economic Studies* 77 (3): 1192–1230.

Newey, Whitney K., and Kenneth D. West. 1994. Automatic lag selection in covariance matrix estimation. *Review of Economic Studies* 61 (4): 631–53.

Palmer, Karen, Dallas Burtraw, and Danny Kahn. 2006. Simple rules for targeting CO_2 allowance allocations to compensate firms. *Climate Policy* 6 (4): 477–93.

Stavins, Robert N., Jonathan Borck, and Todd Schatzki. 2014. Options for addressing leakage in California's climate policy. Analysis Group.

USDA. 2009. A preliminary analysis of the effects of HR 2454 on U.S. agriculture. US Department of Agriculture, Washington, DC. https://www.usda.gov/oce/newsroom/archives/releases/2009files/HR2454.pdf.

US EPA. 2015. Inventory of U.S. greenhouse gas emissions and sinks: 1990–2013. (April). US Environmental Protection Agency, Washington, DC.

US EPA, EIA, and Treasury. 2009. The effects of H.R. 2454 on international competitiveness and emission leakage in energy-intensive trade-exposed industries. https://www.epa.gov/climatechange/interagency-report-international-competitiveness-and-emission-leakage-december-2009.

WenYuan, Huang. 2009. Factors contributing to the recent increase in US fertilizer prices, 2002–08. *Agricultural Resources Situation and Outlook* 1 (33): 1–22.

Weyl, E. Glen, and Michal Fabinger. 2013. Pass-through as an economic tool: Principles of incidence under imperfect competition. *Journal of Political Economy* 121 (3): 528–83.

Zivot, Eric, and Donald W. K. Andrews. 1992. Further evidence on the great crash, the oil-price shock, and the unit-root hypothesis. *Journal of Business and Economic Statistics* 20 (1): 25–44.