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A ban on one is a boon for the other: Strict gasoline content rules and implicit ethanol blending mandates

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ABSTRACT

Ethanol and methyl-tertiary butyl ether (MTBE) were close substitutes in the gasoline additives market until MTBE was banned due to the concerns about groundwater contamination, leading to a sudden and dramatic substitution toward ethanol as an alternative oxygenate and octane-booster. We use variation in the timing of MTBE bans across states to identify their effects on gasoline prices. We find that state bans increased reformulated gasoline prices by 3–6 cents in non-Midwestern states for which the bans were binding, with larger impacts during times of high ethanol prices relative to MTBE and crude oil. We find qualitatively similar, yet smaller effects for conventional gasoline. We argue on the basis of a simple conceptual model and supporting empirical evidence that these bans functioned as implicit ethanol blending mandates in areas that were previously using MTBE to comply with strict environmental constraints. Overall, our results are consistent with the theoretical prediction that mandating a minimum market share for a more costly alternative fuel—either directly, or implicitly through a ban on the preferred conventional fuel—will inevitably increase fuel prices in a competitive market.

Introduction

Gasoline refiners have faced increasingly stringent environmental constraints in recent decades, significantly narrowing their options for maintaining high levels of fuel octane.[1] By the late 1990s, suppliers in many cities came to rely heavily on a fuel additive known as MTBE (methyl-tertiary butyl ether) to boost octane, while suppliers in other cities used ethanol instead. Like ethanol, MTBE was valued for its energy, oxygen content, and high octane—but was found to leak from underground storage tanks and contaminate groundwater. Thus, a total of 19 states banned MTBE from 2000 to 2006 before it was phased out nationwide in mid-2006, leading to a dramatic substitution toward ethanol. We present theory, empirical evidence, and institutional background to shed light on this era of gasoline content regulation, which came after the reformulated gasoline (RFG) regulations of the 1990s, and which served as prelude to the federal Renewable Fuel Standard in the 2000s.

We show theoretically that MTBE bans function as implicit ethanol blending mandates in the presence of existing environmental constraints. We confirm this interpretation empirically, finding that MTBE bans had large, discrete, and immediate effects on ethanol blend shares. We then use variation in the timing of MTBE bans across states to identify their effects on gasoline prices. We distinguish the effects of these bans by (1) conventional gasoline versus reformulated

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[1] High-octane fuels are more resistant to "knocking," which occurs when the pressurized fuel–air mixture in the engine ignites prior to the spark plug firing, reducing engine efficiency.

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gasoline, which faced more stringent environmental constraints, (2) geography, to account for whether the bans were binding or not, and (3) time, based on prices for ethanol, MTBE, and crude oil—the key commodity inputs into oxygenate-blended gasoline.

We find that MTBE bans increased reformulated gasoline prices by 3–6 cents in non-Midwestern states—where MTBE was preferred to ethanol. As expected, price impacts were larger when ethanol prices were high relative to MTBE and crude oil. Consistent with this evidence, we find that MTBE bans increased the monthly pass-through rate of wholesale ethanol prices into retail gasoline prices, while decreasing the pass-through rates of MTBE and crude oil prices. We find little effect of MTBE bans in the Midwest—where ethanol was preferred over MTBE. We also find minimal effects for conventional gasoline, which faced less stringent environmental constraints. Overall, our results are consistent with the prediction that a ban on a less costly conventional fuel—in extreme cases, a de-facto mandate for the more costly alternative fuel—will inevitably increase fuel prices in a competitive market.

This paper contributes to a recent empirical literature that exploits variation in gasoline content regulations across locations and over time to identify their effects on gasoline prices. In general, this literature finds that gasoline content regulations increase average prices by raising production costs (Muehlegger, 2006; Chouinard and Perloff, 2007; Brown et al., 2008; Chakravorty et al., 2008). Seasonally and geographically differentiated regulations also segment markets, exacerbating price spikes following refinery outages (Muehlegger, 2006; Brown et al., 2008) and increasing the exercise of local market power (Brown et al., 2008; Chakravorty et al., 2008). Overall, however, content regulations account for a relatively small share of total costs (Chouinard and Perloff, 2007).[2]

Our paper contributes to this literature in three ways. First, while previous papers focus on the gasoline content regulations following the Clean Air Act Amendments of the early 1990s, we focus on state MTBE bans, which occurred later, which apply to gasoline sold everywhere in a state, and which likely had different impacts on prices. Thus, our paper helps document an important era in gasoline content regulation that led to a significant increase in ethanol consumption. In particular, the MTBE bans are important pre-existing regulations that must be considered when assessing the impacts of the federal Renewable Fuel Standard (RFS).

Second, like previous studies, we study heterogeneous effects by location and regulatory stringency. In particular, we allow the effects of MTBE bans to differ for Midwestern states, which were closer to ethanol supply, as well as for conventional gasoline, which faced weaker environmental constraints. Unlike previous studies, however, we allow the effects of content regulations to vary over time with the prices of key gasoline inputs. Thus, our estimates may have greater external validity in the face of changing market conditions. Controlling for input prices also mitigates potential bias related to spillovers from one state′s policy to another state′s prices via national fuel markets—something that is ignored in previous studies.

Third, we show that state MTBE bans approximated direct state-level ethanol mandates in areas that were previously using MTBE to comply with existing environmental regulations. Thus, our results also help to inform a current policy and research debate about whether ethanol blending mandates increase or decrease gasoline prices (see Knittel and Smith, 2012). In this case, our results suggest that direct, state-level ethanol blending mandates would have increased fuel prices. Our approach may prove to be useful in other contexts, when the impact of a new or future policy cannot be estimated, but can be inferred from a surrogate policy sharing a similar economic structure.[3]

In addition, our paper contributes to the literatures on overlapping environmental policies and rent-seeking behavior. We show that a ban on an input (MTBE) can—in the presence of other policy constraints—lead to dramatic substitution toward one particular close substitute (ethanol). In the extreme, when all other options have been eliminated, a ban on one input is a de-facto mandate for its alternative. Excessive regulation also comes with a hidden political cost: eliminating substitutes via regulation inflates incentives for rent-seeking behavior among the industries that remain viable. Indeed, ethanol producers were among the most ardent supporters of MTBE bans, with virtually all corn-growing Midwestern states banning MTBE.

The rest of this paper proceeds as follows. The section "Industry background and conceptual model" discusses important background on the economics of ethanol and MTBE blending before presenting our conceptual model. The section "State MTBE bans and their effects on blending" presents evidence on MTBE bans and their effects on ethanol usage. The section "Econometric models and estimation results" describes our estimation strategy and presents our regression results for the effects of MTBE bans on retail gasoline prices. The section "Conclusion" summarizes and concludes.

[2] Brown et al. (2008) find that the mean and variance of wholesale prices increased following the implementation of federal Reid Vapor Pressure (RVP) and reformulated gasoline (RFG) regulations in affected cities, while the number of wholesalers decreased. Chakravorty et al. (2008) find that state prices increased following the implementation of RFG and winter oxygenated fuel regulations, attributing the increase both to higher refining and distribution costs, as well as to market power. Muehlegger (2006) also attributes price increases to higher refining and distribution costs and argues that uniform regulations could substantially mitigate the severity of local price spikes. Finally, Chouinard and Perloff (2007) estimate the effects of oil prices, taxes, market power, vertical integration, and environmental regulations on gasoline prices, finding that environmental regulations account for a relatively small share of the retail price.

[3] Other policies that share a similar economic structure include the U.S. federal Renewable Fuel Standard (RFS) and California′s Low-Carbon Fuel Standard (LCFS). While the federal RFS is legislated as a minimum quantity, it is implemented by EPA as a minimum market share requirement. Likewise, in the case of a conventional high-carbon fuel (gasoline) and a single low-carbon fuel (say ethanol), the LCFS is equivalent to a minimum market share for the low-carbon fuel.

Industry background and conceptual model

Gasoline refiners demand ethanol and MTBE to boost fuel octane levels, to comply with oxygenate mandates, and to extend energy supplies during times of high oil prices. In this section, we briefly review the history of environmental regulation that led to this demand, along with the bans that eliminated MTBE from gasoline during the 2000s. We discuss the economics of ethanol versus MTBE blending, and we outline a simple conceptual model that clarifies the predicted effects of MTBE bans.

Maintaining octane under strict environmental constraints

Environmental regulation over the past four decades has imposed myriad constraints on gasoline refiners, significantly narrowing the set of options available for boosting octane. By the late 1990s, suppliers in many cities had few cost-effective alternatives besides blending ethanol or MTBE. In this context—that is, when gasoline suppliers are compelled to blend either ethanol or MTBE to maintain octane or to comply with explicit fuel oxygenation requirements—bans on MTBE act as de-facto ethanol mandates. This is the key insight of our paper.[4]

Initially, gasoline refiners blended an octane-rich, lead-based compound, but EPA eventually banned leaded gasoline in the 1980s due to the serious public health concerns. Industry responded by altering the refining process to boost the production of high-octane components, but this led to a significant rise in emissions of volatile organic compounds (VOCs)—precursors to ground-level ozone. Meanwhile, incomplete combustion of fuel during winter months led to high levels of carbon monoxide in some cities. Thus, EPA placed caps on Reid Vapor Pressure (RVP) in select cities to limit emissions of VOCs and mandated oxygenate blending in select cities to reduce emissions of carbon monoxide. In cities with particularly poor air quality, EPA required reformulated gasoline (RFG), which subjected fuel to a suite of environmental constraints, including caps on RVP and year-round blending of oxygenates—almost always ethanol or MTBE.[5,6,7]

Thus, by the late 1990s, gasoline suppliers faced a range of incentives to blend either ethanol or MTBE. At one extreme, producers selling RFG were required to blend either ethanol or MTBE year-round to comply with explicit oxygenation mandates—and faced additional caps on RVP and toxics that likely would have compelled them to blend ethanol or MTBE regardless, simply to maintain octane levels. In other cities, oxygenation requirements forced producers to blend ethanol or MTBE, but only during winter months. Lastly, even producers in cities lacking such regulations sometimes opted to blend ethanol or MTBE to boost octane levels or to extend fuel supplies. These pre-existing regulations set the stage for the MTBE bans that were to come.

By the late 1990s, some cities noticed that MTBE, a suspected carcinogen, was contaminating their drinking water. Because this problem was most pronounced in RFG areas, it was clear that the cause was leakage of fuel from underground gasoline storage tanks. Thus, starting around 2000, a number of states began to ban MTBE, and pressure built for a national ban (U.S. Energy Information Administration, 2003). Meanwhile, the fuel industry sought liability protection from MTBE-related lawsuits, arguing that they had been compelled to blend MTBE by federal regulation. When the Energy Policy Act of 2005 failed to grant such protection, the industry treated this failure as an implicit ban and opted to phase-out MTBE completely by the summer of 2006 (U.S. Energy Information Administration, 2006). As we argue below, these bans operated as de-facto ethanol mandates in RFG cities, as well as in cities subject to minimum oxygenation requirements during winter months.[8]

Ethanol versus MTBE blending economics

While ethanol and MTBE are close substitutes in the gasoline additives market, their production, distribution, and integration into the gasoline supply chain differ in several important ways (U.S. Energy Information Administration, 2006). Unlike ethanol, MTBE is typically produced and mixed with gasoline at petroleum refineries.[9] After the blending is complete,

[4] The discussion of gasoline production and environmental regulation in this and the subsequent paragraph rely heavily on Stikkers (2002) and Brown et al. (2008).

[5] A fuel's RVP measures its propensity to evaporate and generate emissions of VOCs, which react with nitrogen oxides in the presence of sunlight to form ground-level ozone, causing respiratory illness. Auffhammer and Kellogg (2011) show that California's regulations led to significant improvements in air quality because they targeted the most potent VOCs; limits on RVP outside of California were largely ineffective.

[6] Oxygenation requirements took effect in 39 cities in the early 1990s and mandated a minimum of 2.7% oxygen by weight in most areas. Virtually all demand for oxygenates was met with ethanol or MTBE. Most cities have since exited the program.

[7] The RFG program began in 1995, replacing existing RVP and oxygenation programs in some cities and requiring 2.1% oxygen by weight in most areas. The program was mandatory for 9 large cities with the worst smog, while other cities opted to join.

[8] Besides failing to provide liability protection, the 2005 legislation eliminated the explicit oxygenation requirement in RFG. Rather than stop oxygenate blending altogether, however, refiners switched to ethanol. Why? There are two reasons. First, given other constraints on RVP and toxics, continuing to blend ethanol was the cheapest way for many refiners to maintain octane, at least in the short run (U.S. Energy Information Administration, 2006). Second, this same legislation also imposed the federal Renewable Fuel Standard (RFS). Thus, making costly investments to boost octane in other ways would have been unwise, since the looming RFS would soon boost octane via forced ethanol blending.

[9] MTBE is a petroleum-based chemical fuel additive produced by reacting methanol with isobutylene in dedicated facilities or using byproduct streams of isobutylene at petroleum refineries or petrochemical ethylene plants (Lidderdale, 2001).

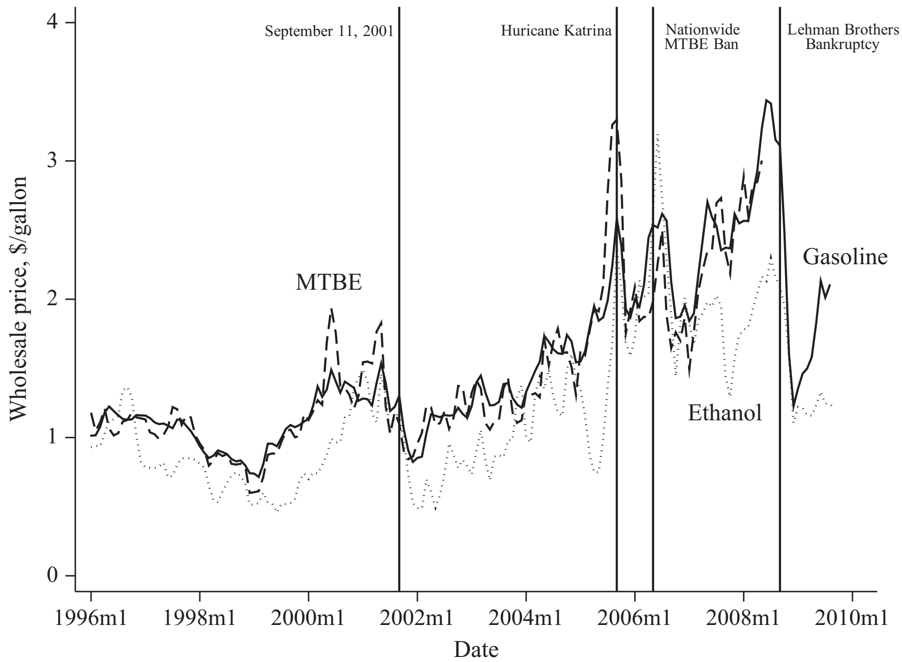

Fig. 1. Fuel price trends. *Note*: This figure shows monthly wholesale rack prices for gasoline (U.S. average), MTBE (Gulf Coast), and ethanol (in Omaha, Nebraska). Ethanol prices are net of the federal ethanol blending incentive. Prices are in real 2009 dollars. See text for details.

the finished gasoline can be shipped through refined product pipelines virtually anywhere in the country at low cost (Trench, 2001).

Ethanol is produced in refineries in the Midwest near corn supplies. Unlike MTBE, it cannot be shipped via existing refined product pipelines.[10] Instead, ethanol must be transported at relatively high cost via rail, barge, or tanker truck to wholesale fuel blending and distribution terminals. In the case of rail transport from the Midwest to the coasts, this cost is about 15 cents per gallon (Hughes, 2011). Upon arrival at a terminal, ethanol is stored separately and then, in the final step, blended with gasoline in the tank of a delivery truck for transmission to a retail station.

These differences in supply and distribution have two key consequences. First, high transport costs, limited fungibility in refined product pipelines, and (until recently) the lack of blending infrastructure outside of the Midwest make it difficult to arbitrage ethanol prices across locations in response to high prices for gasoline or for competing oxygenates and octane enhancers. Thus, while MTBE prices track gasoline prices closely over time, ethanol prices do not (see Fig. 1). Second, ethanol's high transport costs imply significant geographic variation in costs. Thus, suppliers on the coasts that faced high costs for ethanol tended to choose MTBE, while suppliers in the Midwest tended to choose ethanol.[11] All told, ex ante estimates were that the MTBE bans would increase RFG prices by 3.6 cents per gallon on average, with larger increases on the coasts (U.S. Energy Information Administration, 2003).

Direct and indirect ethanol blending mandates

Fig. 2(a) presents a model of a perfectly competitive state fuel market in the presence of a percent ethanol blending mandate. The demanders in this market are fuel blenders, implicitly buying ethanol and gasoline on behalf of retail consumers. To simplify, retail consumers are assumed to have perfectly inelastic demand for fuel, given by the width of the horizontal axis, while treating ethanol and gasoline as perfect substitutes.[12] Thus, fuel blenders inherit these preferences,

[10] Water tends to accumulate at low points in these pipelines. Unlike petroleum, ethanol mixes with water. Thus, if either ethanol or ethanol-blended gasoline were shipped through these pipelines, they would be contaminated by water (U.S. Energy Information Administration, 2006). In addition, existing pipelines are poorly located for moving ethanol from where it is produced to where it is needed.

[11] Other costs are also relevant. First, ethanol has higher RVP than MTBE, which in turn has higher RVP than gasoline. Thus, for suppliers subject to RVP caps, choosing ethanol implies greater reductions in the RVP of the underlying gasoline. Second, suppliers facing winter oxygenation requirements tended to choose ethanol due to ethanol's higher oxygen content per volume. Finally, ethanol benefited from a federal subsidy of about $0.50 per gallon, as well as additional subsidies in some states.

[12] Both assumptions are consistent with recent empirical evidence. Small and Dender (2007) and Hughes et al. (2008) find that the price elasticity of demand for fuel has fallen to less than 0.1 in magnitude in recent years. Anderson (2012) and Salvo and Huse (2012) find that consumers in the United States and Brazil treat high-concentration ethanol blends and gasoline as close, albeit not perfect, substitutes.

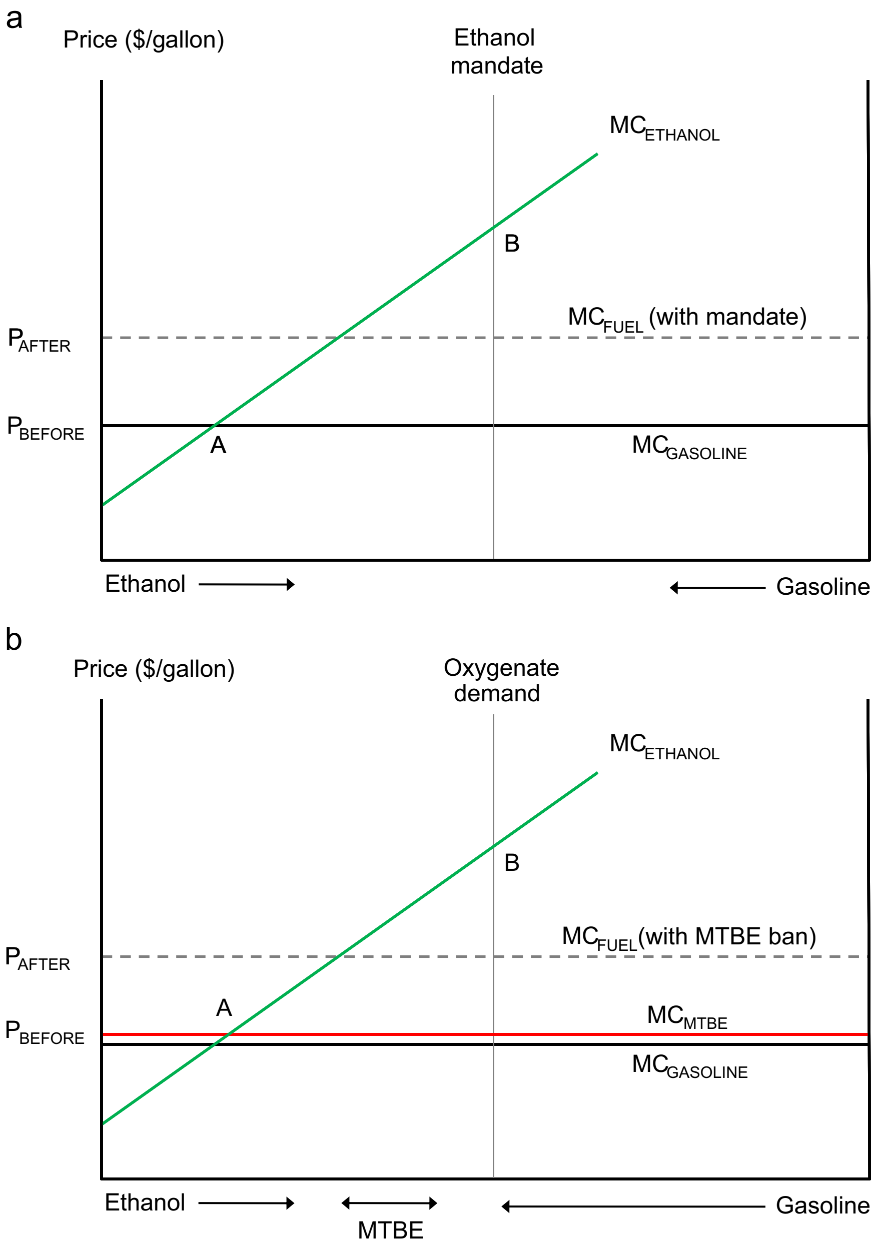

Fig. 2. Illustration of conceptual model. *Note*: (a) illustrates the effects of a direct percent ethanol blending mandate. (b) illustrates the effects of an MTBE ban in the presence of inelastic percent oxygenate demand satisfied using ethanol and/or MTBE. The ethanol mandate in (a) and the MTBE ban in (b) have virtually identical effects when MTBE supply hugs gasoline supply. See text for details.

as well, seeking to minimize the overall cost of fuel, subject to their inelastic demand and fuel blending obligations. The suppliers in this market are fuel refiners and distributors that produce fuel and deliver it to market. Gasoline supply is represented as a horizontal marginal cost curve, while ethanol supply is upward-sloping.[13]

Before the ethanol mandate takes effect, blenders of ethanol are only willing to pay up to the marginal cost of gasoline. Thus, ethanol's market price and quantity are given by point A, at which the marginal cost of ethanol equals the marginal

[13] A horizontal state gasoline supply curve is consistent with a large national market and low transportation costs via refined product pipelines. In contrast, an upward-sloping ethanol supply curve is consistent with a smaller national market, geographic dispersion of ethanol refineries, high transportation costs, limited infrastructure for ethanol blending, and relatively few retail storage tanks that can handle ethanol-blended fuel.

cost of gasoline, with a small amount of ethanol competing directly as a gasoline substitute.[14] Thus, small shifts in gasoline supply pass through fully to fuel prices, while small shifts in the ethanol supply pass through not at all.

After the ethanol mandate takes effect, blenders must increase their ethanol demand to point B, at which ethanol′s marginal cost exceeds that of gasoline. At the standard, the marginal cost to blenders of acquiring one more gallon of fuel while remaining in compliance with the standard—and therefore, the fuel price that retail consumers will pay—is the quantity-weighted average of ethanol′s and gasoline′s marginal costs.[15] Thus, the impact of the mandate on fuel prices is higher when either ethanol supply shifts up or when gasoline supply shifts down. Small shifts in gasoline supply now pass through only partially to fuel prices, and similarly for ethanol supply, according to their respective shares in the overall fuel supply, given by the ethanol mandate.

Fig. 2(b) presents a similar model of a competitive state fuel market in the presence of inelastic demand for oxygenates—to satisfy a minimum oxygenation requirement or to enhance octane—and a potential ban on MTBE. Again, gasoline supply is horizontal, while ethanol supply is upward-sloping. The supply of MTBE is represented as a horizontal supply curve at or just above the marginal cost of gasoline.[16]

Before MTBE is banned, ethanol′s marginal cost and quantity supplied are given by point A, at which a small amount of ethanol competes with MTBE in the market for oxygenates. At this point, the marginal cost of fuel is set by the quantity-weighted average of gasoline and oxygenates, the latter of which is set by the constant marginal cost of MTBE. Thus, small shifts in MTBE and gasoline supply pass through partially to fuel prices according to the share of total oxygenates and gasoline in the fuel supply, respectively, while small shifts in ethanol supply pass through not at all.

When MTBE is banned, ethanol′s marginal cost and quantity supplied are given by point B, at which ethanol is the sole oxygenate. At this point, the price of fuel is set by the average marginal cost of fuel—that is, the quantity-weighted average of ethanol′s and gasoline′s marginal costs. Thus, the impact of the MTBE ban on fuel prices is higher when either ethanol supply shifts up or MTBE supply shifts down. Small shifts in ethanol supply now pass through partially to fuel prices, according to ethanol′s fixed share in the overall fuel supply, while shifts in MTBE supply pass through not at all.[17]

Comparing these two figures, we therefore see that an MTBE ban in the presence of inelastic demand for oxygenates closely approximates the economic structure of an ethanol mandate. In both cases, the policy leads to an increase in fuel prices that is more pronounced either when the supply of ethanol shifts up or when the supply of the conventional fuel (gasoline, in the first case, MTBE in the second) shifts down. Pass-through rates increase for ethanol and decrease for the conventional fuel according their shares in the overall fuel supply before versus after the policy change. Thus, had the states that banned MTBE during the 2000s mandated ethanol instead, we argue that the economic effects would have been quite similar in many cases.

State MTBE bans and their effects on blending

State MTBE bans

Table 1 lists states with MTBE bans based on Weaver et al. (2010), U.S. Energy Information Administration (2003), and U.S. Environmental Protection Agency (2007). The second and third columns list the dates that these bans were enacted and became effective, while the fourth column lists their precise limits on MTBE content. Finally, the fifth and sixth columns present average market shares for RFG and for winter oxygenated fuel by state during the sample period, thereby indicating which states will be included in our regression for RFG prices, as well as the share of conventional fuel subject to minimum oxygenation requirements in affected states. States whose bans took effect prior to the nationwide phase-out in May 2006 are listed first, ordered by the effective dates of their bans, while states whose bans took effect after the nationwide phase-out are listed below, ordered alphabetically.

This table highlights several salient facts. First, roughly two-thirds of states with RFG eventually banned MTBE, although several bans took effect after the nationwide phase-out. Second, for the 12 states that banned MTBE but did not have any RFG, most were in the Midwest. The only exceptions were Colorado and Washington, which had large shares of oxygenated fuel, and North Carolina and Vermont. Lastly, every state in the Midwest banned MTBE, regardless of whether it had RFG, winter oxygenated fuel, both, or neither. In short, it was primarily states that were at risk of groundwater contamination from MTBE and states that had a specific interest in promoting corn-based ethanol that banned MTBE in their fuel supplies.

[14] We have drawn the initial equilibrium as an interior solution. In general, corner solutions at zero or at the 10% upper limit for ethanol blending are also possible. In the former case, our conclusions are unchanged. In the latter case, the ethanol mandate is not binding. The so-called “blend wall” of 10% ethanol is fixed by EPA regulation (only recently increased to 15%) and by manufacturer warranties for most cars.

[15] While we have arbitrarily drawn in the ethanol standard at a 50% blend share, this obviously need not be the case. For example, at a 10% blend share, the marginal cost of fuel would be 10% of ethanol′s marginal cost plus 90% of gasoline′s marginal cost.

[16] Historically, MTBE prices track conventional gasoline prices very closely over time, with relatively few exceptions (see Fig. 1). In addition, the wholesale premium for RFG over conventional gasoline tracks MTBE prices very closely (Lidderdale, 2001). Both facts are consistent with our choice to model MTBE as having a horizontal supply curve at or just above that of gasoline.

[17] While we have drawn inelastic demand for oxygenates as implying the same level of ethanol and MTBE by volume, the relevant choice for suppliers of RFG was typically between 6% ethanol and 11% MTBE. Thus, after the MTBE ban, the impact of the ban should increase with gasoline prices, while the pass-through rate for gasoline should also increase. In practice, this distinction will usually not matter, since MTBE prices track gasoline prices closely.

Table 1
State MTBE bans and regulated fuel shares.

State	Enactment date	Effective date	MTBE cap (%)	RFG size (%)	Oxy-fuel size (%)
South Dakota	2000-02	2000-07	2.00		
Minnesota	2000-04	2000-07	0.33		70
Nebraska	2000-04	2000-07	1.00		
Iowa	2000-07	2001-01	0.50		
Colorado	2000-09	2002-05	0.00		22
Michigan	2000-06	2003-06	0.00		
California	2003-03	2004-01	0.60	63	
Connecticut	2003-06	2004-01	0.50	100	
New York	2000-05	2004-01	0.00	55	
Washington	2001-05	2004-01	0.60		10
Kansas	2001-07	2004-07	0.50		
Illinois	2001-07	2004-07	0.50	60	
Indiana	2002-07	2004-07	0.50	14	
Wisconsin	2003-08	2004-08	0.50	27	
Arizona	2004-05	2005-01	0.30	42	7
Missouri	2002-09	2005-07	0.50	20	
Ohio	2002-09	2005-07	0.50		
North Dakota	2005-04	2005-08	0.50		
Kentucky	2002-07	2006-01	0.50	24	
Nationwide ban		2006-05		33	3
Alaska					5
Delaware				94	
Dist. of Columbia				100	
Maine	2005-08	2007-01	0.50	14	
Maryland				76	
Massachusetts				97	
Montana					1
Nevada				7	14
New Hampshire	2004-06	2007-01	0.50	67	
New Jersey	2005-08	2009-01	0.50	85	
New Mexico					5
North Carolina	2005-06	2008-01	0.50		
Oregon					9
Pennsylvania				26	
Rhode Island	2005-07	2007-06	0.50	97	
Texas				29	
Utah					1
Vermont	2005-06	2007-01	0.50		
Virginia				57	

Note: Table reports states whose MTBE bans took effect prior to the nationwide phase-out in May 2006 (ordered by enforcement date), as well as states whose bans took effect afterwards (ordered alphabetically), along with RFG and oxygenated fuel consumption in all states with such regulations. Most bans took effect on the first day of the indicated month. Bans in California, Colorado, and Iowa took effect on the last day of the month prior to the indicated month. Bans in Illinois, Indiana, and Nebraska took effect during the middle of the indicated month. MTBE cap is the maximum allowable percent MTBE content by volume or weight (in Minnesota). RFG size and oxy-fuel size are the fractions of total fuel statewide sold under the federal RFG and winter oxygenated fuel programs during 1996–2010, based on EIA data available here: http://www.eia.gov/dnav/pet/pet_cons_prim_a_EPM0_P00_Mgalpd_m.htm. See Weaver et al. (2010) and the text for details.

MTBE bans had discrete effects upon enforcement

Our empirical approach compares fuel prices in states with and without MTBE bans, exploiting the staggered timing of the MTBE bans across states. Thus, our approach depends on the MTBE bans having fairly immediate and discrete impacts on fuel composition. Fig. 3 shows monthly ethanol and MTBE blending quantities at the national level and in each of the five Petroleum in Administration of Defense (PAD) Districts, or PADDs, which correspond to the East Coast, Midwest, Gulf Coast, Rocky Mountain, and West Coast regions of the country, all expressed as a volumetric percentage of total gasoline consumption in those regions.[18] The vertical lines correspond to the dates of major MTBE bans affecting these regions. Fig. 4 shows aggregate production of reformulated and conventional gasoline blended with ethanol and MTBE.[19] Table 2 shows ethanol′s share of total oxygenate blending in RFG based on EPA surveys of gasoline content in RFG cities during the summer

[18] We divide ethanol and MTBE blending quantities by total production by region to get regional blending shares. Data from EIA on blending quantities are available here: http://www.eia.gov/dnav/pet/pet_pnp_inpt_dc_nus_mbbl_m.htm. Data from EIA on total production are available here: http://www.eia.gov/dnav/pet/pet_pnp_refp_dc_nus_mbbl_m.htm.

[19] Data from EIA available here: http://www.eia.gov/dnav/pet/pet_pnp_wprodrb_dcu_nus_w.htm.

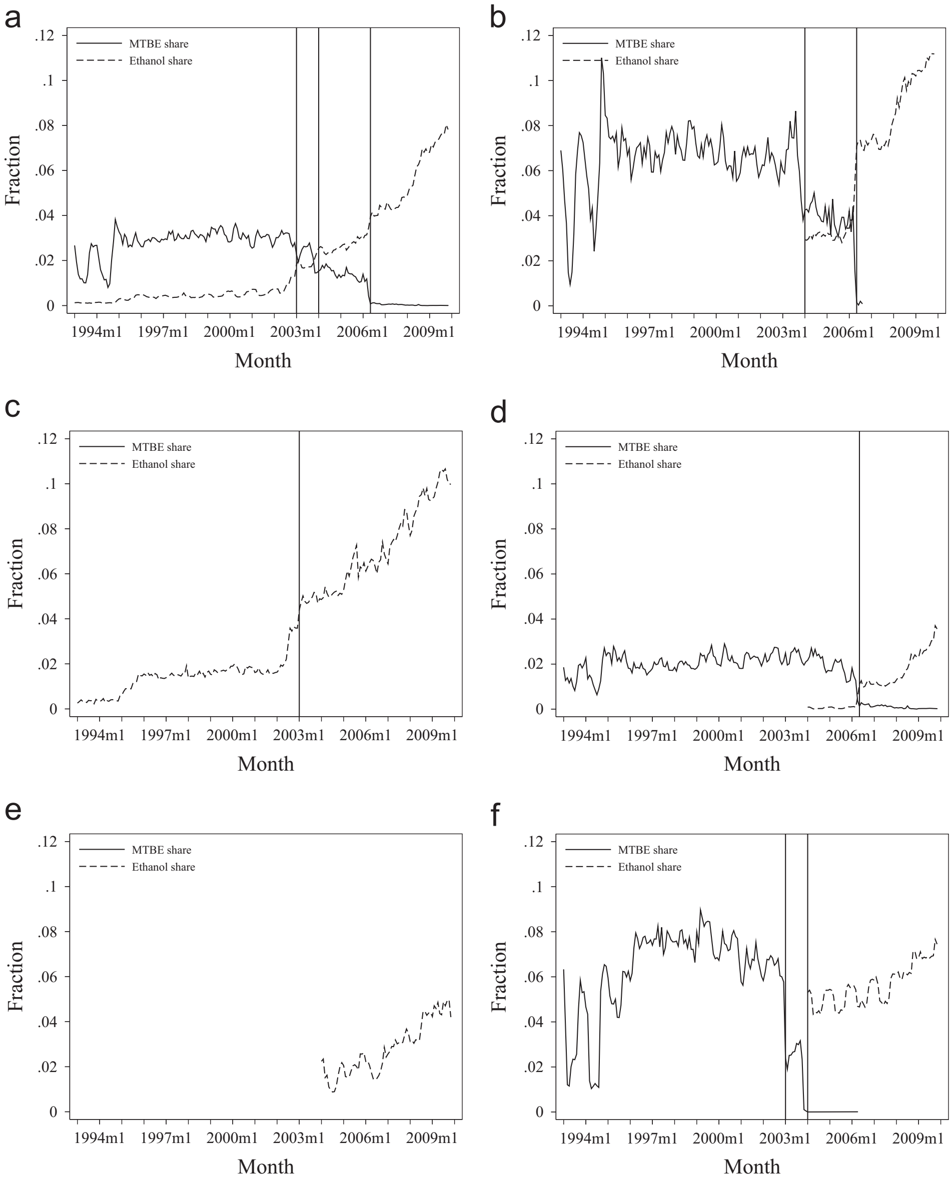

Fig. 3. Ethanol and MTBE blending quantities by region. (a) United States. (b) East Coast (PADD 1). (c) Midwest (PADD 2). (d) South (PADD 3). (e) Rocky Mountain (PADD 4). (f) West Coast (PADD 5). *Note*: These figures show monthly ethanol and MTBE volumetric blending shares by U.S. Petroleum Administration for Defense District (PADD). Vertical lines correspond to California's initial MTBE ban and Kentucky's phase-out (January 2003), bans in California, Connecticut, New York, and Washington (January 2004), and the nationwide ban (May 2006) for the regions in which these policy changes were active. See text for details.

months (U.S. Environmental Protection Agency, 2006).[20] All these data show that the MTBE bans had large, discrete effects that coincided with the timing of their enforcement.

Fig. 3(b) shows a precipitous decline in MTBE consumption on the East Coast in 2004 that coincided with the New York and Connecticut bans that year, another sharp decline in MTBE consumption at the time of the nationwide phase-out in 2006, and a corresponding surge in ethanol consumption in 2006.[21] Similarly, Fig. 3(d) shows a drop in MTBE consumption in the South and corresponding increase in ethanol consumption in 2006. Fig. 3(f) shows a precipitous decline in MTBE

[20] Data from EPA here: http://www.epa.gov/oms/fuels/rfgsurvey.htm

[21] EIA hides ethanol consumption quantities in earlier years to maintain confidentiality; ethanol consumption presumably spiked in 2004 when the New York and Connecticut bans took effect.

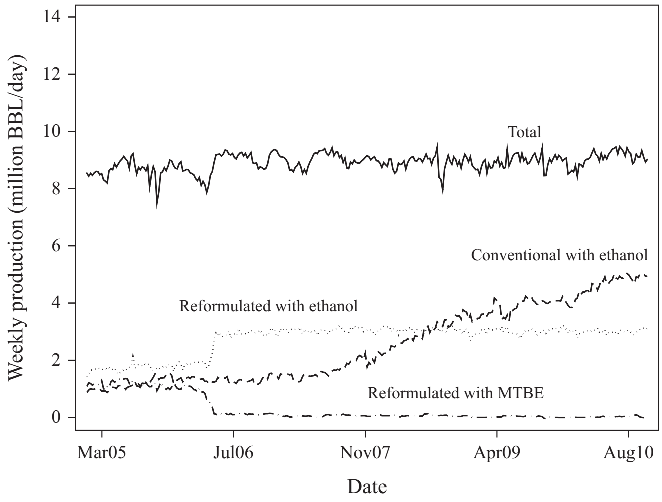

Fig. 4. Gasoline production. *Note*: This figure shows weekly U.S. production of gasoline, conventional gasoline blended with ethanol, reformulated gasoline blended with ethanol, and reformulated gasoline blended with MTBE. See text for details.

consumption on the West Coast that coincided with the California ban in 2003–2004.[22] Table 2 confirms these patterns of ethanol and MTBE consumption in RFG for the East Coast, the South (namely, Texas), and the West Coast.

Fig. 3(c) shows a surprising increase in ethanol consumption in the Midwest in 2002–2003, since no bans affecting RFG areas took effect that year.[23] Table 2 shows that RFG suppliers in Kentucky and Missouri (both located in the Midwest PADD) switched from MTBE to ethanol in 2002–2003. While MTBE bans in these states took effect in 2005 and 2006, the bans were enacted in the summer of 2002.[24] In addition, Michigan's MTBE ban in 2003 also likely played a role. Michigan had no RFG, but ethanol and MTBE are also valued as octane boosters. In any case, most Midwestern states were already using ethanol prior to when their MTBE bans took effect. Thus, it will be important in our empirical analysis to distinguish the Midwest from the rest of the country where the MTBE bans were actually binding.

Figs. 3 and 4 show a marked rise in ethanol blending beyond 2007, even though the industry had all but eliminated MTBE from gasoline by this time. The likely reason is that the federal RFS had begun to bind, creating incentives to blend ethanol beyond what earlier regulations required. Beyond 2007, it is clear that ethanol consumption is rising above the level necessary to replace the banned MTBE. A binding federal RFS will tend to increase national gasoline prices, while diminishing the shadow cost of an individual state's MTBE ban or ethanol mandate relative to gasoline prices in other states. Thus, we suspect that a binding RFS pushes the estimated impacts of state-level MTBE bans toward zero.

Econometric models and estimation results

In this section we present our econometric analyses for retail gasoline prices. We begin by estimating the impact of MTBE bans on average gasoline price levels by state. We then estimate the impact of the bans on the monthly pass-through rates for key commodity inputs, including crude oil, ethanol, and MTBE.

Data sources

We obtain monthly, state-level data on pre-tax retail gasoline prices from the U.S. Energy Information Administration (EIA). These data report average prices for reformulated and conventional gasoline.[25] We express these and all other prices in January 2009 dollars using the Consumer Price Index (all goods, urban consumers) from the Bureau of Labor Statistics. In our econometric analysis below, we focus on the years 1996–2009—a period that covers all state MTBE bans and during

[22] California's ban was originally scheduled to take effect in 2003, with several gasoline suppliers committing to eliminate MTBE that year. The ban was then delayed until 2004 and some suppliers waited (Executive Department State of California, 2002). Table 2 shows that the Los Angeles area nearly eliminated MTBE in 2003, while other areas cut their MTBE consumption roughly in half, and that all areas in California had switched to ethanol by 2004.

[23] While Minnesota increased its explicit ethanol blending requirement from 2.7% to 10% in 2003, the state was already subject to a year-round oxygenation requirement and MTBE ban. Thus, as far as we can tell, Minnesota's policy change in 2003 should have had little effect on ethanol blending.

[24] Besides the MTBE bans, low ethanol prices around this time would have created fairly strong incentives to boost volumes using ethanol as a direct gasoline substitute in regular gasoline, and the Midwest was in a position to do so, given that it already had ethanol distribution and blending infrastructure.

[25] Available here: http://www.eia.gov/dnav/pet/pet_pri_allmg_a_EPM0_PTA_dpgal_m.htm. Conventional gasoline includes winter oxygenated gasoline in cities and time periods subject to such regulation. While price data for winter oxygenated gasoline areas are also reported separately, these data include many missing observations. In addition, the specific cities and time periods subject to winter oxygenation change over time, conflating changes in gasoline content regulations with changes in seasonality and geography.

Table 2
Ethanol market shares in Reformulated Gasoline, Summers 1999–2006.

Area	1998	1999	2000	2001	2002	2003	2004	2005	2006
MIDWEST									
Chicago, IL-Gary, IN	96	100	100	100	100	100	100	100	100
Milwaukee-Racine, WI	97	100	100	100	100	100	100	100	100
St. Louis, MO		20	13	15	98	97	99	100	100
Louisville, KY	30	24	21	26	19	100	100	100	100
Covington, KY	46	75	67	66	67	100	100	100	100
EAST COAST									
Knox-Lincoln Co, ME									
Lewiston-Auburn, ME	0								
Portland, ME	0								
Manchester, NH	0	0	0	0	0	0	0	0	100
Portsmouth-Dover, NH	0	0	0	0	0	0	0	0	100
Springfield, MA	0	0	0	0	0	0	3	24	100
Boston-Worcester, MA	0	0	0	0	0	0	0	3	100
Poughkeepsie, NY	0	0	0	0	0	0	98	100	100
NYC-Long Island, NY-NJ-CT	0	0	0	0	0	0	54	56	100
Hartford, CT	0	0	0	0	0	0	99	100	100
Connecticut	0				0	0	99	100	100
Warren Co, NJ	0	0				0	0	0	100
Atlantic City, NJ		0	0	0	0	0	0	0	100
Rhode Island	0	0	0	0	0	0	0	3	100
Sussex Co, DE		0	0	0	0	0	0	0	99
Philadelphia, PA	0	0	0	0	0	0	0	0	100
Baltimore, MD	0	0	0	0	0	0	0	0	96
Queen Anne-Kent Co, MD				0	0		0	0	93
Washington, DC	0	0	0	0	0	0	0	0	100
Norfolk-Virginia Beach, VA	0	0	0	0	0	0	0	0	99
Richmond, VA	0	0	0	0	0	0	0	0	100
GULF COAST									
Dallas-Forth Worth, TX	0	0	0	0	0	0	0	0	99
Houston-Galveston, TX	0	0	0	0	0	0	0	0	100
WEST COAST									
Phoenix, AZ									
Los Angeles, CA	0	0	0	7	9	93	100	100	
Sacramento, CA	0	0	0	6	7	41	100	100	
San Diego, CA	0	0	0	4	5	65	100	100	
San Joaquin, CA						32	100	100	

Note: This table reports ethanol's summer market share in RFG by year and region, expressed as a percentage of average oxygenate content (ethanol plus MTBE, by weight) that comes from ethanol. The boxes denote location and timing of samples affected by new MTBE bans. All bans are state bans, with the exception of Chicago's city ban in 2001. Note that California's ban initially was to begin in January 2003. See text for details.

which other major fuel regulations that affected oxygenate blending remained largely unchanged. We obtain monthly crude oil prices from the EIA. These data measure national average prices paid by domestic refiners for imported crude oil.[26] We obtain monthly ethanol prices from the State of Nebraska Energy Office, which measures monthly wholesale rack prices in Omaha, Nebraska.[27] We obtain weekly data on wholesale MTBE prices from Platts, which measure wholesale rack prices on the U.S. Gulf Coast. We used these data to calculate monthly average prices. Table 3 presents summary statistics for these price variables.

To preview our pass-through results, Table 4 presents conditional correlations between retail fuel and wholesale input prices both before and after an MTBE ban. Each correlation between a fuel price and an input price is conditional on the input prices of the other two inputs. For example, the reported coefficient between RFG and ethanol prices is the correlation after having controlled for the variation in crude oil and MTBE prices. The table suggests that conditional pass-through rates

[26] Available here: http://tonto.eia.doe.gov/dnav/pet/pet_pri_rac2_dcu_nus_m.htm.

[27] Available here: http://www.neo.ne.gov/statshtml/66.html. We also obtained weekly data on wholesale rack prices for several-dozen individual U.S. cities for 1996–2008. Monthly average prices based on this sample of cities closely align with the Nebraska series, which is publicly available for the entire sample period.

Table 3
Summary statistics.

Variable	Mean	Std. dev.	Observations
$price_{conventional}$	1.56	0.62	7225
$price_{rfg}$	1.58	0.61	2971
$price_{wholesale}$	1.54	0.61	8364
$price_{oil}$	0.97	0.53	8415
$price_{ethanol}$	1.19	0.53	8415
$price_{mtbe}$	1.46	0.59	7599

Note: This table reports summary statistics for the retail gasoline and wholesale input prices used in the estimation. All prices are in real 2009 dollars per gallon. See text for details.

Table 4
Conditional correlations of retail gasoline prices with wholesale input prices.

Wholesale input price	Conventional gasoline		Reformulated gasoline	
	Pre-ban	Post-ban	Pre-ban	Post-ban
$price_{oil}$	0.5671	0.6769	0.6300	0.6594
$price_{mtbe}$	0.2917	0.3390	0.4252	0.3816
$price_{ethanol}$	0.2370	0.5509	0.3434	0.6162
Observations	5719	5719	1880	1880

Note: This table presents correlation coefficients between state-level retail gasoline prices and national wholesale input prices for states and time periods for which no MTBE ban was in effect (Pre-ban), as well as for states and time periods for which MTBE was banned (Post-ban). Correlation coefficients for one input are conditional on the prices for the other two inputs. For example, to calculate the correlation coefficient of 0.5671 in the first row and column, we regressed both conventional gasoline and crude oil prices on MTBE and ethanol prices; the reported number is then the correlation coefficient between the residuals for gasoline and the residuals for crude oil.

for crude oil are similar before and after an MTBE ban. Pass-through rates for ethanol are markedly higher following a ban, while the evidence on MTBE prices is mixed, and the changes are smaller in magnitude.

Gasoline price levels

We estimate the effects of MTBE bans on average pre-tax retail gasoline price levels using the following econometric equation:

$$p_{jst} = \alpha_{jt} \cdot ban_{jst} + \delta_{js} + \theta_t + \varepsilon_{jst}, \tag{1}$$

where p_{jst} is the average price of gasoline sold in state j in calendar month s at time t. The policy variable of interest is ban_{jst}, which is a dummy variable indicating whether a given state is subject to an MTBE ban in a given month, including both state bans as well as the implicit nationwide ban for all states starting in May 2006 and onwards. The coefficient of interest is α_{jt}, which measures the effect of the MTBE ban on average gasoline prices. The variable δ_{js} is a state-calendar month (e.g., Michigan–July) fixed effect that controls for persistent differences in average prices across states and calendar months, including seasonality in local gasoline content regulations. The variable θ_t is a month (e.g., May-1996) fixed effect that controls for time trends that are constant across states.[28] Lastly, ε_{jst} is an error term that we assume is uncorrelated with the MTBE bans.

We have reason to believe that the effect of an MTBE ban will vary over time t and across locations j. For example, MTBE bans will likely have milder effects on gasoline prices in the Midwest, while MTBE bans could raise average prices dramatically when ethanol prices are high. Thus, we allow α_{jt} to vary for Midwestern and non-Midwestern states and with input prices for crude oil, ethanol, and MTBE. In our most general and favored model, the impact of an MTBE ban on gasoline prices takes the form:

$$\alpha_{jt} = \beta_0 + \beta_1 \cdot mw_j + \sum_{input} (\beta_{input} + \gamma_{input} \cdot mw_j) \cdot price_{input,t}, \tag{2}$$

where mw_j is a dummy variable indicating whether a state is in the Midwest PADD and p_{input} is the wholesale price of a particular gasoline input—crude oil, ethanol, or MTBE—less its sample mean (reported in Table 3). Thus, we can interpret β_0

[28] Ancillary regressions show that month and state-calendar month fixed effects alone control for 98.9% and 99.6% of the variation in ethanol and crude oil prices across states and over time, based on the limited number of states for which these more detailed data are available. Thus, it is unlikely that our measurement of input prices at the national rather than at the state level affects our results substantially.

Table 5
Main estimation results: gasoline price levels (dollars).

Coefficient	Conventional gasoline				Reformulated gasoline			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
ban	0.014**	0.017**	0.006	0.007	0.013	0.017	0.044***	0.059***
	(0.007)	(0.008)	(0.006)	(0.011)	(0.010)	(0.011)	(0.014)	(0.015)
$ban \times p_{oil}$			−0.084**	−0.041			−0.041	−0.003
			(0.034)	(0.040)			(0.058)	(0.060)
$ban \times p_{ethanol}$			0.020	0.034**			−0.012	0.003
			(0.013)	(0.017)			(0.019)	(0.020)
$ban \times p_{mtbe}$			0.003	−0.057**			−0.037**	−0.078***
			(0.015)	(0.025)			(0.018)	(0.023)
$ban \times mw$		−0.005		0.002		−0.012		−0.048***
		(0.007)		(0.011)		(0.009)		(0.017)
$ban \times mw \times p_{oil}$				−0.051**				0.013
				(0.025)				(0.031)
$ban \times mw \times p_{ethanol}$				−0.021**				−0.044***
				(0.010)				(0.015)
$ban \times mw \times p_{mtbe}$				0.077***				0.072***
				(0.021)				(0.025)
Observations	7225	7225	6527	6527	2971	2971	2684	2684

Note: This table reports main estimation results. Dependent variable is the average real price of gasoline (either conventional or reformulated) in a given state and month in real 2009 dollars. All regressions control for month (e.g., November 2004) and state-calendar month (e.g., Massachusetts-March) fixed effects. Standard errors in parentheses are robust to serial correlation and heteroskedasticity (Newey–West standard errors with a 7-month lag). *, **, and *** indicate coefficients that are statistically different from zero at the 10%, 5%, and 1% levels, respectively.

as the effect of an MTBE ban on gasoline prices outside of the Midwest when crude oil, ethanol, and MTBE prices equal their sample-mean values, while $\beta_0+\beta_1$ is the corresponding effect in the Midwest. The summation term then allows these effects to vary as input prices deviate from their sample-mean values.[29]

We estimate Eq. (1) separately for conventional gasoline (which includes winter oxygenated fuel in affected areas) and RFG using OLS. Thus, our estimates do not directly yield the average effect of an MTBE ban for all states. Rather, the estimated effect of an MTBE ban on the price of RFG should be interpreted as conditional on a state's use of that fuel in the areas subject to RFG regulation, and likewise for conventional gasoline. The key identification assumption is that the timing of the MTBE bans is uncorrelated with state trends in state gasoline prices. This is a reasonable assumption given that bans were driven primarily by concerns about groundwater contamination and support for the ethanol industry, rather than in response to fuel prices, and were enacted months or years before they became effective. We estimate Newey–West standard errors, which are robust to both heteroskedasticity and serial correlation.[30]

Table 5 presents the results. Focusing on column (4), the coefficients on *ban* and on $ban \times mw$ indicate that the MTBE bans had virtually no effect on gasoline prices for conventional gasoline, either in the Midwest or elsewhere, when evaluated at sample mean oil, ethanol, and MTBE input prices. All else equal, however, a $1 increase in ethanol input prices increases the impact of the MTBE ban by about 3.4 cents per gallon outside of the Midwest, as indicated by the coefficient on $ban \times p_{ethanol}$. All else equal, a $1 increase in MTBE input prices decreases the impact of the MTBE ban by about 5.7 cents per gallon outside of the Midwest, as indicated by the coefficient on $ban \times p_{mtbe}$. The negative coefficients on $ban \times mw \times p_{ethanol}$ and $ban \times mw \times p_{mtbe}$ indicate that these impacts are considerably smaller in the Midwest, which makes sense, given that the Midwest would not have been consuming much MTBE prior to the bans anyway. Higher crude oil prices have a statistically insignificant effect on the ban's impact.

Moving now to column (8), which reports results for RFG, we should expect to see a similar pattern of coefficients. The magnitudes should be larger, however, reflecting the fact that all producers of RFG were required to blend either ethanol or MTBE prior to 2006 and had little flexibility to do otherwise, even after the oxygenation requirement for RFG was removed, given other constraints. The coefficient on *ban* indicates that the MTBE bans increased prices for RFG by 5.9 cents outside of the Midwest, assuming sample-mean input prices.[31] The impact on prices in the Midwest is not statistically different from zero. It is not surprising that these impacts are bigger for RFG than for conventional fuel, since RFG requires oxygenate

[29] Since an MTBE ban in one state could potentially affect gasoline prices in a different state indirectly via national wholesale markets for fuel inputs, these interactions are also important for identifying all-else-equal effects in the presence of general-equilibrium spillovers.

[30] We regressed the OLS residuals on their lagged values after 1 month, 2 months, and so on. We found these autocorrelations to be significant for lag lengths as long as 7 months. Thus, we use a 7-month lag when calculating our Newey–West standard errors. To test the robustness of our standard error estimates, we also varied the lag length from 3 to 11 months. While estimated standard errors tended to increase with longer lag lengths, the increase was so slight that it did not meaningfully affect precision relative to the magnitude of our point estimates.

[31] These results are consistent with Brown et al. (2008) who find that RFG regulations increased wholesale gasoline prices in select Midwestern cities by 4–9 cents *more* than on the coasts, mainly reflecting higher refining costs for the ethanol-ready RFG blendstock used in the Midwest. Our higher estimates for retail gasoline in coastal states reflect both these higher refining costs, as well as the add-on costs for ethanol transportation and blending.

blending, either directly or indirectly—as the lowest-cost approach to meeting other RFG performance standards—and because blending ethanol with RFG requires that refiners significantly reduce the RVP of the underlying gasoline blendstock.

Again, these impacts depend on input prices. Strangely, higher ethanol prices do not increase the impact of the ban, although higher ethanol prices decrease the impact of the ban in the Midwest relative to other states, as expected. Higher MTBE prices strongly reduce the impact of the MTBE ban outside of the Midwest, however, while having little effect on the impact of a ban in the Midwest. These impacts are all higher for RFG than for conventional fuel, which is not surprising, given the greater flexibility of conventional fuel producers. The impact of a ban on RFG prices does not appear to be sensitive to crude oil prices, controlling for other inputs.

In addition to these preferred models, the table also presents results for models that restrict the impacts of MTBE bans to be the same for all states and time periods (columns 1 and 5), different across states but the same across time periods (columns 2 and 6), and different across time periods but the same across states (columns 3 and 7). Two patterns emerge. First, the estimated impact of an MTBE ban is smaller when imposing a constant effect across all locations, which implies that it is important to differentiate the Midwest from states for whom the MTBE bans were binding. Second, the estimated impact of an MTBE ban declines in magnitude when not controlling for nationwide input prices. Apparently, either the timing of the MTBE bans is correlated with wholesale input prices, or local retail markets are connected via national input markets in ways that bias the coefficient estimates toward zero.

Monthly pass-through rates for wholesale inputs

We now estimate how MTBE bans alter monthly pass-through rates for wholesale input costs using the following econometric equation:

$$\Delta p_{jst} = \sum_{input} (\beta_{input} + \gamma_{input} \cdot mw_j) \cdot ban_{jst} \cdot \Delta p_{input,t} + \delta_{js} + \theta_t + \Delta\varepsilon_{jst}, \tag{3}$$

where Δp_{jst} is the monthly change in gasoline prices in state j in calendar month s at time t. The variables of interest are interactions between the state MTBE bans and monthly changes in the various input prices, given by $ban_{jst} \cdot \Delta p_{input,t}$. Thus, the corresponding coefficients given by $\beta_{input} + \gamma_{input} \cdot mw_j$ measure *changes* in input pass-through rates when a state imposes an MTBE ban. As before, these effects are allowed to differ regionally through an additional interaction with mw_j. Of the remaining terms, δ_{js} is a state-calendar month effect that allows retail prices to follow different time trends by state and calendar month in this first-differenced model, θ_t is a month effect, and $\Delta\varepsilon_{jst}$ is an error term. Note that the month effects prevent us from estimating pass-through rates directly, given that our input price data do not vary across states; we are only able to estimate *changes* in pass-through rates. Also note that we have omitted the direct effects of the bans, since the changeovers from MTBE to ethanol in response to state bans, while rapid, typically occurred over the span of several months leading up to the enforcement dates, with the exact timing varying from state to state. Thus, the direct effect on prices would be unlikely to show up in monthly first-differenced data.

As above, we estimate Eq. (3) separately for conventional gasoline and RFG using OLS. Here, the key identification assumption is that the monthly change in gasoline prices in a state is uncorrelated with the timing of its MTBE ban after controlling for linear state-calendar month trends, which is a weaker assumption than before.

Table 6
Main estimation results: gasoline price first differences (dollars).

Coefficient	Conventional gasoline		Reformulated gasoline	
	(1)	(2)	(3)	(4)
$ban \times \Delta p_{oil}$	0.098**	0.010	−0.035	−0.072
	(0.042)	(0.045)	(0.088)	(0.084)
$ban \times \Delta p_{ethanol}$	−0.011	0.046***	−0.051*	0.008
	(0.015)	(0.018)	(0.029)	(0.027)
$ban \times \Delta p_{mtbe}$	0.029*	−0.086***	−0.056**	−0.121***
	(0.016)	(0.018)	(0.025)	(0.024)
$ban \times mw \times \Delta p_{oil}$		0.133***		0.079
		(0.031)		(0.053)
$ban \times mw \times \Delta p_{ethanol}$		−0.080***		−0.152***
		(0.014)		(0.021)
$ban \times mw \times \Delta p_{mtbe}$		0.151***		0.157***
		(0.014)		(0.024)
Observations	6454	6454	2657	2657

Note: This table reports main estimation results. Dependent variable is the monthly change in the average real price of gasoline (either conventional or reformulated) in a given state and month in real 2009 dollars. All regressions control for month (e.g., November 2004) and state-calendar month (e.g., Massachusetts-March) fixed effects. Standard errors in parentheses are robust to serial correlation and heteroskedasticity (Newey–West standard errors with a 6-month lag). *, **, and *** indicate coefficients that are statistically different from zero at the 10%, 5%, and 1% levels, respectively.

Table 6 presents our results. Focusing on column (2), the coefficient on $ban \times p_{ethanol}$ indicates that an MTBE ban increases the monthly pass-through rate for ethanol prices by 0.046 outside of the Midwest, while decreasing the pass-through rate for MTBE prices by 0.086. In the Midwest, an MTBE ban does little to change the pass-through rate for ethanol prices, as expected. Surprisingly, an MTBE ban in the Midwest increases the pass-through rate for MTBE prices by $-0.086+0.151=0.065$ and increases the monthly pass-through for crude oil prices by $0.010+0.133=0.143$.

Now focusing on column (4), the coefficient on $ban \times p_{ethanol}$ indicates that the MTBE ban unexpectedly does little to change the monthly pass-through of wholesale ethanol prices to retail RFG prices outside of the Midwest, while the coefficient on $ban \times p_{mtbe}$ indicates that the ban decreases the pass-through of wholesale MTBE prices by 0.121, which is what we would have expected. In the Midwest, the MTBE ban unexpectedly decreases the pass-through of ethanol prices while having little effect on the pass-through of MTBE or crude oil prices, as expected. Overall, however, the results are consistent with our conceptual model above. The MTBE bans generally increase the monthly pass-through of ethanol prices and decrease the monthly pass-through of MTBE prices outside of the Midwest, while having little effect on the pass-through of crude oil prices. In the Midwest, the ban′s effects either tend to zero or have the opposite sign as in other regions.

In addition to these preferred models, the table also presents results for models that restrict the effects to be identical across states (columns 1 and 3). As expected, imposing coefficients that are equivalent across states tends to reduce their magnitudes, which again implies that it is important to differentiate between the Midwest and the rest of the country.

Specification checks

To probe potential endogeneity and heterogeneity issues in our model, we performed a series of robustness checks. Detailed results tables for these robustness checks are provided in the Online Appendix, available for download from the publisher's online publication platform along with the actual paper.

One possible concern is that trends in omitted determinants of gasoline prices, such as refinery capacity or market structure, may differ across states and lead to biased estimates if these trends are correlated with the timing of MTBE bans. We address this concern by adding controls for state-specific quadratic time trends and PADD-year fixed effects to our main specification. Our estimates for conventional gasoline (columns 2–4 of Table 1 in the Online Appendix) differ little from our main results (column 1 of Table 1 in the Online Appendix). The only anomaly we find is that the average effect of an MTBE ban increases from zero to a small but significant 2.4 cents outside of the Midwest when we add PADD-year fixed effects; however this single coefficient remains small and insignificant in the other two robustness specifications.

Our estimates for RFG (columns 2–4 of Table 2 in the Online Appendix) are also similar to our main results (column 1 of Table 2 in the Online Appendix). Controlling individually for state-specific quadratic time trends and PADD-year dummies leads MTBE bans to have somewhat smaller average effects of 4.6 and 4.1 cents outside of the Midwest, both of which are significant at the 1% level; effects in the Midwest are not statistically different from zero. However, when we include both controls simultaneously, we find an average effect of only 2.6 cents for states outside of the Midwest, although this coefficient remains statistically significant at the 5% level. Coefficients on the various interaction terms are similar to our main results across these specifications.

Another potential concern is that the timing of MTBE bans may respond endogenously to gasoline prices, even after controlling for state and regional trends. For example, legislators may be less willing to enact bans during periods of unusually high prices, leading to bias. To explore this possibility we include a dummy variable for when a state *enacted* legislation banning MTBE, as well as interactions of this variable with input prices and the Midwest dummy variable. Thus, the coefficient on *ban* is identified based on variation across states in the time from enactment in legislation to actual enforcement. The estimates (column 5 of Tables 1 and 2 in the Online Appendix) imply that a ban′s *enactment* has no impact on gasoline prices when evaluated at average input prices, while a ban′s *enforcement* has qualitatively similar effects as in our preferred model when evaluated at average input prices. Surprisingly, the interactions of MTBE enactment with input prices are large and significant in a handful of cases, but the coefficients on the interactions of MTBE enforcement with input prices continue to tell a qualitatively similar story.

Another potential concern is that since the decision to implement a state ban is not randomly assigned, states that enacted a ban before the nationwide ban may be inherently different from states that never passed any MTBE legislation. A related concern is that states that ban and those that do not ban follow different trends, potentially leading to bias. To allow for this heterogeneity, we include a separate set of month (e.g., November-2004) fixed effects for the group of states that actively ban MTBE through state legislation. Thus, states that actively banned MTBE are allowed to follow an entirely different time trend, while the implicit nationwide ban is not used to identify the effects of MTBE bans.[32] Again the estimates (column 6 of Tables 1 and 2 in the Online Appendix) are akin to our preferred specification. When we both control for enactment dates and allow for separate time trends in this way (column 7 of Tables 1 and 2 in the Online Appendix), the results are also similar.

To address all these potential sources of bias simultaneously, we estimate our model using all the aforementioned controls: state-specific quadratic trends, PADD-year fixed effects, dummy variables for enactment dates, and the separate time trend for states that actively ban. Coefficient estimates based on this regression (column 8 of Tables 1 and 2 in the

[32] We have replicated this analysis using a sample that consists only of the states that actively banned MTBE and confirmed that the results are indeed identical.

Online Appendix) differ from our main results in some of the same ways described above, which is not surprisingly, but the signs and magnitudes continue to be consistent with our main results overall.

Another potential concern is that suppliers in some states may have responded to MTBE bans preemptively, potentially contaminating our estimates if these preemptive responses had any impact on gasoline prices. To explore this issue, we run four new regressions in which we add control variables indicating whether enforcement of a ban will begin in 3, 6, 9, or 12 months′ time—that is, we include "leads" of our main policy variable. In each of these four regressions, we find (see Table 3 of the Online Appendix) that the coefficients on the "current" ban variables and their interactions are unchanged, while the "lead" indicators are highly insignificant. In particular, the 3, 6, 9, and 12-month lead indicators have coefficients (and P-values, in parentheses) of 0.011 (0.425), 0.003 (0.781), 0.016 (0.204), and 0.020 (0.123), respectively. In addition, when we include all four of these "lead" variables simultaneously, the results are again the same and we cannot reject that the lead variables are all jointly zero (*P*-value of 0.283). Reassuringly, this "no effect" finding is consistent with our identification assumption above that the timing of MTBE bans is uncorrelated with pre-existing trends in gasoline prices.

Finally, a total of six states enacted MTBE bans that took effect after the nationwide phase-out in the spring of 2006. In principle, these bans should have had no effect on gasoline price levels or input price pass-through rates, given the nationwide phase-out. This is a testable hypothesis. Thus, we create another policy variable, called $lateban_{jst}$, which equals one for states whose bans took effect after May 2006, in the months these "late" bans were in effect, and zero otherwise. We then repeat each of the regressions in Tables 1 and 2, including both $lateban_{jst}$ and its interactions with wholesale input prices as additional controls. There is no need to differentiate this policy variable by location, however, since every state with a late MTBE ban was located outside of the Midwest. We find (see Table 4 of the Online Appendix) that the individual coefficients on the late ban variables are generally small and statistically insignificant. We also test for the joint significance of the *lateban* variables. In our preferred specifications that include both interactions with the Midwest dummy and input prices, the late MTBE bans are only borderline significant at the 8% and 16% levels. Overall, these results are consistent with our identification assumption above that enforcement of state MTBE bans was not timed in a way that correlated with gasoline prices, conditional on controls. When we examine the effects of late bans on pass-through rates for wholesale input prices (see Table 5 of the Online Appendix) the results are somewhat less rosy. While most coefficients are again statistically insignificant, the interactions with ethanol prices are large and significant, and the late ban variables are jointly significant. One possible explanation is that, since the nationwide phase-out was not a literal ban, MTBE is in fact used in some rare circumstances when other options are quite costly. In any case, these late bans only occur in four RFG locations, including Maine, New Hampshire, New Jersey, and Rhode Island.

Conclusion

We estimate the impacts of MTBE bans on gasoline prices. While interesting in their own right, we show that these bans approximate direct ethanol blending mandates in areas that require oxygenate blending. Thus, these bans help us learn about the potential effects of renewable fuel blending mandates on gasoline prices. We find that MTBE bans increased RFG prices by 3–6 cents per gallon in areas where the bans were binding. The impacts of a ban would have been bigger had ethanol prices been higher or had MTBE prices been lower. These results represent the first rigorous empirical confirmation of the theoretical result that a percent ethanol blending mandate will inevitably increase fuel prices in a competitive market when the ethanol supply curve is more steeply sloped than that of gasoline (see Holland et al., 2008)—with the obvious qualification that this inference is based on a surrogate policy with similar economic structure.

There are several important caveats to our results and their interpretation. First, we have identified the effects of the MTBE bans on consumers through retail prices. A more complete welfare analysis would obviously require information on producer costs, as well as information on the potential health benefits to those not exposed to environmental contamination. Second, we only present reduced-form impacts on retail prices during the era of the MTBE bans. While we partially decompose these effects according to prices for wholesale inputs, the effects could look different in the long run, as new ethanol blending infrastructure is added, or under substantially different market conditions. Third, while we have shown qualitatively that a state MTBE ban can approximate a state ethanol mandate under certain conditions, the two policies are not identical. Moreover, the shapes of the ethanol and gasoline supply curves to a particular state could look quite different from the shapes of national supply. Thus, while a state ethanol mandate might have qualitatively similar effects to a national RFS, the precise magnitudes would likely differ considerably.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016//j.jeem.2013.11.009.

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