Regulated and Unregulated Almost-Perfect Substitutes: Aversion Effects from a Selective Ethanol Mandate

Michael D. Noel* and Travis Roach†

April 28, 2014

Abstract

The Lucas Critique warns that regulations not accounting for potential market reactions can be mitigated or even defeated by those changes in behavior. We highlight a unique example of this with the recent ethanol blending mandate on gasoline in Australia. The Australian mandate was "selective" in that it called for ethanol to be blended into regular grade gasoline but not into premium gasoline, even though those products are near perfect substitutes for the majority of drivers. We test for and find significant aversion switching away from the newly mandated ethanol blend and towards its unregulated premium grade substitute. The effect was so pronounced that premium grade gasoline became the number one selling grade of gasoline and not even the second of the mandate's four ethanol percentage targets could be reached. We estimate the total burden of the mandate on consumers and find it to be substantial. We then discuss the insights of the Australian experience as they inform the current controversial debate in the U.S. about whether to raise the ethanol-in-gasoline "blendwall" from ten to fifteen percent.

*Corresponding author. Michael D. Noel, Associate Professor, Department of Economics, Texas Tech University, Lubbock, Texas, michael.noel@ttu.edu.

†Travis Roach, Department of Economics, Texas Tech University, Lubbock, Texas, travis.roach@ttu.edu.

1 Introduction

Regulation is a tool policymakers can use to help steer markets away from socially suboptimal outcomes and toward more efficient ones. Regulations work by altering market incentives, potentially changing choice sets, and inducing reactions by market participants. Some market reactions are by design but others can have unexpected or undesirable side effects. The Lucas Critique warns that the latter can potentially offset or even defeat the goals of a regulation if not properly understood.

In this article, we examine an interesting example of a regulation where the Lucas Critique potentially plays an important role—the case of the selective ethanol blending mandate in the state of New South Wales, Australia.[1] The regulation required increasingly higher levels of ethanol to be blended into the overall gasoline supply over a five year period. It was "selective" in that it only required blending of ethanol into regular grade gasoline and not into premium grade gasoline. Regular gasoline would gradually be replaced with a ten percent ethanol blend, E10, while the much more expensive premium grade would remain ethanol-free.

The potential for Lucas Critique effects stems from the fact that regular and premium gasoline are perfect physical substitutes for one another in any vehicle that does not require the higher octane of premium gasoline already.[2] As regular is phased out, these consumers have the option of switching to E10, as was envisioned by regulators, or switching to the more expensive premium grade substitute that contained no ethanol at all.

[1] New South Wales is the most populous state and home to the city of Sydney.
[2] We discuss perceptions of quality differences between regular and premium grades later.

Regular and E10 grades are also close substitutes, but with two important caveats. First, E10 has a lower energy content per liter and so it tends to cost more. Second, for a small minority of consumers especially with older vehicles, there is the possibility that E10 could harm engine parts that were not originally designed for ethanol use. For this minority, regular and E10 are not good substitutes at all.[3]

More generally, ethanol blended fuel has been perceived by many as a lower quality and potentially riskier fuel. This is true even though the energy-adjusted price of E10 was roughly similar to regular, and even though the vast majority of consumers could use E10 without incident. Concerns surrounding ethanol, true or not, give rise to the potential for aversion effects when an ethanol free alternative is available.

We have two broad goals in the article. The first is to estimate the extent to which consumers avoided the mandated E10 by switching to the much more expensive but ethanol-free premium grade substitute. We find the effect to be surprisingly large and significant. So pronounced was the exodus into premium that soon after the inception of the mandate, premium grade gasoline went from an 18.4% market share to become the best selling fuel in New South Wales. As a result, not even the second of the four seemingly attainable ethanol targets could be met. We conclude the goals of the regulation were significantly offset by negative consumer reactions consistent with the Lucas Critique.

We also find interesting dynamics and strong diminishing marginal returns of the mandate over time. The least ethanol-averse consumers switched over to E10

[3] The desire to have a non-ethanol-blended product available to motorists with incompatible vehicles was a motivation for not mandating ethanol into premium grade gasoline.

relatively smoothly but, as regular became harder to find, the more ethanol-averse consumers had to switch and were increasingly likely to switch to premium. By the third phase of the mandate, six out of every ten consumers who lost access to regular passed over E10 and filled up with premium instead.

In addition to the mandate's impact on the composition of grades, we also test for potential price effects within grades, given the increased demand for premium, decreased availability of regular and increased the availability of E10. We found the price effects to be insignificant in every case, consistent with competitive constant cost industries. The main impact of the mandate was through the changing of the composition of grades purchased, away from the least expensive regular grade, and towards the slightly expensive E10 and the much more expensive ethanol-free premium grade.

We explore potential reasons for premium grade switching and distinguish between two general types – "incompatibility switching" by motorists who cannot use E10 due to potential vehicle compatibility issues, and "aversion switching" by motorists who can, but choose not to. We conclude each is substantial.

The second goal of the article is to estimate the consumer burden of the mandate in terms of the increased cost of fuel, in light of the unexpected switching that took place under the Lucas Critique.[4] We find the burden to be significant and, due to diminishing marginal returns, growing quickly over time. It averaged sixty million Australian dollars a year since the inception of the mandate in 2007, but by 2013 it was already two and a half times its average. We find that replacing one liter of

[4] There are many potential sources of burden and benefit from the mandate. Our focus is specifically on estimating the burden associated with the higher cost of fuel.

regular for one more liter of E10 into the overall fuel supply cost *forty-five* times as much in 2013 as it did in 2009. We also find that the burden borne by consumers who switched to premium (and paid a higher price for it) dwarfed the more obvious source of burden commonly associated with ethanol mandates – from consumers who switched to E10 (and paid a higher energy-adjusted price for it).

We discuss how the insights from the Australian experience are relevant to the current debate in the U.S. about raising the ethanol "blendwall" – i.e. the maximum allowable percentage of ethanol in a gallon of fuel for conventional (non-flex-fuel) vehicle use. With the current U.S. blendwall of 10% no longer sufficient to meet the escalating ethanol volume requirements under the U.S. mandate, one controversial option has been to increase it to 15%, i.e. switch out E10 for E15 at the pumps. It is controversial in part because auto manufacturers have warned that E15 is not compatible with 90% of the vehicles on the road (including almost all vehicles manufactured prior to 2012) and stated its use will void warranties. In spite of this, the EPA began rolling out E15 in 2012 labelled for use with all vehicles manufactured after 2001.

The competing claims from auto manufacturers and the EPA about the compatibility of the new fuel with the existing vehicle fleet, and the uncertainty it creates, parallels the Australian experience. Although the market share of E15 is still very small, we argue that if the EPA were to move too quickly on E15 and run ahead of vehicle compatibility and consumer confidence, there is the potential for both incompatibility and aversion switching, as occurred in a rather extreme way in Australia. We discuss recommendations on how to avoid the pitfalls of the Australian experience and transition to a higher ethanol blend – if it were in fact desirable to do so – with a minimum of transitional welfare loss.

2 Background

Ethanol mandates have become common over the past decade and currently sixty-two countries have some form of one (GRFA (2014)). A typical mandate requires producers to blend a certain percentage or certain volume of ethanol into the overall supply of gasoline. The U.S. mandate, for example, requires 18.2 billion gallons of renewable fuels, primarily ethanol, be blended into the gasoline supply in 2014, up from 16.6 billion in 2013 (EPA (2013)).[5] The European Union mandate requires 5.75% renewable fuels in gasoline by 2010 and 10% by 2020 (EU (2003, 2007)).

Ethanol mandates have been controversial (Rodriguez et al. (2011), Grafton et al. (2012), Serra & Zilberman (2013), Westbrook et al. (2014), and others). Proponents argue they help decrease the accumulation of greenhouse gases, promote a renewable source of energy, slow down the depletion rate of fossil fuels, and reduce dependence on foreign oil. They also point out increased profits accruing to the domestic farming and ethanol production industries which is sometimes considered a goal in and of itself.

Critics, on the other hand, argue the speculative benefits do not exceed the cost. Critics question the environmental value of the mandate given ethanol's energy-intensive production cycle, its low energy yield, and easier tendency to evaporate.

[5] The 2014 mandate is equivalent to requiring all gasoline have a 14% ethanol blend, instead of 10%, which is not immediately feasible. In addition to beginning to roll out E15, the EPA has proposed scaling back the mandate.

They argue against the need for fossil fuel replacement, pointing out the higher cost of ethanol-blended fuel (adjusting for its lower energy content) and the risk of higher food prices when crops grown for food are converted to ethanol use (Carter et al. (2013)). In the United States, for example, corn prices tripled following the introduction of the ethanol mandate.[6] Ethanol blending is also more costly because it requires a dual delivery infrastructure (since it is blended with gasoline only at delivery to the retailer) and there are concerns surrounding fuel-vehicle compatibility and the potential for long run damage especially for older vehicles.

New South Wales (NSW) is currently the only Australian state with an ethanol mandate. Other Australian states, notably Queensland, considered a similar mandate but plans were scrapped after public dissatisfaction. E10 was sold in fair quantities for a time in Queensland in anticipation of the mandate, but has since fell to insignificant levels. In other states, E10 has a negligible market share.

The mandate took effect in October 2007 and initially required that ethanol comprise a minimum of 2% of all gasoline volume sold in the state. That target was met only in late 2009. The minimum was then increased to 4% effective January 2010 and was scheduled to increase to 6% in January 2011. The latter was postponed to October 2011 and legislation that would have required all regular gasoline to be blended with 10% ethanol beginning in July 2012 was repealed and abandoned altogether.[7]

[6] The President of the National Corn Growers' Association testified before Congress in 2013 that there was no "discernable" effect of the mandate on the subsequent tripling of corn prices. NCGA (2013).

[7] See the Biofuels Act 2007; Biofuels Amendment Act 2009; NSW Government Gazette No. 133 of 10 December 2010, p. 5811; NSW Government Gazette No. 66 of 3 June 2011, p. 4667; Biofuels Amendment Act 2012.

Concerns about the use of ethanol in Australia have centered primarily around two issues. The first is about potential long run vehicle damage. While all vehicles can drive away on E10, there is concern that ethanol may cause corrosion and breakdown of engine valves, gaskets and seals over time in some vehicles, especially older ones.[8] (In contrast, all vehicles in the U.S., including those built before the notion of ethanol mandate was conceived, use a 10% ethanol blend today largely without incident.)

The second concern relates to the lower energy content and higher consumption rate of E10. Straight ethanol has about 33% less energy content than non-blended regular gasoline, and E10 has about 3.3% less. However, consumer perceptions about the true energy content of E10 vary substantially. E10 typically sells for a lower nominal price than non-blended regular, but because of the energy content differential, the energy-adjusted price is a little higher.

At a more general level, there is a perception that E10 is a lower quality fuel than non-blended regular and that (ethanol-free) premium gasoline is the highest quality of the three. In terms of fuel efficiency and, for some vehicles, compatibility, E10 is indeed lower quality than the other two. Ethanol-free gasoline contains approximately 114,000 BTUs (British Thermal Units) of energy per gallon, whereas E10 contains 110,300 BTUs.

However, premium's reputation as a higher quality fuel derives mainly from its

[8] Ethanol's quality and safety reputation in New South Wales was marred in the 1990s and early 2000s when hundreds of independent stations began selling a 20% ethanol blend at the pump without labelling it. Labels were not legally required at the time. Claims of vehicle damage following its use bolstered its reputation as an unsafe fuel. See, for example, Cornford & Seccombe (2002).

higher price and not from its performance.[9] The defining difference between premium and regular is the octane rating, or resistance to pre-ignition. In the absence of engine knocking, the higher octane has no advantage over the lower octane contained in regular grade gasoline.[10] All else equal, for motorists whose vehicles do not require the higher octane, regular and premium gasoline are almost perfect physical substitutes.

3 Data

To evaluate the impacts of the mandate, we use data on volumes and on retail and wholesale prices for each grade of gasoline – non-blended regular, E10, and premium for each mainland state – New South Wales, Victoria, Queensland, South Australia, and Western Australia. The data period extends from January 2004 to June 2013.

Gasoline volumes, by state, grade, and month, were obtained from the Bureau of Resources and Energy Economics (BREE) of Australia and converted to millions of liters per month.[11]

Average retail prices for regular and premium grades of gasoline, by month, for each major city in each state were obtained from Fueltrac.[12] Average retail prices for E10 for the same cities and months were obtained from Informed Sources.[13] Wholesale prices in Australia, known as terminal gate prices, for each major city

[9] See, for example, Setiawan & Sperling (1993).

[10] There is an irony in that ethanol increases the octane of fuel, so that the octane rating of E10 is close to that of premium fuel. We are not aware of any direct evidence that the mandate caused motorists whose vehicles require premium to switch "down" to E10.

[11] Premium and E10 volumes are available from July 2005.

[12] The price data covers a geography accounting for 62% of the population within those states.

[13] We have regular grade prices from both data sources and the two series are very similar.

and by month, were obtained from Orima Research. All retail and terminal gate prices are in Australian cents per liter.

Data on new vehicle sales, by month and state, were obtained from BREE and are reported in thousands of vehicles. Unemployment data was obtained from the Australian Bureau of Statistics. Information on fuel-vehicle compatibility was obtained from the Federal Chamber of Automobile Industries (FCAI), the Independent Pricing and Regulatory Tribunal (IPART), and Wilson et al. (2011).

Summary statistics for key variables are shown in Table 1.

4 Methodology

We use a difference-in-differences framework to estimate the impact of the ethanol mandate on the composition of grades sold and on prices within each grade. We estimate both reduced form models on equilibrium volumes and equilibrium prices, and then simultaneously estimate structural supply and demand systems, in each case controlling for relevant cost and demand factors.

The treatment state is New South Wales and the other mainland states act as mandate-free controls. The treatment period depends on the specification. We consider both a "single treatment" period model, with a single estimated effect following the inception of the mandate in October 2007, and a "multiple treatment" periods model, with three separate treatment periods commencing in October 2007, January 2010, and October 2011 respectively, and corresponding to the introduction of the three mandated percentages of ethanol, 2%, 4%, and 6%.

As a preliminary measure, we estimated pre-treatment trends in volumes and prices and found they were very similar and statistically insignificantly different from one another.

The basic estimating equation used in the reduced form analyses is given by

$$\begin{aligned} Y_{gst} &= \alpha_0 + \alpha_1 D_s + \alpha_2 D_{2,t} + \alpha_3 D_{4,t} + \alpha_4 D_{6,t} \\ &\quad + \alpha_5 D_s D_{2,t} + \alpha_6 D_s D_{4,t} + \alpha_7 D_s D_{6,t} + X_{gst}^A B^A + \varepsilon_{gst} \end{aligned} \tag{1}$$

where Y_{gst} is the variable of interest, either $VOLUME_{gst}$ or $PRICE_{gst}$, of gasoline grade g in state s at time t. Dichotomous variable D_s takes on a value of one for New South Wales, and dichotomous variables $D_{2,t}$, $D_{4,t}$ and $D_{6,t}$ take on values of one after October 2007, January 2010, and October 2011, respectively, so that the total effects of the mandate in the 4% and 6% periods, relative to the pre-mandate period, are the sums of the relevant coefficients. The "multiple treatment" model regressions are as written, and the "single treatment" model regressions impose the constraints $\alpha_2 = \alpha_3 = \alpha_4$ and $\alpha_5 = \alpha_6 = \alpha_7$. The coefficients of interest showing the impact of the mandate on Y are given by α_5, α_6, and α_7. The ε_{gst} is a normally distributed white noise error term.

The matrix X_{gst}^A contains additional control variables affecting equilibrium volume, from both supply and demand side sources. Let $X_{gst}^A = [X_{gst}^D, X_{gst}^S]$, where the columns of X_{gst}^D contain demand side explanatory variables and the columns of X_{gst}^S contain supply side explanatory variables. Let X_{gst}^D include the number of new vehicle registrations, lagged vehicle registrations, contemporaneous and lagged unemployment rates, and dichotomous indicator variables for each calendar month.[14] Let X^S_{gst} contain wholesale, or terminal gate, prices. Finally, let $B^A = [(B^D)^T, (B^S)^T]^T$,where B^D and B^S are column vectors of demand-side and supply-side parameters and T is the transpose operator.

For the structural analysis, we jointly estimate supply and demand functions. We consider two different joint specifications. The first joint specification is given by

$$\begin{aligned} VOLUME_{gst} &= \beta_0 + \beta_1 D_s + \beta_2 D_{2,t} + \beta_3 D_{4,t} + \beta_4 D_{6,t} \\ &\quad + \beta_5 D_s D_{2,t} + \beta_6 D_s D_{4,t} + \beta_7 D_s D_{6,t} + \beta_8 PRICE_{gst} + X^D_{gst} B^D + u_{gst} \end{aligned} \tag{2}$$

$$PRICE_{gst} = \gamma_0 + \gamma_1 VOLUME_{gst} + X^S_{gst} B^S + v_{gst} \tag{3}$$

where D_s, $D_{\{2,4,6\},t}$, X^D, X^S, B^D and B^S are as above, and u_{gst} and ν_{gst} are bivariate-normally distributed error terms. The matrix X^S instruments for $VOLUME$ and X^D instruments for $PRICE$.

The second structural specification recognizes that price may not only respond to current wholesale costs (terminal gate prices) but also to lagged costs. Moreover, the speed of price responses over time can depend on whether cost shocks are positive

[14] The number of new vehicle registrations is related to the stock of vehicles through the equation

$$STOCK_{st} = NEWVEHICLE_{sR} * \sum_{r=0}^{R} (1 + g_{t-r})/d$$

where g_{t-r} is the growth rate of new vehicle registrations in period $t - r$, d is a constant scrappage rate, and $NEWVEHICLE_{sR}$ is the number of new vehicle registrations in state s in the first year R. The new vehicle measure is preferable to a stock measure because, for relatively short sample period, it better reflects recent changes in the fuel efficiency of cars and because new cars on average are driven much more intensively than older cars. Thus it better reflects changes in gasoline demand.

or negative. The response pattern is known as asymmetric pass-through and it has been studied extensively (Borenstein, Cameron & Gilbert (1997), Noel (2009), Lewis (2009), Tappata (2009), Lewis & Noel (2011), and many others). To allow for lagged and asymmetric pass-through, and recognizing the cointegrated nature of retail and rack prices, we consider a vector autoregressive error correction model (VAR) in the spirit of Engle and Granger (1987):

$$\begin{aligned}\Delta PRICE_{gst} \quad = \quad & \delta_0 + \sum_{i=0}^{I} \delta^{+}_{1+i} \Delta TGP^{+}_{gs,t-i} + \sum_{i=0}^{I} \delta^{-}_{1+i} \Delta TGP^{-}_{gs,t-1} \\ & + \sum_{j=1}^{J} \delta^{+}_{1+I+i} \Delta PRICE^{+}_{gs,t-j} + \sum_{j=1}^{J} \delta^{-}_{1+I+i} \Delta PRICE^{-}_{gs,t-j} \\ & + \phi_2 (PRICE_{gs,t-1} - \varphi TGP_{gs,t-1} - X^S \Gamma) + v_{gst}\end{aligned} \tag{4}$$

where $\Delta TGP^{+}_{gs,t-i} = \max(0, \Delta TGP_{gs,t-i})$, $\Delta TGP^{-}_{gs,t-i} = \min(0, \Delta TGP_{gs,t-i})$, and $\Delta PRICE^{+}_{gs,t-j}$ and $\Delta PRICE^{-}_{gs,t-j}$ are similarly defined. The error correction term, in parentheses on the last line, represents the long run relationship between retail price and terminal gate prices, to which it can be expected to return.[15]

Decomposing the left hand side $\Delta PRICE_{gst} = PRICE_{gst} - PRICE_{gs,t-1}$, then adding $PRICE_{gs,t-1}$ to both sides, and adding $VOLUME_{gst}$ to the right yields our second version of the price equation:

[15] In the main reported specifications, X^S is a constant vector. We also estimated a model in which we included monthly indicator variables in X^S as we do for X^D. Coefficients on these variables were largely insignificant and their inclusion had no meaningful effect on any of the other parameters. We do not include prices other than own price in the X^S because prices are almost perfectly collinear in the sample, with pairwise correlations of 0.98, 0.98 and 0.997 for the three pair combinations. Shocks to relative price are effectively non-existent and therefore consumers cannot be switching as the result of changing relative prices. Our approach is consistent with the literature which, in its focus on regular grade of gasoline, typically uses a single price.

$$
\begin{aligned}
PRICE_{gst} &= \delta_0 + \sum_{i=0}^{I} \delta^{+}_{1+i} \Delta TGP^{+}_{gs,t-i} + \sum_{i=0}^{I} \delta^{-}_{1+i} \Delta TGP^{-}_{gs,t-1} \\
&+ \sum_{j=1}^{J} \delta^{+}_{1+I+i} \Delta PRICE^{+}_{gs,t-j} + \sum_{j=1}^{J} \delta^{-}_{1+I+i} \Delta PRICE^{-}_{gs,t-j} + \phi_1 VOLUME_{gst} \\
&+ (1+\phi_2) PRICE_{gs,t-1} - \phi_2 \varphi TGP_{gs,t-1} - \phi_2 X^{S} \Gamma) + v_{gst}
\end{aligned} \tag{5}
$$

that, along with the demand equation, is jointly estimated in the second structural specification.

For readability in the accompanying results tables, we denote D_s as NSW, and $D_{N,t}$ as $MANDATE\text{-}N$.

In the structural estimations, the mandate enters as a demand shock. For the premium gasoline analysis, the mandate is a pure demand shock since it did not affect premium supply or availability in any way, but only demand through the change in availability of a substitute. For other grades of gasoline, the mandate is an exogenous availability shock that manifests itself much like a demand shock does. This is because, for any given set of fixed prices, consumers were willing to purchase more E10 and less regular grade gasoline for that set of prices, because that is what was readily available – a $de\ facto$ shift of the respective demand curves.

Once armed with estimates of the impacts of the mandate on prices and volumes, we estimate the overall burden of the mandate by estimating the counterfactual path of volumes and prices in New South Wales absent the mandate and compare them to the actual paths. We are specifically interested in the change in the overall cost of fuel, for an identical amount of energy. We decompose the burden into the portion incurred by consumers who switched to premium and that incurred by consumers who switched to E10. We further decompose the premium switching component into "incompatibility" switching and "aversion" switching subcomponents and discuss their causes.

Throughout our burden calculations, we use energy-adjusted volumes and prices of E10, to reflect the same energy content of other grades. We assume that premium contains the same energy per liter as regular, all else equal, and later relax that assumption within reasonable bounds.

5 Results

5.1 Premium Grade Volumes

We begin with an examination of the mandate's impact on the volume of premium grade gasoline. Ethanol was not blended into premium and premium did not physically change as a result of the mandate. Its availability was also unchanged. In the absence of aversion switching, one would expect the mandate to affect premium volumes relatively little and only to the extent that there were consumers whose vehicles, typically older ones, were not compatible with E10.

Table 2 reports the difference-in-differences estimates on the impact of the mandate on premium grade volumes. We report reduced form estimates as Specification (1) through (4) and structural estimates as Specifications (5) and (6).

Specifications (1) and (2), without and with the full set of controls in X^A respectively, assume a single treatment period commencing in October 2007 through to the end of the sample period. Specifications (3) and (4), without and with additional controls respectively, allow for separate 2%, 4% and 6% treatment periods.

Specifications (5) and (6) contain the demand side parameter estimates from the jointly estimated structural supply and demand systems. Supply side results will follow in Table 3. Both specifications allow for three separate treatment periods. The difference between (5) and (6) is with the associated supply curve – in Specification (5), supply is a simple function of terminal gate prices using Equation 3 and in (6), it is a function of terminal gate prices embedded in the vector autoregressive framework as in Equation 5. Demand side variables include the difference-in-differences variables, price (instrumented by terminal gate prices on the supply side) and demand side variables in X^D. The coefficients of interest are the $NSW * MANDATE\text{-}N$ interaction terms.

We now turn to the results. The table shows that, for Specification (1), premium volumes increased by $NSW * MANDATE = \alpha_5 = \alpha_6 = \alpha_7 = 39.9$ million liters per month more than increases in control states, following the inception of the mandate in October 2007. It is significant at the 1% level with a t-statistic of about seven. This corresponds to an impressive 43.8% increase in premium volumes as a result of the mandate. Adding additional supply side and demand side controls in Specification (2) yields similar results.

This is our first main result – the mandate which sought to eliminate regular gasoline in favor of E10 caused a large shift away from the regulated (mandated) good towards its unregulated (non-mandated) almost perfect substitute – premium gasoline. As we discuss later, the shift was largely unexpected, costly to consumers, and did not advance the goals of the mandate. No ethanol was contained in premium gasoline.

Turning to the other control variables in Specification (2), the demand side controls are generally significant and of the expected sign, while the supply side control, terminal gate prices, is insignificant. These coefficients together suggest that, controlling for the presence or absence of a mandate, equilibrium volumes are largely driven by changes in demand side factors and not by changes in supply side factors. The result is a constant theme throughout our analysis.

Specifications (3) and (4) break down the effect of the mandate on premium volumes into three separate mandate periods–the 2%, 4%, and 6% periods. We find that premium volume increases are insignificantly different than zero in the 2% period but significantly higher, and dramatically so, in the 4% and 6% periods.

The fact that premium volumes did not increase as much in the early 2% period can be expected, as regular was still widely available and it would have been relatively easy for ethanol averse consumers wishing to avoid E10 to do so. The actual percentage of ethanol blended into gasoline lagged well behind the mandated minimum, increasing just 1% after one year and reaching the 2% level only at the very end of the 2% period, 26 months later.[16]

In the 4% and 6% periods, E10 continued to crowd out regular gasoline at the pump and regular became difficult to find in many areas. Premium volumes surged. Using Specification (3), we find that premium volumes in the 4% period increased by $\alpha_5 + \alpha_6 = -0.51 + 47.47 = 46.96$ million liters per month relative to the pre-mandate

[16] The early part of the 2% period corresponds with the record run-up in oil prices in the first half of 2008.

period and relative to control states, statistically significant at the 1% level. In the 6% period, premium volumes increased $\alpha_5 + \alpha_6 + \alpha_7 = 46.96 + 37.91 = 84.87$ million liters per month from the pre-mandate period, also significant at 1%. These correspond to 53.2% and 94.3% percent increases relative to pre-mandate levels. In other words, by 2012, premium volumes had almost *doubled* over pre-mandate levels in avoidance of the mandated good. Specification (4) yields similar results.

Specifications (5) and (6) report the estimates of the demand side parameters from the jointly estimated structural supply and demand model. In both specifications, estimates on the demand side control variables and the price variable are of the correct sign and generally significant. In Specification (5), corresponding to the simpler supply side model, the demand-side price coefficient is statistically significant and equal to -0.18 (a one cent price increase would decrease quantity demanded overall by 0.18 million liters). This implies an aggregate elasticity of demand at the means equal to -0.41. In Specification (6), which incorporates the full supply side VAR model, the implied demand elasticity is significant and equal to -0.26.

Turning to the effects of the mandate itself, the $NSW * MANDATE\text{-}N$ interaction term estimates are nearly identical across the two structural specifications. In Specification (5), monthly volumes of premium gasoline were higher by 48.68 million liters in the 4% period and 80.27 million liters in the 6% period. In Specification (6), the corresponding estimates are 48.03 million liters and 79.35 million liters per month. All are statistically significant at the 1% level with t-statistics of 11 or greater.

We note that the difference-in-differences estimates from the structural demand equation are very similar to those from the reduced form volume equation. This means that the mandate-induced increase in the volume of premium gasoline demanded, while holding prices constant (as in the structural model), and the mandate-induced equilibrium increase in volume, allowing prices to adjust (as in the reduced form model), are very similar. This in turn suggests that supply is highly elastic and we should expect little in the way of price effects from the mandate. We test and confirm this in the next section.

Taken together, the results of Table 2 show that the mandate led to a significant surge in premium grade volumes. The market share of premium grade gasoline in New South Wales rose from 18.4% in October 2007 to 38.6% in July 2013, while premium shares in other states were stable (increasing only half a percent during that period). In the United States, for comparison, the combined midgrade and premium share was stable at 15.4% over the same period.

Figure 1 shows a time series of the predicted premium market share in the absence of the mandate, with confidence intervals, and the actual premium market share in the presence of the mandate. The divergence between actual and predicted is clear in the graph.

The mandate's effect on premium volumes was so large that as of 2013, premium grade gasoline became the number one selling grade of gasoline in New South Wales. This significant switching behavior has important implications for the overall burden of the mandate on consumers, since premium grade gasoline is about 8% more expensive on average.

5.2 Premium Grade Prices

Table 3 reports difference-in-differences estimates of the mandate's impact on premium prices. There is a potential for premium prices, already higher to begin with, to become even higher because of the increased demand. If economies of scale dominate, they could fall instead. To assist matching with the earlier table, we report reduced form estimates of premium grade price effects as Specifications (1) through (4) again. As before, Specifications (1) and (2) assume a single treatment period and Specifications (3) and (4) use three treatment periods corresponding to the 2%, 4% and 6% mandate periods. We report estimates of supply side parameters from the simultaneously estimated supply and demand systems in Specifications (5) and (6), corresponding to the demand side estimates using the same specification numbers in Table 2. We report an abbreviated set of estimates for the VAR model of Specification (6) in Table 3, and report the complete set of VAR estimates, for this and later VAR models, in Appendix Table A1.

The reduced form specifications taken together point to the same conclusion – price effects of the mandate on premium prices are statistically insignificant and close to zero. In Specification (1), the monthly premium price increase in New South Wales relative to control states is estimated at $\alpha_5 = \alpha_6 = \alpha_7 = -0.27$ cents per liter with a t-statistic of just -0.1. In Specification (2), which controls for terminal gate prices, the $NSW * MANDATE$ variable continues to be insignificant. The coefficient on the terminal gate price variable itself is 0.995 with the t-statistic of over 90, showing the importance of controlling for wholesale prices in retail price regressions.

Specifications (3) and (4) taken together show a similar pattern – price effects due to the mandate are insignificant.[17] Terminal gate prices are important with a t-statistic of 83 in Specification (4). We include terminal gate prices in all specifications hereafter.

The lack of price effects in the reduced form price models is consistent with our earlier observation, that the similarity in the difference-in-differences estimates from the demand side of the structural model (which holds prices fixed) and from the reduced form volume model (which allows prices to vary) implies small and insignificant price effects.

This is further confirmed in the structural supply price equations. In Specification (5), the coefficient on quantity is positive and significantly different from zero but small, 0.04, implying an elasticity of supply at the means of 54.5 (very elastic). In Specification (6), with the full VAR model, the quantity coefficient is small and insignificant, implying an elasticity of supply at the means of $4,553$, insignificantly different from infinity (perfectly elastic). The supply curve is very close to flat, and premium prices were not significantly affected by the mandate and the subsequent shift in premium demand.

The coefficient on the terminal gate price, on the other hand, is 1.00 with a t-statistic of 68, using Specification (5). It cannot be statistically distinguished from one, i.e. complete pass-through.

[17] The opposite-sign coefficients on $NSW * MANDATE$-4 and $NSW * MANDATE$-6 in Specification (3) are indicative of the importance of terminal gate prices in the regression.

5.3 Regular and E10 Volumes

Table 4 reports difference-in-differences estimates of the mandate's impact on regular grade and E10 grade volumes. It will not be a surprise that regular volumes decreased and E10 volumes increased due to the mandate, as Table 4 shows. But getting the point estimates are important for estimating the burden. When consumers switched from regular to E10, they paid a little more per liter for it. Also, it turns out that these point estimates reveal important dynamics in consumer switching patterns over time, which in turn has important implications for the viability of the mandate.

The regular-to-E10 composition change is the one most commonly associated with consumer burden from an ethanol mandate. E10 replaces non-blended regular and since the energy-adjusted price of E10 is more, consumers pay more overall.

Specifications (7) and (8) report reduced form estimates of the reduction in regular grade volumes due to the mandate. Specification (9) is the demand equation for regular gasoline from the structural supply and demand system, where the corresponding supply equation uses the vector autoregressive error correction model. Both use multiple treatment periods, though conclusions are unchanged with single treatment period models. Specifications (10) through (12) are the matching specifications relating to E10. Each set corresponds to Specifications (3), (4) and (6) for premium grade volumes. An abbreviated set of estimates for the VAR specifications (9) and (12) are included, with complete results in Appendix Table A1.

Specification (7) shows that regular grade volumes in New South Wales decreased by $\alpha_5 = -49.37$ million liters per month (11.9%) in the 2% period, $\alpha_5 + \alpha_6 = -178.28$ million liters per month (42.9%) month in the 4% period, and $\alpha_5 + \alpha_6 + \alpha_7 = -241.21$

million liters per month (58.2%) in the 6% period, all relative to the pre-mandate period and relative to control states. Specification (8) adds additional controls and yields similar results. Turning to the structural demand estimates in Specification (9), the difference-in-differences estimates largely agree with the reduced form results (-41.94, -172.62, and -259.74 million liters per month respectively, corresponding to 10.1%, 41.6%, and 62.5% increases over pre-mandate levels). The price coefficient is -0.31, statistically significant, and implying a price elasticity of demand evaluated at the means of -0.17.

As regular volumes sank, E10 volumes rose. Specification (10) shows that E10 volumes increased by $\alpha_5 = 50.24$ million liters per month in the 2% period, $\alpha_5+\alpha_6 = 139.94$ million liters per month in the 4% period, and $\alpha_5 + \alpha_6 + \alpha_7 = 166.17$ million liters per month in the 6% period, all relative to the pre-mandate period and relative to non-affected states.[18] Specification (11) adds additional controls and yields similar results. The structural demand estimate in Specification (12) also shows a similar effect, with increases of 44.39, 133.84, and 164.81 million liters respectively. The price coefficient for E10 in the structural demand model is -0.002, small but statistically significant, and implying a price elasticity of demand evaluated at the means of -0.01.

Figure 2 shows a time series of the regular grade market share in the presence of the mandate (actual), and the counterfactual regular grade market share in the absence of the mandate (predicted), with confidence intervals. Figure 3 shows the same for E10. The effect of the mandate on regular and E10 volumes was significant,

[18] This corresponds to 1,149%, 3,201%, and 3,800% increases over the very tiny volumes that were sold prior to the mandate.

with regular falling precipitously and E10 volumes rising.

5.4 Diversion Ratios

The pattern of coefficients over time reveal interesting dynamics with important implications for the viability of the mandate. E10 did not rise as fast as regular fell, and over time, the two rates of change diverged. In other words, there was increasing diversion to premium, and therefore diminishing marginal returns of the mandate. The cost of adding each additional liter of ethanol into the overall fuel supply was rising.

Figure 4 shows estimated volume changes, by grade, in each mandate period and the diversion ratios implied by them. Specifications (3), (7) and (10) are used. The top panel shows the estimated volume changes for each period, except that for regular grade gasoline, we report the absolute value of the estimated change instead of the estimated change itself (for readability). Standard errors are shown as "whiskers" on the figure.

The bottom panel shows diversion ratios. The diversion ratio from regular to premium is the fraction of replaced regular volumes that were replaced by premium. The definition for the regular to E10 diversion ratio is similar.[19]

We find that, in early 2% period, the decrease in regular sales (-49.37 million liters per month) was almost entirely offset by an increase in E10 sales (50.24 million

[19] The number of liters of E10 and premium gained is close, but not exactly equal, to the number of liters of regular lost. There was a small overall net loss in volumes due to the mandate. Thus we normalize the diversion ratios so that the sum of the diversion ratio is to equal 100%. This means that the diversion ratio from regular to grade g is the number of additional liters of grade g sold divided by the number of regular liters lost that were replaced with either premium or E10.

liters, or 48.61 million energy-equivalent liters per month). There was no diversion to premium.

But thereafter, consumers in ever larger numbers began passing over E10 and diverting to premium gasoline instead. During the 4% period, not even $2/3^{rds}$ of lost regular volumes went to E10. Over $1/3^{rd}$ were converted to premium instead. The 128.9 million liter per month decrease in regular was replaced with 47.5 million liters of premium and 86.8 million energy-equivalent liters of E10. This implies for every additional one hundred liters of regular replaced, just 64.6 of those liters became E10 while 35.4 liters became premium. The latter does not advance the goals of the mandate, but costs consumers more.

Then, by the time of the final 6% period, premium actually became the first choice for replacement gasoline for consumers who switched. The loss of 63.4 million more liters of regular gasoline per month was replaced with just an additional 26.2 million liters of E10 but with an additional 37.9 million liters of premium. In other words, for every 100 liters of regular volumes replaced, only 40.1 liters went to E10 while 59.9 liters went to premium.

The increase in the regular-to-premium diversion ratio has important economic implications. There are diminishing marginal returns to forcing more ethanol into the supply. The Australian mandate appears to be well down that curve. In larger and larger numbers, consumers losing access to regular do not switch to E10. They switch to premium. The diversion ratios in the 6% period imply that mandating one more liter of E10 into the overall gasoline supply in 2013 was approximately *forty-five* times more expensive than it was in 2009.[20]

In fact, conditional on the current vehicle fleet, current public opinion, and these diversion ratios, the 6% mandated level of ethanol – which has not yet been reached in practice – cannot be reached at all. The maximum ethanol percentage by volume implied by these diversion ratios (if they stayed constant) is approximately 4.5%. The higher cost of increasing ethanol content in the short run and the benefit of doing so grew more imbalanced.

The escalation in diversion ratios over time is consistent with the following story of heterogeneous consumers in their degree of ethanol aversion. In the early days of the mandate, consumers who were not ethanol averse would simply use E10 if that is what the station they were at had. Ethanol averse consumers would continue to seek out regular. It was still relatively easy to do so because regular was still widely available. Then, as regular became more scarce, moderately ethanol averse consumers had to choose between making greater search efforts to find regular, or to use E10, or to switch to premium. A third of those who gave up on regular chose premium. Finally, as regular became more inconvenient, even the most ethanol averse consumers had to switch to either E10 or premium, and for the majority of them, almost 60%, they chose premium. There is reason to expect that a high proportion of those still purchasing regular as of 2014 are among the most ethanol-averse.

[20] In 2009, when the regular-to-E10 diversion ratio was 100%, one liter of regular was replaced with one liter of E10, which cost approximately 0.4 cents per liter more. In 2013 when the diversion was 40%, one more liter of E10 required a loss of 2.5 liters of regular and a collateral gain of 1.5 liters of premium. The extra cost of the one extra liter of E10 in 2013 was close to zero but the extra cost of the extra 1.5 liters of premium was approximately 19 cents. Dividing 19 cents by 0.4 cents, the 2013 cost is about 45 times greater than the 2009 cost.

5.5 Regular and E10 Prices

Table 5 reports estimates of the mandate's impact on regular and E10 prices. Specifications (8) and (9) relate to regular prices and Specifications (11) and (12) relate to E10 prices. All specifications include three treatment periods. The first specification in each set estimates equilibrium price impacts from the reduced form models using the full set of controls. The last one in each set estimates the supply relations from the jointly estimated structural supply and demand models, using the vector autoregressive error correction model, similar to Specification (6) for premium. All specifications are numbered the same as their volume/demand counterpart in Table 4 to facilitate matching.

As with the premium grade models, the reduced form and structural form models for regular and E10 point to the same conclusion–equilibrium price effects of the mandate are statistically insignificantly different from zero. This is true for both grades and for all mandate periods.

The lack of significance of the $NSW * MANDATE\text{-}N$ interactions is consistent with our earlier finding where we showed the impact of the mandate on quantity demanded, holding prices fixed (from the structural regressions), and on equilibrium volumes, allowing prices to vary (from the reduced form regressions), are similar. In other words, supply curves are flat.

Terminal gate prices, however, are highly significant, with a coefficient of 0.99 and a t-statistic of over 113 in Specification (8) and a t-statistic over 63 in Specification (11).

5.6 Burden and Incidence of the Mandate

We now turn to estimating the total burden of the mandate and the incidence across different types of consumers. The results have shown that the mandate caused a significant change in the composition of fuels, with more premium, more E10 and less regular purchased relative to a world without the mandate. One set of consumers switched from regular to premium, and paid about twelve cents (8%) more than they had for each liter (or about 43.1 U.S. cents per gallon). A second set of consumers switched from regular to E10, and paid 0.2 cents more. Other consumers did not switch between grades and, while they could still have been affected by mandate-induced price changes, we found price effects within grade were universally insignificant. The burden of the mandate thus stems from the change in the composition of fuels sold. Cheaper fuel was replaced with more expensive fuel, some of it much more expensive.

Table 7 shows our estimates of the total burden of the mandate. The estimates cover the period from the inception of the mandate in October 2007 through to June 2013. We report the burden in total dollars over that period and in cents per liter for each liter purchased by E10 and premium switchers.

We report two calculations. The first set is a CV-type (compensating variation type) calculation – the additional cost, due to the mandate, for the same amount of energy that would have been used absent the mandate. The second is an EV-type (equivalent variation type) calculation – the additional cost due to the mandate for the same amount of energy that was actually used with the mandate.[21] Because the

[21] Standard errors for each are calculated numerically using the Cholesky decomposition and

mandate resulted in a small overall decline in energy-adjusted total volumes in New South Wales relative to control states (albeit statistically insignificant), the CV-type estimate is above the EV-type estimate.

The two calculations bound consumer welfare loss.[22] The CV-type calculation assumes that consumers would have purchased the same amount of energy-adjusted fuel with the mandate as they would have absent the mandate, but in reality they did not. They purchased a bit less. By revealed preference, purchasing something else in the presence of the mandate was preferred to purchasing the additional fuel and so the CV-type calculation is an upper bound on the burden. The EV-type calculation assumes consumers would have purchased the same amount of fuel absent the mandate as they did with the mandate, but in reality they purchased more. By revealed preference, purchasing more fuel in the absence of the mandate was preferred to something else, so EV-type is a lower bound on the burden.

Table 7 shows a large consumer burden stemming from the mandate. From the inception of the mandate in October 2007 to the end of our sample in June 2013, the total burden imposed on consumers from the change in the composition of fuels under the CV-type calculation was \$345.2 million dollars (about 327 million US dollars).[23] Under the EV-type Calculation it is \$337.2 million dollars. Under both calculations, it is equivalent to about 3.4 cents per liter (12.2 US cents per gallon) for each liter purchased by consumers who switched to either E10 or premium due to the mandate.

The burden amounts to \$5.1 million dollars per month on average (CV-type

simulating 10,000 draws of the parameter vector. See Krinsky & Robb (1986) for advantages of this method over linear approximations.

[22] We abstract from welfare changes other than those associated with changes in the cost of fuel.

[23] Using the 2009-2013 average exchange rate of 1 AUD = 0.95 USD.

calculation) but has been accelerating over time. In 2009, the one-month burden averaged 1.2 million dollars. In 2010, it rose to 3.5 million dollars and in 2011, it was 8.2 million. By 2013, it was 12.3 million dollars per month. The average monthly burden could rise further if the regular-to-premium diversion ratio continues to climb.

We now turn to the incidence of the mandate. Typically, the consumers most commonly associated with bearing a burden from an ethanol mandate are those who must switch from regular to the newly mandated ethanol blended fuel. However, in New South Wales, the burden of this group is dwarfed by the burden borne by consumers who switched to the ethanol-free premium grade substitute instead.

Table 7 reports estimates of the incidence of the mandate's burden on these two groups. It shows that consumers who switched to premium grade gasoline paid an additional 331.2 million Australian dollars (about 314.6 million US dollars) from October 2007 to June 2013. This corresponds to 96% share of the total. They paid an additional 12 cents per liter (about 43.1 US cents per gallon) over what they used to pay. Some of these consumers switched for fuel-vehicle incompatibility reasons – "incompatibility switching" – while others switched for other reasons – "aversion switching", a distinction to which we will return.

So large was the exodus away from E10 that premium grade gasoline became the number one selling grade of gasoline in New South Wales beginning in late 2011. By the time of the 6% mandate period, consumers were one and a half times more likely to switch to premium than to E10. It is hard to imagine this was the intended design of the mandate. Switching to premium was very costly to consumers and purchasing premium did not increase the volume of ethanol in the fuel supply.

Consumers who switched to E10 also absorbed a burden, but a smaller one – 14.0 million dollars (CV-type calculation), corresponding to 4% of the total burden. The energy-adjusted price of E10 was close to the price of regular.

Throughout our calculations, we have assumed that the energy content of premium grade gasoline and regular grade are the same. The defining difference between them is that premium has a higher octane rating and is more resistant to pre-ignition and engine knock. Some vehicles require it. Absent engine knock, the higher octane has no advantage.[24] Nonetheless, it is popular belief that premium is a higher quality and more energy abundant fuel. To gauge how our estimates might be affected with different energy content assumptions about premium, within reasonable limits, we re-estimate consumer burden assuming a 1.5% and a 3% upward energy adjustment for premium. Our estimates of the total burden under these assumptions are 286.1 and 227.6 million dollars respectively (CV-type calculation). Therefore, our conclusion holds even under liberal assumptions about the energy content of premium fuel. The burden remains high and significant.

In putting our results on the size of the burden in their proper context, it is important to remember that our focus is only on changes in the cost of gasoline due to the mandate. There are numerous other potential sources of consumer loss that are also important but outside the scope of this article. First, there are potentially significant search costs for those consumers that continued to seek out regular gasoline as it became increasingly scarce. This search cost on a per liter basis can be as high as the premium-regular price differential itself, since only once a consumer's own

[24] Setiawan, W. and D. Sperling (1993).

search cost exceeds the price differential will he or she switch from regular to premium. (The fact that the regular-to-premium diversion ratio rose over time suggests search costs were relevant.) Second, there are potential repair costs if consumers unknowingly use E10 in a truly incompatible vehicle and suffer vehicle damage. To the extent vehicles are damaged and stories about ethanol's dangers are circulated, this can contribute to additional aversion effects by owners of compatible vehicles and additional burden. There is also the potential for increased costs of food products for human consumption. Other negative welfare effects are possible.

On the other hand, the mandate was imposed because regulators sought particular long run benefits – benefits to grain producers, benefits from a secure domestic supply of fuel, potential benefits to the environment. We do not attempt to quantify any of these benefits.

This article makes a specific contribution to the cost-benefit analysis by quantifying the increased cost of the fuel supply to consumers, holding fixed the amount of energy, in the presence of the mandate versus in the absence of the mandate. We found that this burden was large and is almost entirely attributable to the consumer exodus away from the regulated good and toward its unregulated, ethanol-free, and almost-perfect substitute.

6 Discussion

6.1 The Ethanol Blendwall

The number of ethanol averse consumers switching to premium grade gasoline instead of E10 was unexpected by policymakers. The surprise is evidenced by the fact the mandated percentage of ethanol in gasoline could not even be met in the second phase of the four phase plan. Because the designers failed to take into account relevant consumer responses as warned by the Lucas Critique, the mandate fell well short its goals.

The first three mandate phases were defined by a 2%, 4% and 6% ethanol volume minimum, and the fourth called for the replacement of non-blended regular with E10 entirely. Figure 3, reported earlier, shows the actual market share of E10 along with the start dates of the first three implemented phases. An upper bound for the actual percentage of ethanol blended into the gasoline supply is one-tenth of the E10 share (i.e. a 20% E10 market share implies a maximum of 2% ethanol in gasoline).

During the 2% phase of the mandate, the actual percentage of ethanol in gasoline increased albeit more slowly than expected. It reached 2% only near the end of the first phase. The ethanol percentage then stalled midway through the 4% phase, topping out at 3.5% of total volume, and did not recover even during the 6% phase.

Because of the design of the mandate, the amount of switching out of E10 and into premium applied additional pressure on suppliers and created a difficult feedback loop. The mandated percentage of ethanol was a percentage of *all* gasoline sold, even though ethanol was blended only with regular gasoline. The exodus therefore did not change the absolute amount of ethanol required to be blended into gasoline. As a result, more premium switching by consumers forced suppliers to convert more regular gasoline to E10 more quickly, which caused more premium switching, more E10 conversions, more premium switching, and so on.

Beginning to recognize consumers' aversion of the E10 grade, the New South Wales government delayed the implementation of the 6% phase by nine months, to October 2010, but to no avail. The actual percentage of ethanol actually fell slightly during the third (6%) phase. The government then scrapped legislation that was to go into effect in July 2012 that would have phased out regular gasoline in favor of E10 altogether (the fourth phase). The actual percentage of ethanol in gasoline stood at 3.5% at the end of our sample in 2013, *less than half* of the mandate's original goal.[25]

Figures 1 through 3 show the impact of the regulation on the market shares of premium, regular, and E10, respectively, in New South Wales over time. The share of premium grade fuel, equal to 18.4% prior to the mandate, surged to almost 40% by 2013. These consumers were now purchasing premium at an 8% higher cost than regular and the majority of them using it in a vehicle that did not need it.

At the most recent diversion ratio from regular to premium of 60% and the current remaining regular market share of 27.2%, the maximum attainable ethanol content would be about 4.5%. Ironically, that would have made the fourth and final phase of the mandate theoretically weaker than the third phase – clearly not an original design. Meanwhile, the premium grade market share would rise from almost 40% to

[25] Given an 18.4% initial premium market share, and assuming no switching to premium grade, this would be equivalent to a 8.14% ethanol requirement.

54.6% of total volumes, an increase of 36%, and about triple its pre-mandate level.[26]

Clearly, regulators did not anticipate the consumer response. Consistent with the Lucas Critique, consumers paid a high cost to avoid the mandated good and, by doing so, the mandate failed to reach even its intermediate targets.

6.2 Incompatibility Switching and Aversion Switching

A question worth exploring is why there was such a large and unexpected shift into premium gasoline. In this section, we distinguish between two general types of premium switching – "incompatibility switching" and "aversion switching". We argue that both components contributed substantially to the total.

"Incompatibility switching" occurs when a consumer avoids E10 because his or her vehicle is truly incompatible with that fuel. "Aversion switching" we define as everything else. Therefore, if a consumer is uncertain or concerned about potential incompatibility and avoids E10 just in case, even though his or her vehicle is truly compatible, we consider it aversion switching. Other reasons for aversion switching include uncertainty about the relative energy content in E10, the belief that E10 is a lower quality fuel, a general distaste for government interference, concerns about warranties, and so on.

While the mandate was flawed in several respects, the most obvious failure must

[26] Regular gasoline still existed as of 2014 due to exemptions embedded in the regulation. Exemptions have been granted to small retailers with less than twenty stations each, retailers in areas where ethanol (which requires a separate delivery system) would be too costly to transport, and in cases where a retailer would suffer undue hardship from the cost of converting underground tanks to ethanol use, or for other reasons. Some stations have unsuccessfully sought exemptions from E10 on the argument that their consumers do not want it. As of 2014, regular was difficult to find in populated areas.

be that regulators chose to replace regular grade gasoline with an ethanol blend that as much as a quarter of the entire population was warned not to use because it could not be guaranteed compatible and safe. The Federal Chamber of Automotive Industries (FCAI) is the industry source for the widely cited list of vehicles and models that are either certified for E10 or deemed potentially incompatible for E10 use. Information on compatibility comes directly from vehicle manufacturers.

The FCAI list has been criticized as being on the conservative side and potentially overstating the number of vehicles that are incompatible.[27] The reason is that vehicles sold in Australia prior to the notion of an ethanol mandate may not have been certified for E10 because there was no need to do so at the time. European imports, for example, were often certified at the time of manufacture for E5 only, the European standard. Manufacturers may have little incentive to certify cars already sold since the certification process is costly, it unnecessarily opens the door to liability issues if E10 damage if claimed, and could in theory negatively impact new vehicle sales as well.[28] Absent a certification, the FCAI lists these vehicles as incompatible. But regardless of the controversy over its accuracy, the fact remains it is still the most widely cited source of compatibility information used by consumers and it still recommends against E10 in a large number of makes and models.

The list has been combined with automobile registrations by IPART (2012) and

[27] For example, see the National Roads and Motorists' Association submission to the Independent Pricing and Regulatory Tribunal in 2012, available at http://www.mynrma.com.au/media/independent_pricing_submission.pdf , last accessed March 9, 2014.

[28] Not certifying certifiable but already sold vehicles would be in the spirit of planned obsolesence, e.g. Bulow (1986), except that here obsolesence is only planned by ex post coincidence, i.e. the mandate taking effect.

independently by Wilson et al. (2011) to estimate the number of registered vehicles that are potentially incompatible with E10. We combine this information with our results on market share changes to get a sense of the relative sizes of the incompatibility switching and aversion switching groups, recognizing the potential conservative nature of the FCAI list. Table 7 shows our calculations using separate columns for the IPART starting point and the Wilson et al. starting point.

The IPART report estimates that in 2014, 21% of registered vehicles on the roads were on the FCAI list as incompatible with E10, and Wilson et al. estimates it at 16.8%. (The difference in estimates is partly symptomatic of the uncertainties involved.)

While these estimates are intended to represent an upper bound on the number of incompatible vehicles, they do not represent an upper bound on the size of the incompatibility switching group. There are several reasons. First, many cars on the incompatible list were using premium already, including luxury cars and the substantial number of European imports.[29] Owners of vehicles who would always have purchased premium did not switch and cannot be a part of the incompatibility switching group. We make the conservative assumption that the proportion of vehicles on the incompatible list requiring premium gasoline was the same as the proportion of vehicles requiring premium in the entire vehicle fleet. (We further assume that vehicles on the list would have used the same proportion of premium liters to other liters as the entire fleet.) This yields estimates of the proportion of potentially incompatible vehicles that had previously been using regular gasoline, rather than

[29]The octane in Australian premium gasoline is roughly equivalent to the octane of regular gasoline in Europe, so that European cars generally require premium in Australia.

premium, and would eventually have to switch. The figures are 17.6% and 13.5% under the two measures respectively.

However, this is still not an appropriate upper bound estimate on incompatibility switching. As of 2013, non-blended regular gasoline was still available in many areas, so not all consumers who would need to switch already had, and therefore some vehicles on the incompatibility list were still using regular. We make the conservative assumption that consumers did not search for regular, but rather purchased regular it if were available at a given station and purchased premium if it were not. With the market share of regular out of total non-premium fuels (i.e. regular and E10) at 44.1% in 2013, this implies these consumers purchased would have purchased premium gasoline (instead of E10) at most 55.9% of the time.

The calculations imply an upper bound on the magnitude of the incompatibility switching component. It is 9.9% using the FCAI estimates, and 7.6% using the Wilson estimates. The percentages would be lower if incompatible vehicles were more likely to be premium only vehicles, were more likely to be driven less often, or if owners made positive efforts to seek out regular instead of buying premium.

The upper bound estimates are well below the total amount of premium switching estimated at 20.2%. As a result, a rough lower bound for the magnitude of "aversion switching" ranges from 10.3% to 12.6%. Consumer aversion, as warned by the Lucas Critique, was important.

To the extent aversion switching is due to concerns about long run vehicle safety, the difference in price between E10 and premium can be thought of as an insurance premium - a "premium insurance premium". By purchasing premium gasoline instead of E10, the consumer reduces his or her risk of ethanol damage to zero. We calculate that in 2012, the premium insurance premium was 12.0 cents per liter. Multiplying by the average fuel consumption per vehicle per year of 1,268 liters yields an annual premium of $152 for each consumer who switched. The number of premium switchers gives the number of potential insurance "policies" – about 982,000.

6.3 Relevance to the U.S. Blendwall Debate

The Australian experience was a debacle. But the lessons from it are very relevant to the current controversy in the United States about increasing the ethanol blendwall from 10% to 15%. The U.S. has an aggressive renewable fuels mandate which requires an increasing absolute volume of ethanol to be blended into gasoline each year. Currently, virtually all gasoline sold in the U.S., of all grades, contains 10% ethanol by volume, the maximum limit approved for non-flex-fuel vehicles (the "blendwall"). In spite of this, the industry is on course to fall short of the requirements year after year. One reason for the shortfall is the lack of popularity of E85 (an up to 85% ethanol blend), lackluster sales of flex fuel vehicles, and a significant decline in overall gasoline demand due to the recession and increases in hybrid vehicle sales.

One proposed option is to scale back the overall mandated volume as too ambitious. Another is to increase the blendwall to 15%, by phasing out E10 pumps in favor of E15 pumps. Both are being pursued.

The 15% option has been controversial. In 2010, the Environmental Protection Agency (EPA) approved the use of E15 in all model year vehicles 2001 and newer, and in 2012, some retailers began selling it. However, manufacturers quickly responded that E15 was not compatible in over 90% of vehicles they sold (all except a few post 2012 models) and its use would void manufacturers' warranties. Twelve manufacturers wrote to Congress opposing the fuel and warning consumers not to use it.[30]

This has parallels with the Australian experience. It is an example of a mandate potentially running ahead of vehicle compatibility and ahead of consumer confidence. In Australia, as many as 21% of vehicles were listed as incompatible and many more consumers had concerns. In the U.S. as many as 90% of vehicles are incompatible with E15. Even if it were less, the lack of clarity and a lack of agreement between auto manufacturers and the EPA only adds to the uncertainty.

In Australia, the number of potentially incompatible vehicles meant there had to be an ethanol free substitute available. The price also had to be higher to ensure adequate supplies available to those who needed it. Premium grade gasoline, already widely available, was the obvious choice, and the results of this article document what happened next.

Similarly, in the United States, if the EPA were to roll out E15 faster than the existing vehicle fleet could handle it, it would need to simultaneously maintain an E10 alternative. E10 would also need to be more expensive to ration its use. Again, the usual option is to change the blend in regular fuel and leave the more expensive premium unchanged, (i.e. in the US, blend 15% into regular, 10% in premium, and a 50/50 mix of 12.5% in midgrade). This prevents retail stations from having to install new expensive underground storage tanks to handle the new grade. In any

[30] See http://sensenbrenner.house.gov/uploadedfiles/e15_auto_responses.pdf, last accessed March 9, 2014.

event, whether by premium-piggybacking, price incentives, or market forces, E10 would necessarily become more expensive and this increases the cost to consumers who cannot use E15. If consumers are not confident in the mixed signals from auto manufacturers and the EPA, aversion switching can add to the cost more. In short, the Australian experience teaches that the extra burden created by rolling out a mandate ahead of the ability of the vehicle fleet to handle it or ahead of consumer confidence can be potentially – and unnecessarily – high.[31]

As a general matter, mandates should not run ahead of fuel-vehicle compatibility. We argue that if there must be a mandate, the more logical approach would be to mandate new vehicles to be compatible with the desired blend first, wait, and then switch over to that fuel once the vehicle fleet is ready for it. Vehicle compatibility first, ethanol mandate second. Not the other way around.

7 Conclusion

The Australian experience is an example of an ethanol mandate implemented before the vehicle fleet was ready for it and before consumers had confidence in it. One of the criticisms of the New South Wales government was that it did not adequately make its case for ethanol or address safety and efficacy concerns. The mandate had to be selective to allow access to an ethanol free substitute for incompatible vehicles, and this created an escape valve for large numbers of ethanol averse consumers to

[31] The 2012 Minnesota Omnibus Agriculture Policy Act mandates twenty percent ethanol content in that state to commence in 2013, since postponed to 2015, as the state seeks an EPA waiver for introducing E20 fuel. Researchers at Minnesota State University have produced a series of studies funded by the Renewable Fuels Assocation and the Minnesota Corn Growers Assocation arguing no ill effects of using E20.

avoid the mandate through aversion switching.

The result was a significant shift in the composition of fuel grades sold that was not originally envisioned. In spite of the higher price of premium, premium grade gasoline become the number one selling grade of gasoline in New South Wales beginning in mid-2011, just three years into the mandate.

The magnitude of the exodus into premium caused the market share of E10 to hit a ceiling short of the mandate's targets. The mandated percentage of ethanol had been set to increase in four distinct phases, but not even the second phase of the mandate could be met. Postponing the third phase did little good and the fourth phase had to be abandoned altogether.

The burden of the mandate was high – 345.2 million dollars through June 2013, and about 12.3 million dollars a month in 2013. Consumers who avoided E10 and purchased premium grade gasoline bore 96% of the burden. Consumers who switched to E10 still bore a cost but a much smaller one.

The Lucas Critique warns that regulations and other policy initiatives change individual incentives and produce an assortment of different responses by market participants. Some are expected and by design, while others are unexpected side effects that can potentially offset or even defeat the goals of a regulation. This appears to be the case with the Australian ethanol mandate.

This is not to say that the Australian mandate cannot meet its (still controversial) targets in the long run. A rollout of E10 that is more gradual and in sync with the capabilities of the vehicle fleet, and combined with greater transparency, should be achievable without hyperinflating costs to consumers for what is already a costly mandate. Whether or not an ethanol mandate is appropriate to begin with is another question, and outside the scope of our study.

Finally, the Australian experience provides insights on the current controversial debate in the U.S. over whether to increase the ethanol blendwall to 15%. If E15 were to be rolled out too quickly, ahead of the capabilities of the vehicle fleet and consumer confidence, it could potentially result in incompatibility and aversion switching and higher costs to consumers than necessary. The vehicle fleet turnover rate is slow and, in spite of the aggressiveness of the U.S. mandate, it is still the case that a vehicle fleet capable of handing a particular fuel has to be established before a fuel can be widely used. A more careful and measured approach to increasing ethanol into the gasoline supply, should it be done at all, is advised.

8 References

Borenstein, S., A. Cameron, & R. Gilbert (1997). "Do Gasoline Markets Respond Asymmetrically to Crude Oil Price Changes?", *Quarterly Journal of Economics* 112, pp. 305-339.

Bulow, J. (1986). "An Economic Theory of Planned Obsolescence", *Quarterly Journal of Economics* 101:4, pp. 729-750.

Carter, C., G. Rausser & A. Smith (2013). "The Effect of the US Ethanol Mandate on Corn Prices". UC Davis Working Paper.

Cornford, P. and M. Seccombe (2002). "The Tiger in her Tank Bit a Hole in her Budget", *Sydney Morning Herald*, December 18, 2002.

Engle, R. and C. Granger (1987). "Co-Integration and Error Correction: Representation, Estimation, and Testing", *Econometrica* 55:2, pp. 251-276.

Environmental Protection Agency (EPA) (2013). "EPA Proposes 2014 Renewable Fuel Standards, 2015 Biomass-Based Diesel Volume". Available at http://www.epa.gov/otaq/fuels/renewablefuels/documents/420f13048.pdf , last accessed March 18, 2014.

European Union, Council of, (EU) (2003) "Directive 2003/30/EC of the European Parliament and of the Council". Official Journal of the European Union L123, 17 June 2003, pp. 42-46.

European Union, Council of, (EU) (2009) "Directive 2009/28/EC of the European Parliament and of the Council". Official Journal of the European Union L140, 5 June 2009, pp. 16-62.

Federal Chamber of Automotive Industries (FCAI) (2014). "Can my Vehicle Op-

erate on Ethanol Blend Petrol?", available at
http://www.fcai.com.au/environment/can-my-vehicle-operate-on-ethanol-blend-petrol-
, last accessed March 18, 2014.

Grafton, R. Q., T. Kompas and N. Van Long (2012). "Substitution between Biofuels and Fossil Fuels: Is There a Green Paradox?", *Journal of Environmental Economics and Management* 64, pp. 328-341.

Global Renewable Fuels Alliance (GRFA) (2014). "Global Biofuel Mandates", available at http://globalrfa.org/biofuels-map/ , last accessed March 18, 2014.

Independent Pricing and Regulatory Tribunal of New South Wales (IPART) (2012), "Ethanol Supply and Demand in NSW". Report prepared by IPART pursuant to the Independent Pricing and Regulatory Tribunal Act, pp. 1-77.

Lapan, H. and G. Moshcini (2011). Second-best Biofuel Policies and the Welfare Effects of Quantity Mandates and Subsidies", *Journal of Environmental Economics and Management* 63, pp. 224-241.

Krinsky, I. and A. Robb (1986). "On Approximating the Statistical Properties of Elasticities", *Review of Economics and Statistics* 68:4, pp. 715-719.

Lewis, M. (2009). "Temporary Wholesale Gasoline Price Spikes have Long Lasting Retail Effects: The Aftermath of Hurricane Rita", *Journal of Law and Economics* 52(3), pp. 581-606.

Lewis, M. and M. Noel. (2011). "The Speed of Gasoline Price Response in Markets with and without Edgeworth Cycles", *Review of Economics and Statistics* 93:2, pp. 672-682.

National Corn Growers' Association (NCGA) (2013). "Testimony of Pam John-

son, President of NGCA, before the U.S. House of Representatives Subcommittee on Energy and Power". Available at
http://democrats.energycommerce.house.gov/sites/default/files/documents/
Testimony-Johnson-EP-Renewable-Fuel-Standard-Stakeholder-Perspectives
-2013-7-22-23.pdf , last accessed March 18, 2014.

Serra, T. and D. Zilberman (2013). "Biofuel-Related Price Transmission Literature: A Review", *Energy Economics* 37, pp. 141-151.

Setiawan, W. and D. Sperling (1993). "Premium Gasoline Overbuying in the U.S.: Consumer-Based Choice Analysis", University of California Transportation Center Discussion Paper UCTC-457, pp. 1-24.

Tappata, M. (2009). "Rockets and Feathers: Understanding Asymmetric Pricing", *Rand Journal of Economics* 42(4), pp. 681-704.

Westbrook, J., G. Barter, D. Manley and T. West (2014). "A Parametric Analysis of Future Ethanol Use in the Light-Duty Transportation Sector: Can the U.S. Meet its Renewable Fuel Standard Goals without an Enforcement Mechanism?", *Energy Policy* 65, pp. 419-431.

Wilson, A., N. Bolton, S. Thomas, and P. Dargush (2011). "The E10 Compatibility of the Australian Fleet", UQ SMART Working Paper.

Table 1. Summary Statistics

	Mean	Std. Dev.	Minimum	Maximum
Premium Volume	61.43	42.45	11.74	204.12
Regular Volume	222.65	107.69	82.72	457.50
E10 Volume	28.28	50.75	0.00	208.56
Premium Price	136.01	17.08	96.63	169.19
Regular Price	126.69	16.14	89.49	162.59
E10 Price	128.92	12.31	101.50	159.89
Terminal Gate Price	120.96	15.30	82.78	154.93
New Vehicle Registrations	16.23	8.11	4.13	37.19
Unemployment Rate	5.00	0.73	2.70	6.60

Volumes in millions of liters per month. Prices, including terminal gate prices, in Australian cents per liter (approximate exchange rate 1 AUD = 0.95 USD from 2009 to 2013.) New vehicle registrations in thousands of vehicles per month.

Table 2. Mandate Impact on Volume of Premium Grade Gasoline

Dep. Var. = $VOLUME_{PREM}$	Reduced Form Single Treatment		Reduced Form Multiple Treatments		Stuctural Demand Multiple Treatments	
	1	2	3	4	5	6
NEW SOUTH WALES	50.359**	9.095**	50.359**	11.735**	11.916**	11.510**
	(5.508)	(1.721)	(5.555)	(1.084)	(3.172)	(3.192)
MANDATE	8.288**	3.552**				
	(2.488)	(1.160)				
NSW*MANDATE	39.893**	38.851**				
	(5.767)	(4.746)				
MANDATE-2%			3.657	3.990**	3.451**	3.448**
			(2.863)	(0.765)	(1.254)	(1.247)
MANDATE-4%			3.789	0.789	0.735	1.568
			(3.899)	(1.258)	(1.384)	(1.387)
MANDATE-6%			5.203	6.695**	6.196**	5.430**
			(4.101)	(1.426)	(1.600)	(1.587)
NSW*MANDATE-2%			-0.513	0.480	0.505	0.371
			(3.807)	(2.434)	(2.308)	(2.315)
NSW*MANDATE-4%			47.470**	47.721**	48.170**	47.656**
			(6.658)	(5.672)	(2.598)	(2.605)
NSW*MANDATE-6%			37.910**	31.001**	31.589**	31.320**
			(6.657)	(5.372)	(2.690)	(2.698)
RETAIL PRICE					-0.184**	-0.119*
					(0.052)	(0.051)
NEW VEHICLES		2.019**		1.844**	1.889**	1.906**
		(0.617)		(0.274)	(0.241)	(0.241)
LAGGED NEW VEHICLES		1.347*		1.357**	1.334**	1.306**
		(0.615)		(0.270)	(0.242)	(0.243)
UNEMPLOYMENT		11.368		12.038**	12.283**	14.937**
		(6.621)		(3.290)	(3.685)	(3.688)
LAGGED UNEMPLOYMENT		-9.105		-11.185**	-11.437**	-13.526**
		(6.604)		(3.283)	(3.653)	(3.659)
TERMINAL GATE PRICE		0.126*		-0.202**		
		(0.083)		(0.044)		
MONTHLY DUMMIES	N	Y	N	Y	Y	Y
R-SQUARED	0.615	0.867	0.746	0.969	0.967	0.967
NUM. OBS.	485	485	485	485	480	480

Standard errors in parentheses. * Significant at 5% level, ** Significant at 1% level.

Table 3. Mandate Impact on Price of Premium Grade Gasoline

Dep. Var. = PRICE $_{PREM}$	Reduced Form Single Treatment		Reduced Form Multiple Treatments		Stuctural Supply Multiple Treatments	
	1	2	3	4	5	6
NEW SOUTH WALES	1.534	-0.381	1.534	-0.062		
	(2.250)	(0.441)	(2.258)	(0.451)		
MANDATE	24.183**	5.777**				
	(1.224)	(0.319)				
NSW*MANDATE	-0.279	-0.609				
	(2.732)	(0.534)				
MANDATE-2%			19.293**	4.844**		
			(1.643)	(0.370)		
MANDATE-4%			-4.543**	1.319**		
			(1.368)	(0.415)		
MANDATE-6%			17.606**	2.990**		
			(0.592)	(0.424)		
NSW*MANDATE-2%			-0.188	-0.349		
			(3.659)	(0.712)		
NSW*MANDATE-4%			6.258	0.801		
			(3.441)	(0.790)		
NSW*MANDATE-6%			-5.268**	-1.194		
			(2.051)	(0.661)		
VOLUME					0.041**	0.0005
					(0.004)	(0.002)
NEW VEHICLES		0.004		-0.017		
		(0.081)		(0.070)		
LAGGED NEW VEHICLES		0.153		0.168		
		(0.080)		(0.069)		
UNEMPLOYMENT		2.960*		2.795*		
		(1.448)		(1.311)		
LAGGED UNEMPLOYMENT		-1.921		-2.559		
		(1.442)		(1.327)		
TERMINAL GATE PRICE		0.995**		0.937**	1.003	†
		(0.011)		(0.011)	(0.015)	
MONTHLY DUMMIES	N	Y	N	Y		
R-SQUARED	0.478	0.973	0.584	0.979	0.911	0.985
NUM. OBS.	570	565	570	565	480	480

Standard errors in parentheses. * Significant at 5% level, ** Significant at 1% level. † The full results of the VAR model, including lagged price, terminal gate price, and lagged price and terminal gate prices changes, are presented in Table A1.

Table 4. Mandate Impact on Volume of Regular and E10 Grades of Gasoline (Multiple Treatments)

Dep. Var. = VOLUME $_{\{REG, E10\}}$	Regular			E10		
	Reduced Form		Structural	Reduced Form		Structural
	7	8	9	10	11	12
NEW SOUTH WALES	196.421**	32.875**	32.915**	1.057	-12.881**	-9.498
	(8.247)	(3.818)	(4.372)	(1.132)	(2.138)	(10.561)
MANDATE-2%	-21.127	-19.935**	-19.362**	12.088**	11.737**	6.347
	(11.624)	(2.904)	(3.367)	(2.526)	(2.592)	(6.924)
MANDATE-4%	-15.830	-27.724**	-28.324**	6.234	3.985	8.611
	(14.395)	(3.497)	(3.996)	(5.172)	(4.884)	(4.941)
MANDATE-6%	5.629	3.611	4.885	-10.391*	-8.899	-13.151*
	(13.949)	(3.900)	(4.189)	(4.813)	(4.823)	(5.594)
NSW*MANDATE-2%	-49.368**	-41.819**	-41.941**	50.235**	50.561**	44.393**
	(13.574)	(6.431)	(6.191)	(5.434)	(5.091)	(11.311)
NSW*MANDATE-4%	-128.916**	-131.498**	-130.680**	89.704**	91.777**	89.457**
	(18.774)	(11.888)	(7.573)	(9.692)	(9.487)	(8.389)
NSW*MANDATE-6%	-63.384**	-88.752**	-87.119**	26.226**	23.888**	30.991**
	(17.330)	(11.537)	(7.848)	(8.448)	(8.347)	(9.723)
RETAIL PRICE			-0.312**			-0.006
			(0.106)			(0.187)
NEW VEHICLES		7.193**	6.618**		0.624	0.906
		(0.758)	(0.668)		(0.609)	(0.921)
LAGGED NEW VEHICLES		6.051**	6.600**		0.398	0.109
		(0.746)	(0.673)		(0.607)	(0.927)
UNEMPLOYMENT		9.802	8.025		15.687	45.425**
		(9.343)	(10.035)		(8.871)	(16.010)
LAGGED UNEMPLOYMENT		-5.921	-3.454		-13.051	-43.139**
		(9.305)	(9.929)		(9.102)	(15.404)
TERMINAL GATE PRICE		-0.277**			-0.145	
		(0.095)			(0.105)	
MONTHLY DUMMIES	N	Y	Y	N	Y	Y
R-SQUARED	0.380	0.957	0.957	0.845	0.866	0.826
NUM. OBS.	575	570	545	485	485	268

Standard errors in parentheses. * Significant at 5% level, ** Significant at 1% level.

Table 5. Mandate Impact on Price of Regular and E10 Grades of Gasoline (Multiple Treatments)

	Regular		E10	
Dep. Var. = PRICE $_{\{REG,E10\}}$	Reduced	Structural	Reduced	Structural
	8	9	11	12
NEW SOUTH WALES	-0.883**		-0.676	
	0.339		0.561	
MANDATE-2%	2.065**		3.606**	
	(0.282)		(0.438)	
MANDATE-4%	0.578		0.477	
	(0.342)		(0.352)	
MANDATE-6%	0.884*		1.155*	
	(0.374)		(0.468)	
NSW*MANDATE-2%	-0.532		-0.996	
	(0.409)		(0.610)	
NSW*MANDATE-4%	0.867		0.238	
	(0.632)		(0.662)	
NSW*MANDATE-6%	-0.951		-1.078	
	(0.649)		(0.783)	
VOLUME		0.001		-0.002
		(0.001)		(0.002)
NEW VEHICLES	-0.048		-0.079	
	(0.055)		(0.068)	
LAGGED NEW VEHICLES	0.187**		0.148*	
	(0.054)		(0.066)	
UNEMPLOYMENT	1.236		0.253	
	(0.958)		(1.253)	
LAGGED UNEMPLOYMENT	-0.945		-0.497	
	(0.959)		(1.198)	
TERMINAL GATE PRICE	0.993**	†	0.951**	†
	(0.009)		(0.015)	
	Y	Y	Y	Y
R-SQUARED	0.985	0.988	0.976	0.982
NUM. OBS.	565	545	288	268

Standard errors in parentheses. * Significant at 5% level, ** Significant at 1% level. † The full results of the VAR model, including lagged price, terminal gate price, and lagged price and terminal gate prices changes, are presented in Table A1.

Table 6. Total Burden of the Ethanol Mandate

		Total Dollars	Cents per Liter
CV-Type Calculation			
Increased Cost to All Switching Consumers for the Same Amount of Energy that Would Have Been Used Absent the Mandate	$	345,212,889	3.42 ¢
		(5,228,300)	(0.05)
Increased Cost to Those Consumers who Switched from Regular to Premium Grade Gasoline	$	331,177,249	12.01 ¢
		(5,385,200)	(0.20)
Increased Cost to Those Consumers who Switched from Regular to E10 Grade Gasoline	$	14,035,640	0.19 ¢
		(177,080)	(0.01)
EV-Type Calculation			
Increased Cost to All Switching Consumers for the Same Amount of Energy Actually Used With the Mandate	$	337,194,383	3.44 ¢
		(1,349,700)	(0.01)
Increased Cost to Those Consumers who Switched from Regular to Premium Grade Gasoline	$	323,484,758	12.44 ¢
		(1,659,900)	(0.06)
Increased Cost to Those Consumers who Switched from Regular to E10 Grade Gasoline	$	13,709,624	0.19 ¢
		(315,330)	(0.01)

Total dollars and cents per liter calculated October 2007 to June 2013.

Table 7. Incompatibility Switching and Aversion Switching

	IPART	Wilson et al.
Listed Compatible Vehicles	78.1%	83.2%
Potentially Incompatible Vehicles	21.9%	16.8%
Potentially Incompatible Vehicles that Do Not Require Premium Already	17.6%	13.5%
Potentially Incompatible Vehicles that Do Not Require Premium Already and Do Not Have Ready Access to Regular	9.9%	7.6%
Total Estimated Premium Switching from Inception of Mandate to mid-2013	20.2%	20.2%
Estimated Incompatibility Switching	9.9%	7.6%
Estimated Aversion Switching	10.3%	12.6%

Table A1. Complete VAR Results from Structural Supply Model

Dep. Var. = PRICE	Premium (6)	Regular (9)	E10 (12)
$VOLUME_t$	0.0005	0.001	-0.002
	(0.002)	(0.001)	(0.002)
ΔTGP^+_t	0.657**	0.923**	0.912**
	(0.032)	(0.028)	(0.044)
ΔTGP^+_{t-1}	0.337**	0.477**	0.429**
	(0.059)	(0.068)	(0.097)
ΔTGP^+_{t-2}	0.345**	0.420**	0.517**
	(0.055)	(0.067)	(0.092)
ΔTGP^+_{t-3}	0.176**	0.175**	0.221*
	(0.052)	(0.064)	(0.089)
ΔTGP^+_{t-4}	0.083	0.147*	0.015
	(0.047)	(0.057)	(0.080)
ΔTGP^-_t	0.730**	0.897**	0.924**
	(0.026)	(0.024)	(0.033)
ΔTGP^-_{t-1}	0.400**	0.710**	0.679**
	(0.060)	(0.066)	(0.093)
ΔTGP^-_{t-2}	0.232**	0.350**	0.250*
	(0.061)	(0.073)	(0.101)
ΔTGP^-_{t-3}	0.278**	0.217**	0.317**
	(0.061)	(0.072)	(0.102)
ΔTGP^-_{t-4}	0.171**	0.144*	0.240*
	(0.056)	(0.066)	(0.097)
$\Delta PRICE^+_{t-1}$	-0.153*	-0.471**	-0.355**
	(0.072)	(0.062)	(0.085)
$\Delta PRICE^+_{t-2}$	-0.434**	-0.367**	-0.441**
	(0.071)	(0.063)	(0.084)
$\Delta PRICE^+_{t-3}$	-0.163*	-0.199**	-0.233**
	(0.071)	(0.061)	(0.082)
$\Delta PRICE^+_{t-4}$	-0.169**	-0.124*	-0.048
	(0.063)	(0.054)	(0.074)
$\Delta PRICE^-_{t-1}$	-0.380**	-0.627**	-0.652**
	(0.082)	(0.066)	(0.094)
$\Delta PRICE^-_{t-2}$	-0.198*	-0.386**	-0.289**
	(0.082)	(0.071)	(0.100)
$\Delta PRICE^-_{t-3}$	-0.315**	-0.177**	-0.321**
	(0.080)	(0.068)	(0.097)
$\Delta PRICE^-_{t-4}$	-0.11252	-0.139*	-0.188*
	(0.071)	(0.060)	(0.090)
$PRICE_{t-1}$	0.965**	0.859**	0.828**
	(0.024)	(0.036)	(0.052)
TGP_{t-1}	0.014	0.155**	0.172**
	(0.028)	(0.039)	(0.054)
R-SQUARED	0.985	0.988	0.982
NUM. OBS.	480	545	268

Standard errors in parentheses. * Significant at 5% level, ** Significant at 1%

Figure 1. Premium Market Share - Actual and Predicted

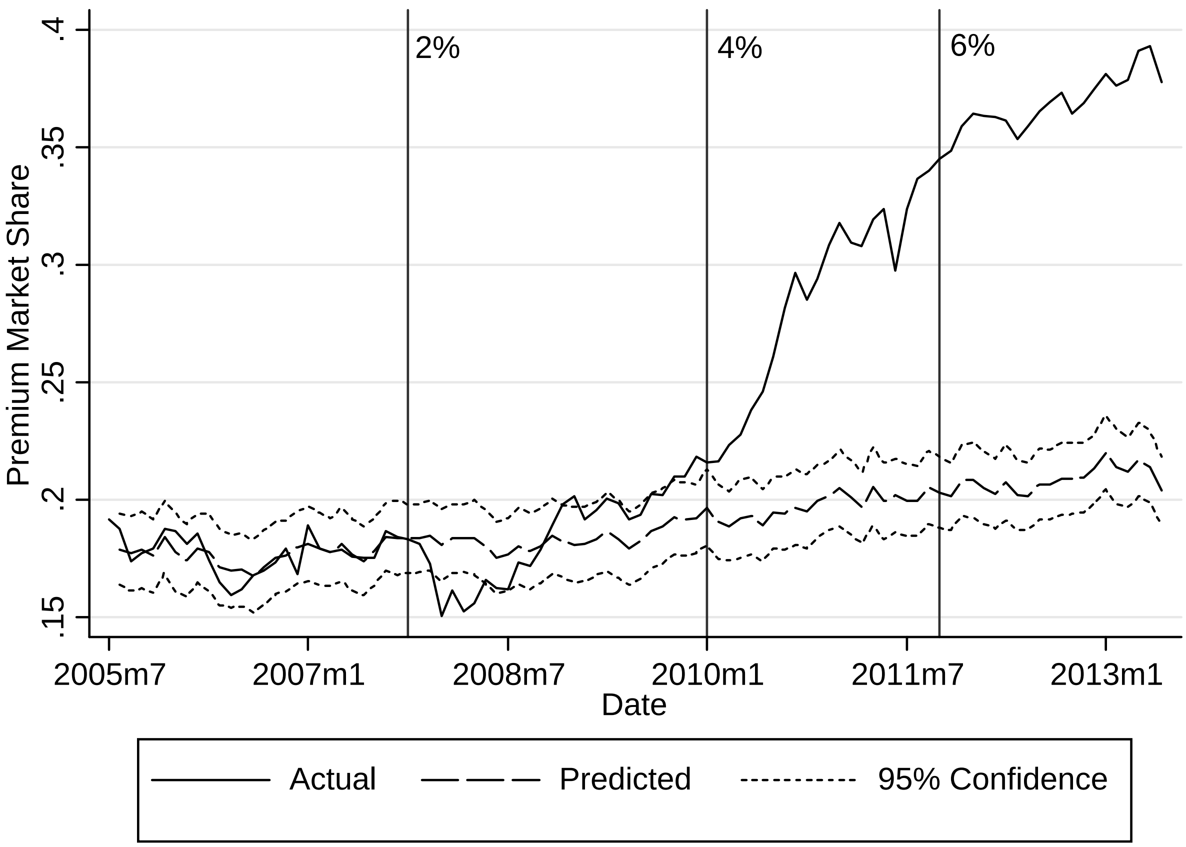

Figure 2. Regular Market Share - Actual and Predicted

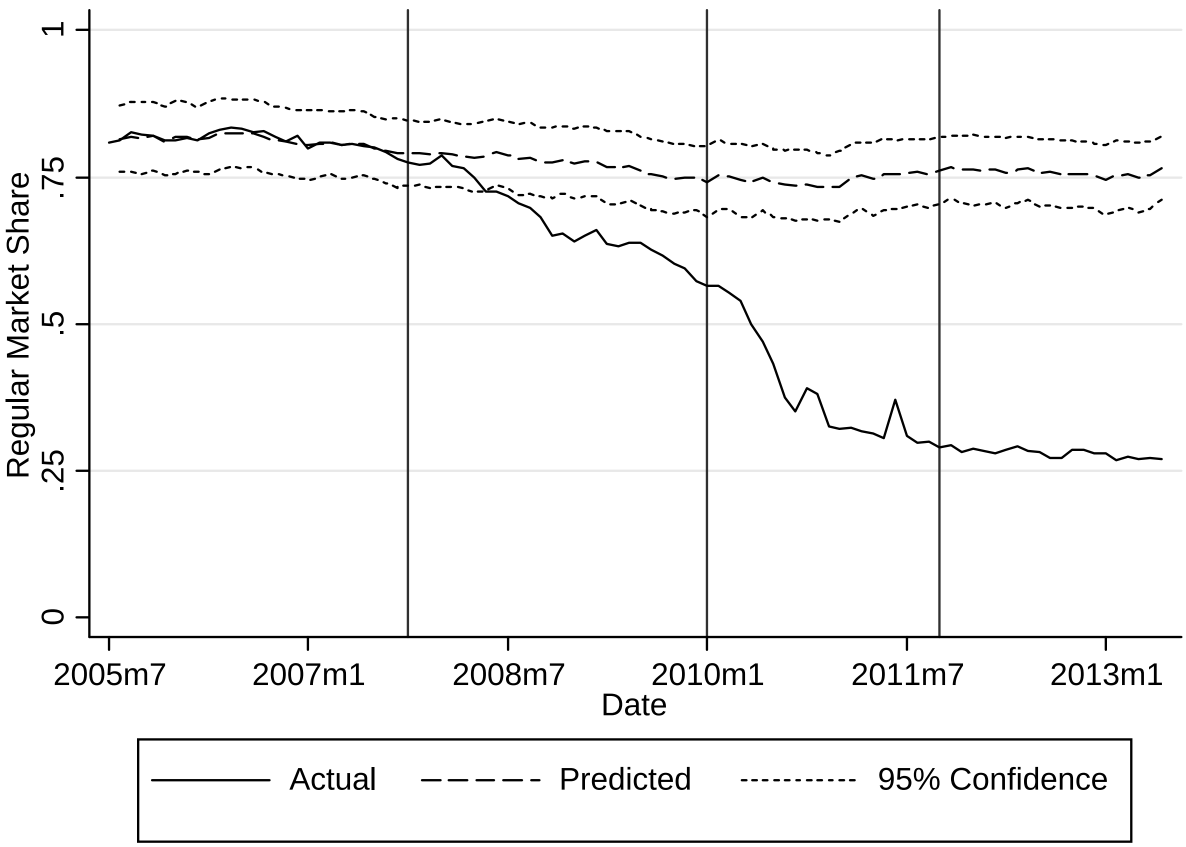

Figure 3. E10 Market Shares - Actual and Predicted

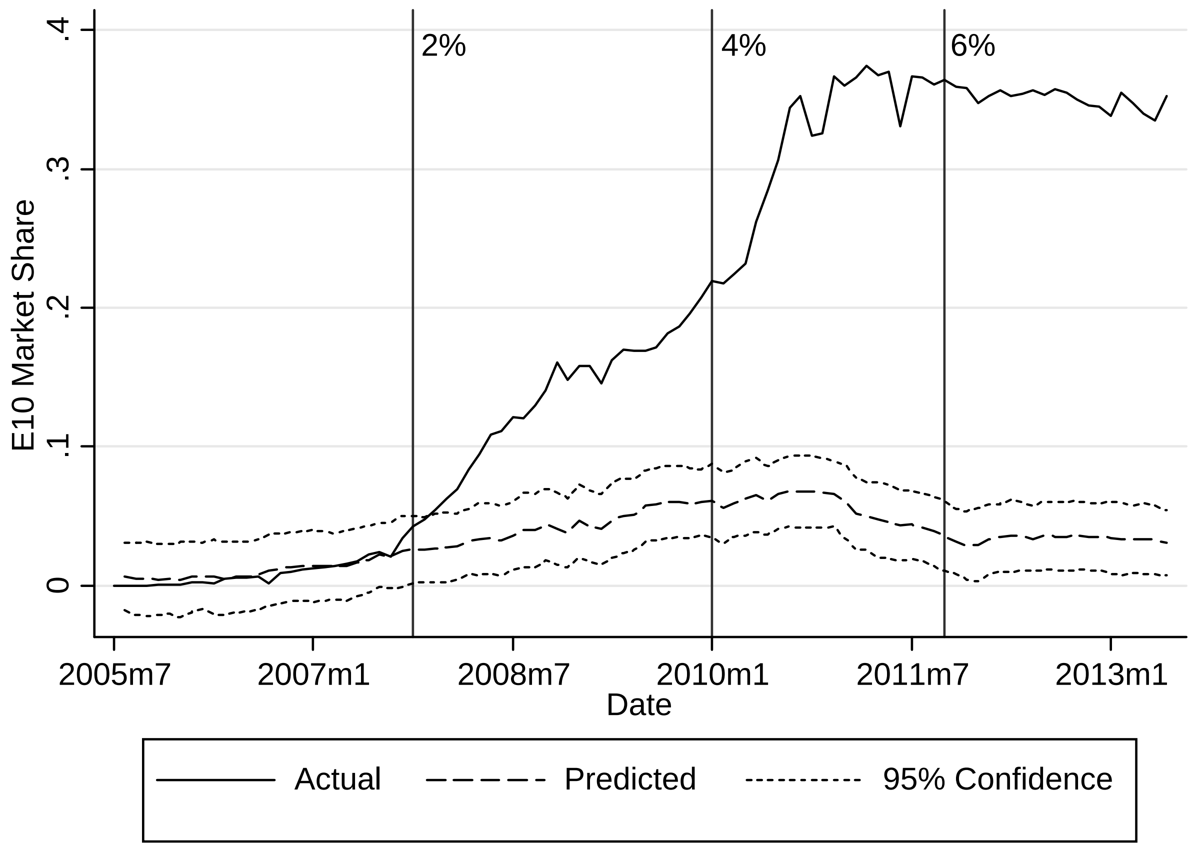

Figure 4. Predicted Volume Changes and Diversion Ratios for Each Mandate Period