

Web Appendix for “Network Effects in Alternative Fuel Adoption: Empirical Analysis of the Market for Ethanol”

A Visualization of FFV installed base and E85 availability

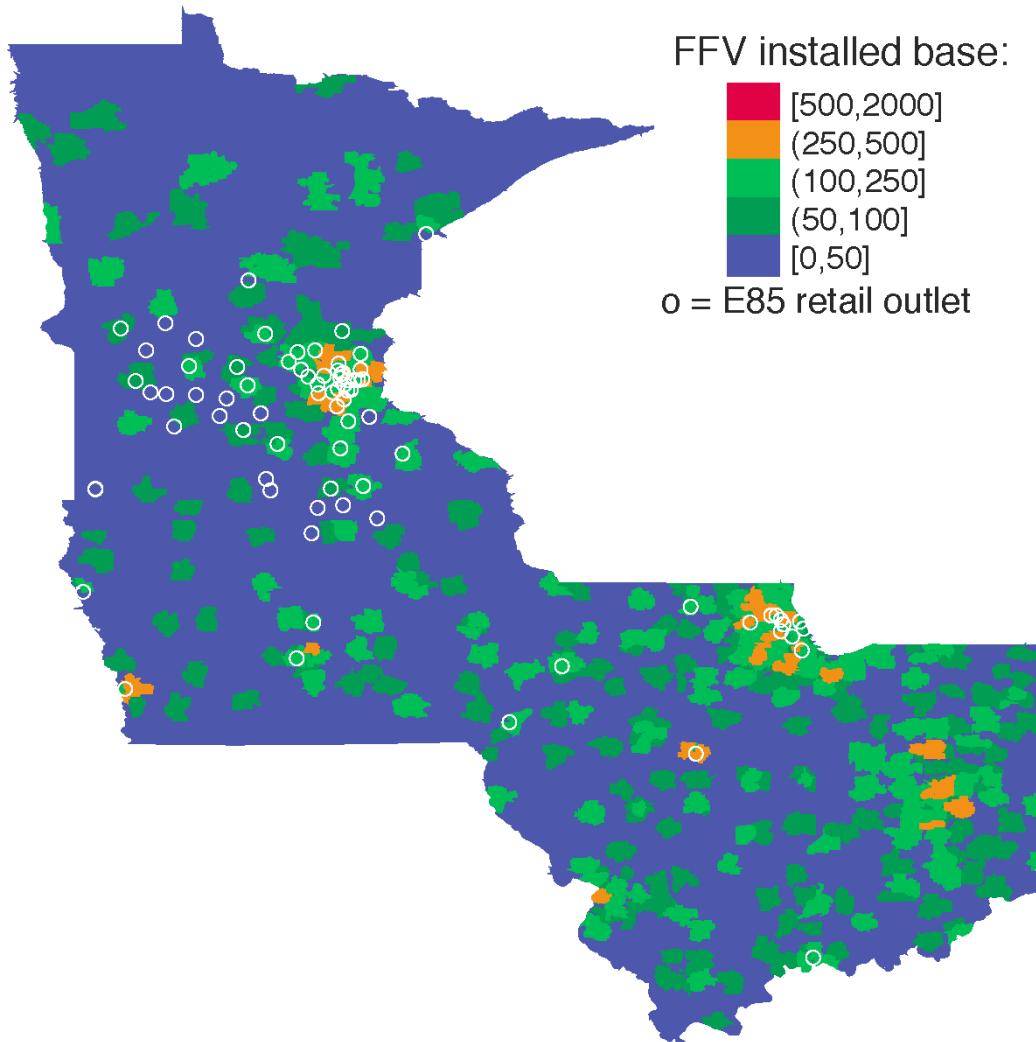


Figure 1: FFV installed base and E85 retail locations, 2001

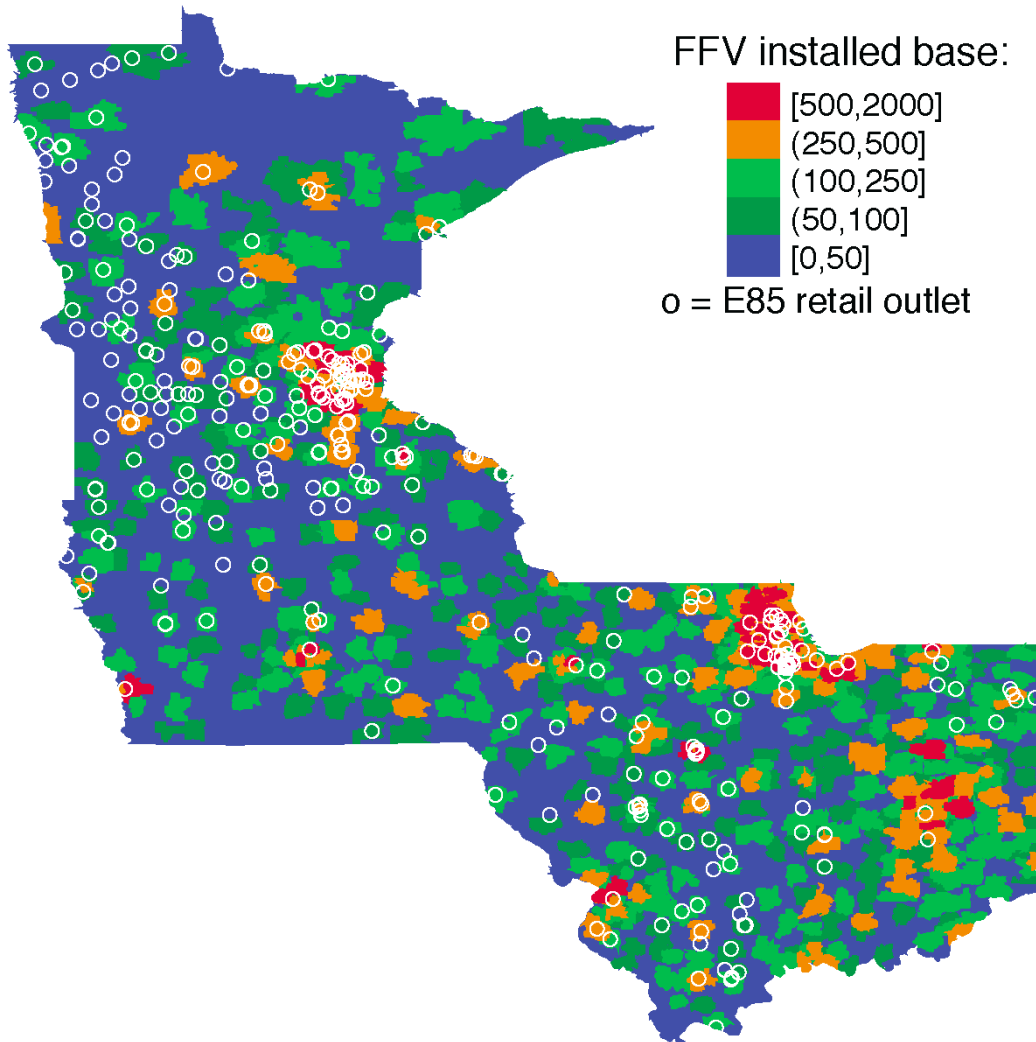


Figure 2: FFV installed base and E85 retail locations, 2005

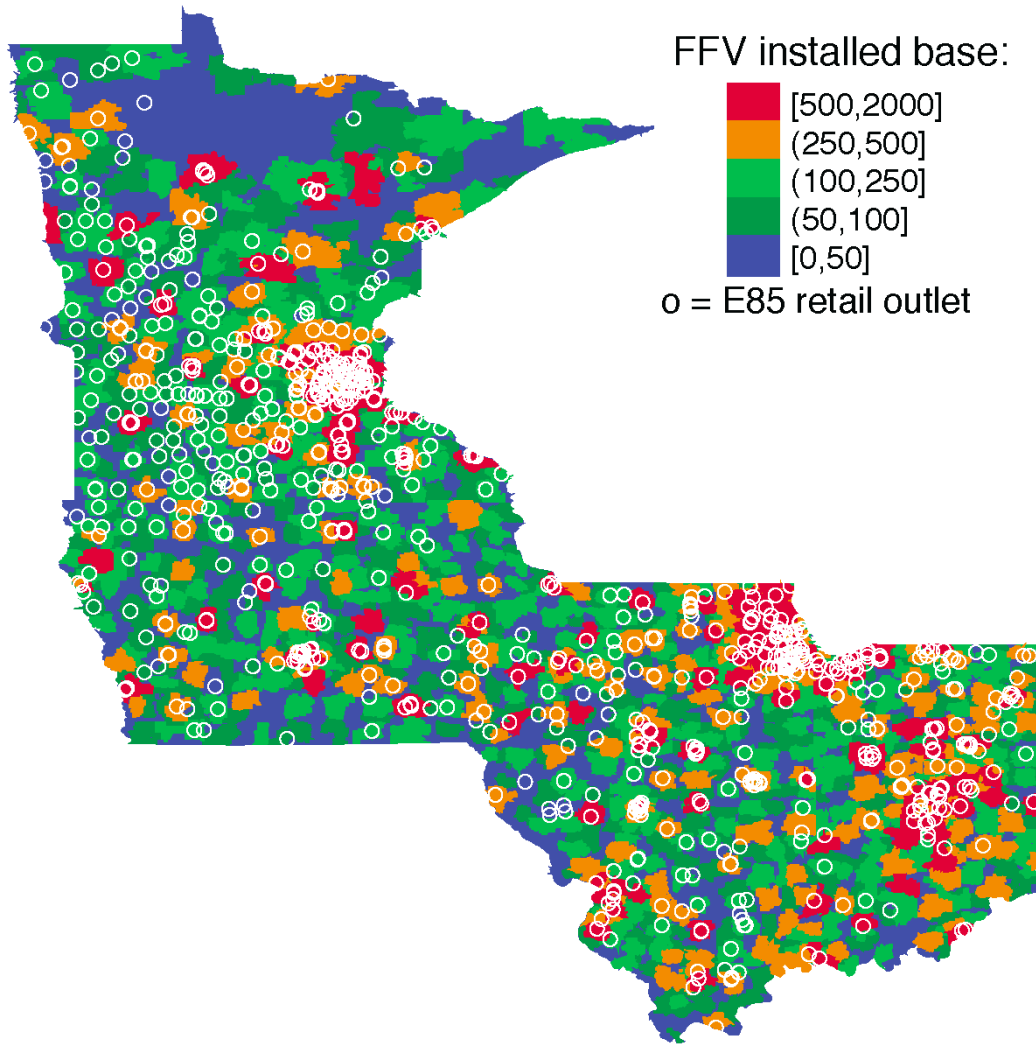


Figure 3: FFV installed base and E85 retail locations, 2009

B Derivation of the E85 retailer profit function

To motivate the reduced form profit function described in 4.2, I derive period demand for E85 under the following assumptions:

1. Market demand is given by $D = \sum_{f=1}^N d_f = S(a - P)$, where f indexes the fuel retailers active in a market and d_f represents per-firm demand for E85.
2. Variable costs are linear in output and common to all firms: $C_f = cd_f$.
3. Firms are identical and compete in output (Cournot competition).

Now, using (1) above, the inverse demand curve may be written as:

$$P = a - \frac{D}{S} = a - \frac{1}{S} \sum_{f=1}^N d_f$$

Given Cournot competition, the first order condition for firm f is given by:

$$\begin{aligned} \frac{\partial \Pi_f^N}{\partial d_f} &= \frac{\partial}{\partial d_f} [d_f(P - c)] = 0 \\ &= P - c + d_f \frac{\partial P}{\partial d_f} = 0 \\ &= a - \frac{1}{S} \sum_{f=1}^N d_f - c + d_f \left(-\frac{1}{S} \right) = 0 \end{aligned}$$

The symmetry of firms implies that $\sum_{f=1}^N d_f = Nd_f$. Using this condition and solving for optimal firm quantity yields:

$$d_f^* = \frac{S}{1+N} (a - c)$$

The equilibrium market price will therefore be:

$$P^* = a - \frac{Nd_f^*}{S} = a - \frac{N}{1+N} (a - c)$$

Finally, reduced form profits may be expressed as:

$$\Pi^N = \Pi_f^N = (P^* - c)d_f^* = S \frac{(a - c)^2}{(1 + N)^2}$$

C Derivation of the entry equilibrium constraint

To derive the constraint condition imposing $\frac{\partial \Pi^N}{\partial N_1} \leq 0$, I suppress all subscripts and introduce the following shorthand notations relating to equations (3) and (4). Let:

$$H_1 = \ln\left(\frac{Q_1}{P_1 - Q_1}\right) = \alpha_1 N_1 + k_1, \text{ where } : k_1 = \beta_1' Z_1 + \delta_1 + \omega_1 + \zeta_{1rt} + t v_{1m} + \varepsilon_1$$

$$H_2 = \ln\left(\frac{Q_2}{P_2 - Q_2}\right) = \alpha_2 N_1 + k_2, \text{ where } : k_2 = \alpha_{22} N_2 + \beta_2' Z_2 + \delta_2 + \omega_2 + \zeta_{2rt} + t v_{2m} + \varepsilon_2$$

Then the current period consumer and fleet flex-fuel sales may be written:

$$Q_1 = P_1 \frac{\exp(H_1)}{1 + \exp(H_1)} = P_1 \frac{\exp(\alpha_1 N_1 + k_1)}{1 + \exp(\alpha_1 N_1 + k_1)}$$

$$Q_2 = P_2 \frac{\exp(H_2)}{1 + \exp(H_2)} = P_2 \frac{\exp(\alpha_1 N_1 + k_2)}{1 + \exp(\alpha_1 N_1 + k_2)}$$

Differentiating Q_1 with respect to N_1 yields:

$$\frac{\partial Q_1}{\partial N_1} = \frac{\partial}{\partial N_1} P_1 \frac{\exp(\alpha_1 N_1 + k_1)}{1 + \exp(\alpha_1 N_1 + k_1)} = \alpha P_1 \frac{\exp(\alpha_1 N_1 + k_1)}{(1 + \exp(\alpha_1 N_1 + k_1))^2} = \frac{\alpha_1 Q_1}{1 + \exp(H_1)}$$

Similarly, for Q_2 we obtain: $\frac{\partial Q_2}{\partial N_1} = \frac{\alpha_{21} Q_2}{1 + \exp(H_2)}$. Let B_1 (B_2) represent the prior period, predetermined installed base of consumer (fleet) FFVs: $B_1 = \sum_{\tau=-\infty}^{t-1} w_{t-\tau} Q_{1\tau}$. Then, from equation (6) we have:

$$\frac{\partial S}{\partial N_1} = \frac{\partial}{\partial N_1} ((B_1 + Q_1) + \gamma(B_2 + Q_2) + \lambda' X_5) = \frac{\partial Q_1}{\partial N_1} + \gamma \frac{\partial Q_2}{\partial N_1}$$

Using these side calculations and referring to the profit equation (5), the constraint $\frac{\partial \Pi^N}{\partial N_1} \leq 0$ takes the form:

$$\begin{aligned} \frac{\partial \Pi^N}{\partial N_1} &= \frac{\partial}{\partial N_1} \left[S(N_1) \frac{(a-c)^2}{(1+N_1)^2} - F \right] \leq 0 \\ &\implies \frac{\partial S}{\partial N_1} \frac{(a-c)^2}{(1+N_1)^2} - \frac{2S(a-c)^2}{(1+N_1)^3} \leq 0 \\ &\implies \frac{(a-c)^2}{(1+N_1)^2} \left[\left(\frac{\partial Q_1}{\partial N_1} + \gamma \frac{\partial Q_2}{\partial N_1} \right) - \frac{2S}{(1+N_1)} \right] \leq 0 \\ &\implies \frac{\alpha_1 Q_1}{1 + \exp(H_1)} + \frac{\gamma \alpha_{21} Q_2}{1 + \exp(H_2)} - \frac{2S}{1 + N_1} \leq 0 \end{aligned}$$

D FFV installed base initial conditions

Estimation of the E85 entry model requires computation of the FFV installed base. Uncertainty arises in this computation because I do not observe flex-fuel vehicle demand in periods prior to 2001 ($t = 1$), resulting in an initial conditions problem. Fortunately, the severity of this problem is moderate: according to Department

of Energy figures, only 14% of cumulative FFV production through 2009 occurred during the period 1998-2000 [?]. Nevertheless, I attempt to address this issue by imputing FFV demand for the years 1998-2001. I perform the imputation by modeling the *proportion of manufactured FFVs* that are registered in a given zip code (by registrant type), using a generalized linear model with a logit link and binomial family. That is, for each zip code I estimate regression intercepts (and their standard errors) using my nine yearly observations of FFV registrations and the aggregate FFV production quantities for the corresponding year.¹ To simulate FFV registrations for unobserved periods, I draw the registration proportion from the corresponding market distribution and multiply by the aggregate FFV production for that period. As with the error terms ε , I take 30 draws per market, so that the effect of the initial conditions are integrated out of the objective function (10) when N_1^* is computed. For the purpose of reporting the installed bases of FFVs in Table 1, I use average values of the simulated data from 1998-2001.

E Robustness results

Here I explore the robustness of my results to three key assumptions: the spatial independence of markets, the competitive conduct of firms, and the specification of fleet FFV demand. The assumption of Cournot competition only has implications for the entry model estimation, while spatial independence and fleet demand specifications affect both FFV demand and E85 supply estimates.

There are two potential concerns related to the assumption of spatial independence. First, the assumption rules out regionally-correlated shocks such as advertising campaigns that span multiple zip codes. Second, model does not explicitly account for potential “spillovers” in ethanol adoption (in FFV demand or E85 supply) from nearby markets. I employ two procedures to assess the robustness of model estimates to the assumption of market independence. First, I explore the robustness of model estimates to increased geographic isolation of markets, which should attenuate the influence of regional shocks and spillovers. That is, I estimate the model using markets in which E85 retailers are increasingly separated by some minimum distance. I use samples which satisfy 5, 10, and 20 mile minimum separation criteria, and report results in columns 2 to 4 of Tables 1, 2, and 3 below. I include the main estimation results in the first column of the tables below to facilitate comparisons. Inspection of the results suggests that estimates are generally robust to the extent of geographic isolation (and hence spatial independence). Point estimates of the α parameters in the flex-fuel demand equations are statistically consistent (with 95% confidence intervals) but significance levels fall rapidly

¹The latter data come from the Department of Energy and date to the first production year for FFVs. Available at <http://www.afdc.energy.gov/afdc/data/vehicles.html>.

with increasing distance, reflecting in part the smaller sample sizes as separation distances increase. Parameters of the E85 entry model also generally remain consistent within 95% confidence intervals. Measurement of the entry thresholds, the primary object of inference in the entry model, is highly consistent across specifications. As a second robustness check, I estimate a version of the model in that includes “spatial lags” of the endogenous variables (column 5 in the tables below). The spatial lags are weighted sums of the variable of interest, where weights are inversely proportional to the distance to the focal market. A cutoff distance of 15 miles is imposed – i.e., weights for markets more than 15 miles from the focal market are set to zero. As an example, the variable SL_{N_1} in Tables 1 and 2 contains the weighted sum of the number of E85 retailers (outside the focal market) in zip codes up to 15 miles from the focal market. The E85 entry model similarly includes spatial lags of the consumer and fleet FFV installed bases, as well as interactions with the number of interstates (which presumably might shift cross-market contact). The spatial lag terms are insignificant in the FFV demand models and the α parameters are virtually unaffected, further implying that the FFV demand specification is robust. Unsurprisingly, the E85 entry model estimates differ to a greater extent across the specifications as they employ fewer controls, but the net effect in terms of the predicted entry thresholds is generally robust.

Fleet demand specifications are explored in columns 6 and 7 of Tables 2 and 3. In column 6, I take the fleet market size to be the market population (as in the consumer FFV demand regressions). Comparing results in this column to the first, it is readily apparent that the using population as the market size results in a significantly larger FFV demand response to E85 availability. Also, the entry model results using this demand specification imply that fleet vehicles contribute less to E85 profitability than consumer FFVs. These factors lead me to conclude that the employee market size measure is preferable as it is more conservative (FFV demand) and more realistic (E85 entry). In column 7, I report estimates from a linear regression where fleet FFV registrations (Q_2) is the dependent variable. This model is estimated using the System GMM procedure with the same regressors and instruments as in the main model estimation. As the dependent variable in the fleet demand regression is different here, it is inappropriate to compare the estimated coefficients with the other columns of Table 2. I include this specification purely as a robustness check in the E85 entry model. In Table 3, comparing column 7 to the first reveals that these results are highly consistent, lending support to the premise that the results of the main (aggregate logit) model are plausible and robust.

Finally, in column 8 of Table 3, I explore an alternative assumption about firm competition. The Cournot assumption implies that installed bases should increase at a rate proportional to $(1 + N_1)^2$. However, casual inspection of the FFV installed base conditional upon N_1 in Table 2 suggests that installed bases may increase at

a slower rate. Cartel behavior is an alternative model of competitive conduct that is consistent with a slower rise in the installed base (linear in N_1). The cartel model also represents a lower bound for the effect of competition on ethanol retailer profits. Comparing the cartel model estimates (column 8) to the analogous Cournot model (column 1), we see that all reported parameter estimates are statistically equivalent (some differences do exist in the unreported state fixed effects). Monopoly thresholds for this model are essentially the same as in the Cournot model, suggesting that the specification of competition has relatively little influence in determining the estimated parameters.

Specification	1	2	3	4	5
E85 station separation (mi)	0	5	10	20	0
retail E85 stations (N_1)	0.059*	0.057*	0.046	0.028	0.059*
spatial lag retail E85 stations (SL_{N_1})					-0.001
<i>rural</i>	0.022	0.007	-0.004	0.041	0.025
<i>income</i>	0.016***	0.015***	0.013***	0.013***	0.016***
<i>commute</i>	0.004	0.007*	0.010*	0.011*	0.004
<i>gas_stations</i>	-0.011***	-0.010***	-0.009***	-0.010***	-0.011***
<i>dealerships</i>	-0.012***	-0.012***	-0.012**	-0.012*	-0.012**
Zip fixed effects	Yes	Yes	Yes	Yes	Yes
Period fixed effects	Yes	Yes	Yes	Yes	Yes
State/Year FE	Yes	Yes	Yes	Yes	Yes
Zip time trends	Yes	Yes	Yes	Yes	Yes
Observations	34713	31121	24078	14707	34713

Significance levels: * 5%, ** 1%, *** 0.1%

Table 1: Robustness results – consumer FFV demand

Specification	1	2	3	4	5	6	7
Fleet market size	Employees	Employees	Employees	Employees	Employees	Population	N/A
E85 station separation (mi)	0	5	10	20	0	0	0
retail E85 stations (N_1)	0.064*	0.059*	0.040	0.031	0.061**	0.172***	1.005***
spatial lag retail E85 stations (SL_{N_1})					0.008		
private E85 stations (N_2)	0.026	-0.013	-0.217	-0.102	-0.052	-0.060	0.388
<i>rural</i>	0.016	-0.003	-0.006	0.038	0.020	0.051	-0.848*
<i>income</i>	0.013***	0.015***	0.013***	0.013**	0.016***	-0.003	0.037***
<i>commute</i>	0.003	0.007	0.010	0.010	0.003	-0.005	0.016
<i>gas_stations</i>	-0.009***	-0.010***	-0.009***	-0.010***	-0.011***	-0.038***	0.103***
<i>dealerships</i>	-0.015**	-0.014**	-0.013*	-0.014*	-0.011**	-0.015	0.174***
Zip fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Period fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
State/Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Zip time trends	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	34713	31121	24078	14707	34713	34713	34713

Significance levels: * 5%, ** 1%, *** 0.1%

Table 2: Robustness results – fleet FFV demand

Specification		1	2	3	4	5	6	7	8
E85 station separation (mi)		0	5	10	20	0	0	0	0
Competition		Cournot	Cournot	Cournot	Cournot	Cournot	Cournot	Cournot	Cartel
Fleet market size		Employees	Employees	Employees	Employees	Employees	Population	N/A	Employees
Variable	<i>rural</i>	0.791***	0.615***	0.596***	0.571***	0.743***	0.758***	0.803***	0.791***
profits	<i>income</i>	-0.021***	-0.024***	-0.020***	-0.021***	-0.021***	-0.022***	-0.022***	-0.021***
	<i>commute</i>	-0.028***	-0.022***	-0.025***	-0.027***	-0.027***	-0.029***	-0.028***	-0.027***
	<i>gas_stations</i>	-0.011***	-0.028***	-0.030***	-0.020***	-0.027***	-0.026***	-0.027***	-0.026***
	<i>refineries</i>	0.316***	0.298***	0.302***	0.207***	0.315***	0.305***	0.323***	0.300***
	State FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Period FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Infrastructure	State FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
costs	Period FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	ρ_{12}	0.024	-0.005	0.008	-0.002	0.017	-0.018	-0.011	0.008
	ρ_{13}	0.002	-0.012	0.004	-0.005	0.001	-0.001	0.000	0.022
Market size	<i>interstates</i>	26.608***	30.964***	29.443***	38.179***	36.472***	26.557***	26.296***	27.511***
	<i>flt_ffv_ib</i>	1.415***	1.907***	1.789***	2.997***	1.711***	0.652***	2.095***	1.394***
	<i>N₂*flt_ffv_ib</i>	-1.226**	-2.078**	-0.526	-1.175	-1.043*	-0.791*	-1.503	-1.127**
	<i>SL_con_ffv_ib</i>					0.065***			
	<i>SL_ftl_ffv_ib</i>					-0.463***			
	<i>SL_con_ffv_ib*interstates</i>					-0.088***			
	<i>SL_ftl_ffv_ib*interstates</i>					0.459***			
Observations		34713	31121	24078	14707	34713	34713	34713	34713
Monopoly entry threshold		299	315	296	399	321	288	305	296
Significance levels: * 5%, ** 1%, *** 0.1%									

Table 3: Robustness results – E85 market entry