The Effect of Fuel Economy Standards on Vehicle Weight Dispersion and Accident Fatalities

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Motivation

- Economists and policy makers are concerned with the response of firms to regulation:
  - Heterogeneous response along the product space
  - Opportunities for additional competition
- Concern with miscalculation/perception of risk associated with product choices and the creation of internalities

Fuel Economy Standards

- Fuel economy standards—the CAFE Standard (Corporate Average Fuel Economy)
  - Requires firms to increase average fuel economy
- Direct compliance costs (Jacobsen, 2013; Anderson and Sallee, 2011)
- Indirect costs: If CAFE brings light-weight vehicles to the fleet will accidents become more deadly?
  - With normal V.S.L., accidents costs can quickly overshadow direct costs.
  - Approximately 70 extra deaths annually is enough.

Media is Convinced CAFE is Deadly

"Depending on which study you choose, the total [number of deaths] ranges from 41,600 to 124,800."… "In the past thirty years, fuel standards have become one of the major causes of death and misery in the United States"

— Deroy Murdock, National Review

Attempt to increase in 1991 was opposed because it would "have adverse effects on vehicle safety"

– Senator Richard Bryan (D-Nev.)

Approach of this paper

- First paper to empirically measure dispersion caused by CAFE standards.
  - Estimate impact of CAFE on unconditional quantiles using RIF-regression
  - Were there interactions with unbound Asian firms?
- Simulate fatalities without CAFE.
  - Estimate fatality risk using state level accident data.
  - Change vehicle weights.
  - Simulate total change in accidents.

Our Findings

- CAFE generates weight dispersion.
  - Down-weight already light weight vehicles (40-50 lbs. per MPG increase in standard)
  - Consumers more concerned with prices than attributes.
  - Lower mean, more dispersion in weight.
  - Offsetting by unbound Asian firms.
- CAFE saved 1,343 to 100 lives per year.
  - Weight dispersion increases fatalities.
  - Lower mean weight decreases fatalities.
  - Roughly half of all accidents involve 1 vehicle (no dispersion).
  - Lower mean dominates dispersion.
  - Robust to changes in footprint, omitting effects of foreign firms, various data issues.

Prior Studies—CAFE & Fatalities

- The most influential study in this area Crandall and Graham (1989) found CAFE lowered weight 470 lbs.
  - Vehicles 500lbs below the mean have higher fatalities (Evans, 1984).
- Our concern
  - Can we approximate the outcomes of a lighter fleet by looking at lighter vehicles?
  - Can a dispersion result be applied to the mean?

Prior Studies—Arms Race

- Well established fact that heavier vehicles pose a danger to lighter vehicles (White, 2004; Li, 2012; Anderson and Auffhammer, 2014).
  - How does weight shift risk between vehicles?
  - Not asking how weight changes total fatalities.

Evolving Understand of Compliance Channels

- Simulation based studies (White, 2004; Jacobsen 2013)
  - Not measuring if dispersion occurred.
  - Change shares of vehicles, keep attributes fixed.
  - Only allows for quantity shifting, no attribute changes.
- Prices are shifted to change quantities to achieve standard. (Goldberg, 1998; Austin and Dinan, 2005; Bento, Goulder, Jacobsen and von Haefen, 2009; Gillingham, 2012).
- Firms may change attributes (Knittel, 2011; Klier and Linn 2013; Roth, 2013; Whitefoot, Fowlie, and Skerlos, 2013).

Outline

- Review key details of CAFE
- Why dispersion might occur
- How to estimate dispersion
  - Traditional Quantile Regression, Binned, Panel
- Data
- Results
- Accident Simulation
  - Effect of weight on fatalities
  - Change vehicle weights
- Conclusions

CAFE as an Environmental Policy

- The Corporate Average Fuel Economy Standard sets minimum fuel economy standards in the US.
- Increased between 1978-1990.
- For cars 27.5 mpg from 1990 to 2010.
  - Binding for US firms
  - Asian firms exceeded target.
- Differentiated standard based on cars vs. trucks.
  - Differentiated on 2WD and 4WD in early years for trucks.
- Can borrow and bank credits up to 3 years.
- New standard: 54.5 miles per gallon by 2025.
  - Punishes smaller footprint: length × width
  - May break historic link between weight and footprint.

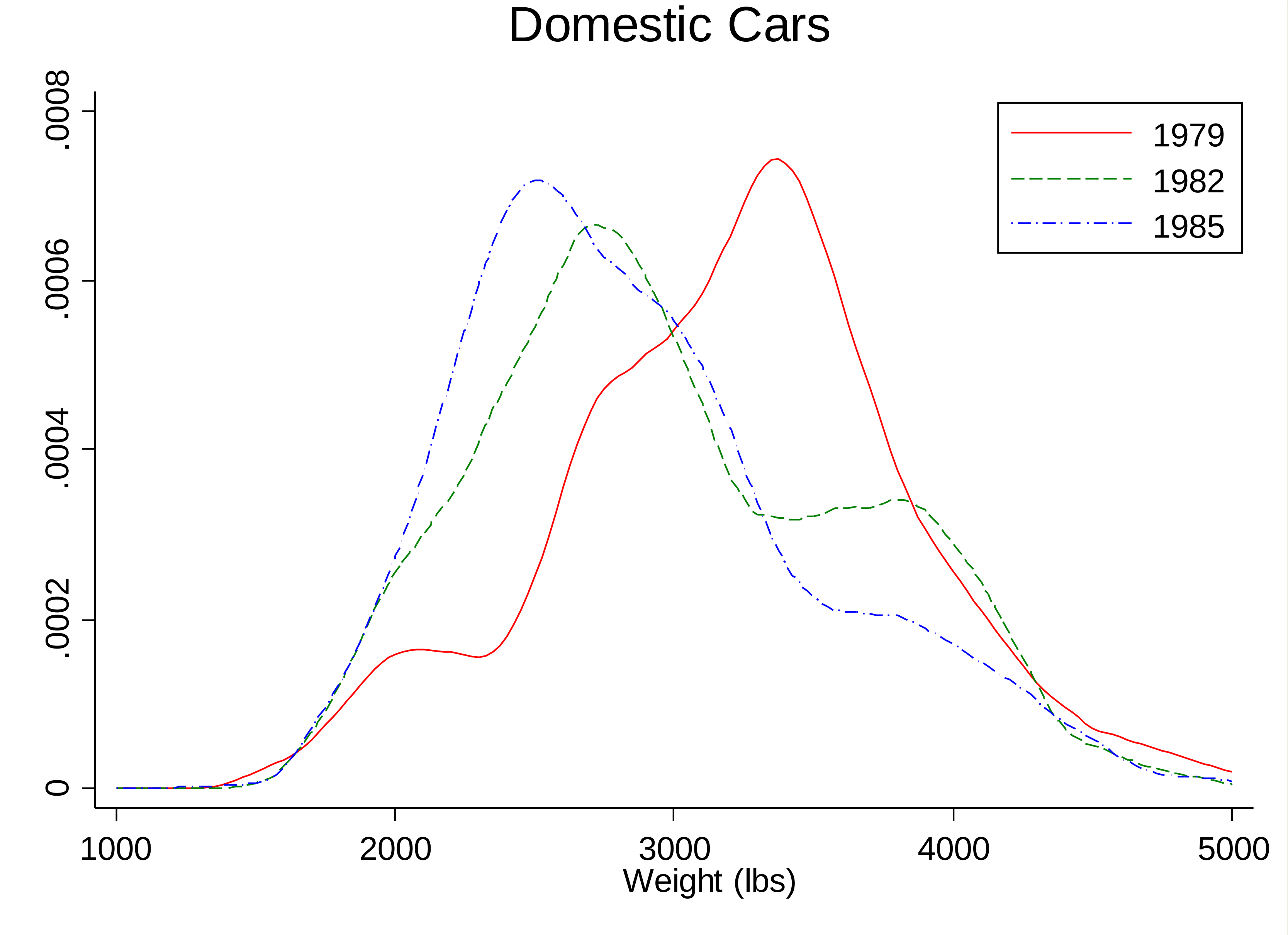
Channels of Adjustment

- In stylized oligopoly models, firms have a few options to comply with CAFE
  - Change vehicle <u>prices</u> to deter sales of inefficient vehicles.
    - Quantity shifting.
  - Reduce vehicle <u>weight</u> (or horsepower) to improve fuel economy.
    - Small price effects but lower quality vehicle.
  - Install new <u>technology</u> to improve fuel economy.
    - Preserves attributes but increases costs.
  - Game standard
    - Loopholes.
    - Convert vehicles to category with lower standard.

Heterogeneous response?

- Where consumers are more sensitive to price than quality, may down-weight.
- Where consumers are sensitive to quality, may install new technology.

- For Asian firms not constrained by CAFE, this may open up product space.
- Asian vehicles may respond via competitive effects, even if not directly affected by CAFE



- Not uniform down-weighting
- Some large vehicles are largely preserved.

Chosen Approach: RIF Regression

- We use RIF-regression to analyze these changes.
- RIF is a transformation of each dependent observation, y.
- What the transformation is varies by statistic. (E.g. quantile τ)
- The mean of the RIF is the statistic, and using it as data recovers the marginal effect of the covariate on that statistic.

$$RIF(y;q_\tau) = \beta_\tau^{0} + \beta_\tau^{1} S_t + \beta_\tau^{2} X_t + \varepsilon$$

  - q_τ: τ-quantile (or other statistic: variance, gini)
  - S_t: Stringency of regulation
  - X_t: Other regressors
- Interpretation: β_τ^{1} is the effect of S_t on τ-th unconditional quantile of y, as OLS is with the mean.
- Like OLS, inclusion of X_t does not change the interpretation of β_τ^{1}. This is not true of traditional, conditional quantile regression.

Other approaches

- OLS will only measure the mean.
- Where the down-weighting occurs helps to understand firm strategy, fatality effects.
- Possible other techniques:
  - Panel of models
    - Model introduction/termination influenced by policy
  - Binned OLS/Semi-parametric estimation by weight
  - Traditional, conditional quantile regression
  - New unconditional quantile techniques used to analyze wage dispersion in labor: RIF-regression.
  - Monte Carlo to compare these methods.

Turnover Model

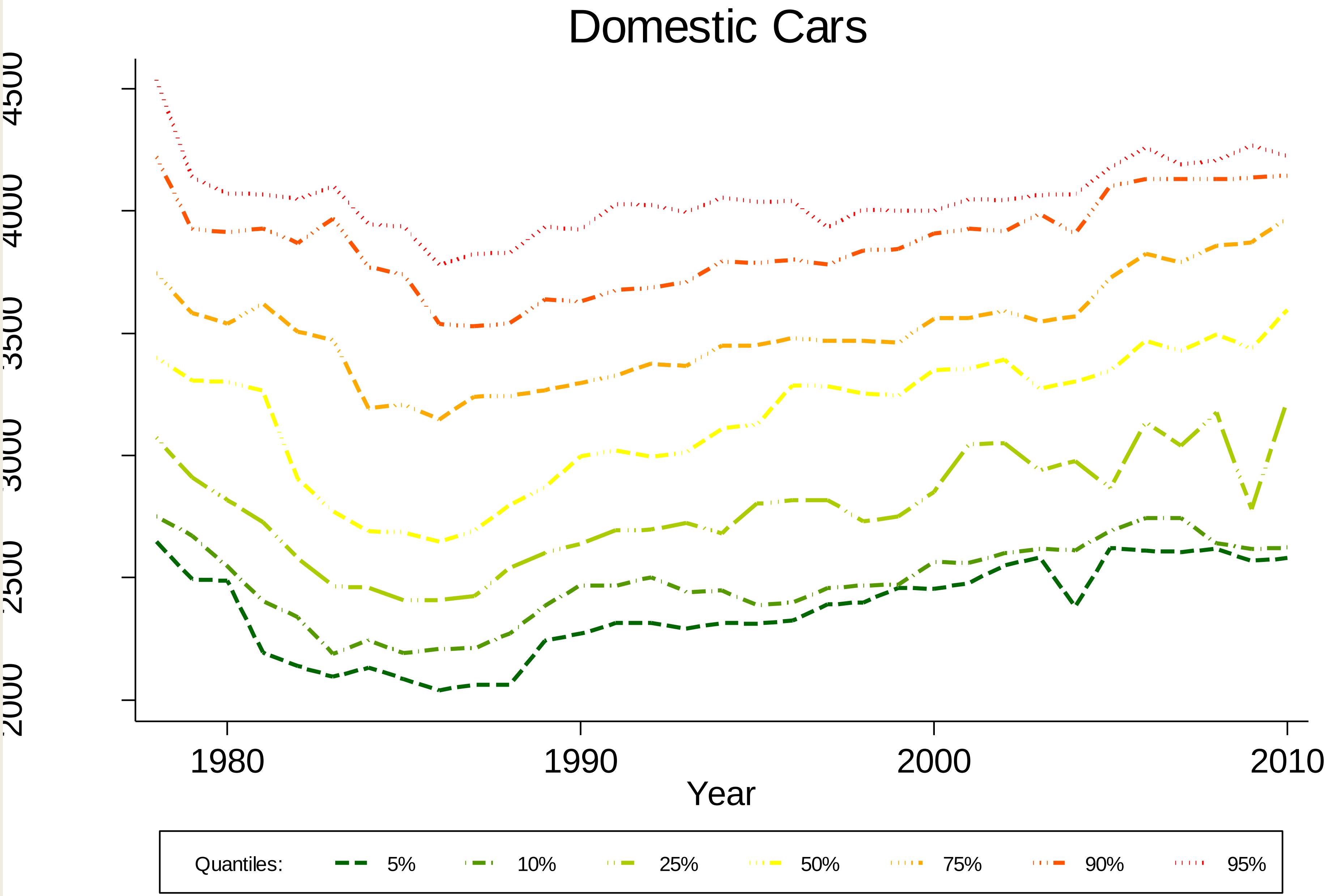
Recover effect using 3 methods

- Binned OLS:
  - Put all data into weight quantiles.
  - Run OLS with data in each bin.
  - All changes outside of bin ignored.
- Conditional Quantile.
  - Most previous quantile regression.
  - Condition on type
  - Examine effect of treatment within each type.
  - Average estimates of treatment across types.
- RIF regression.
- In all regressions we control for high/low type.

Unique Data

- Wards Automotive Yearbooks, 1971-2011
- Detailed *trim* level data on vehicle characteristics including, weight, fuel economy, make, model, class.

  94,000 trims; 10,000 models; 18 classes
- Wards Automobile Yearbooks, 1977-2011
- *Model* level sales
- Will deal with vehicle prevalence using accident data.
- Automobile Catalogue 1945-2011
- Trim level characteristics of vehicles (for limited makes).
- Unique in showing pre-CAFE behavior.



Data Sources

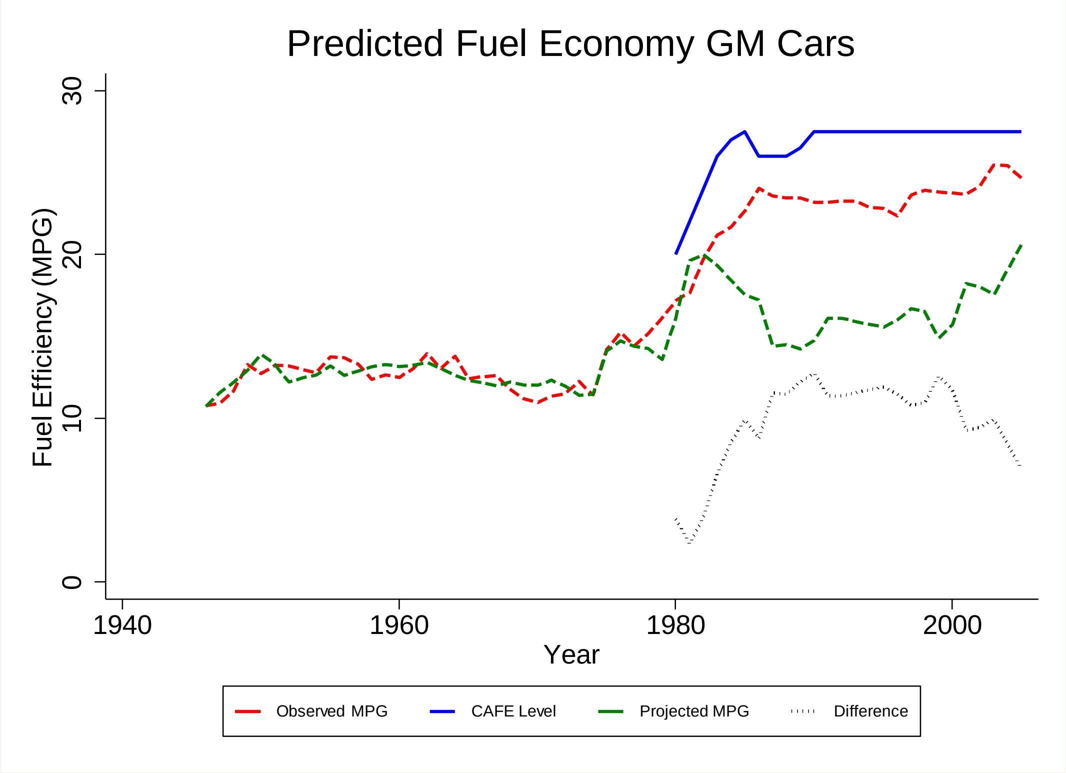
Measure the Effect of CAFE on these Data?

- Need a measure of CAFE stringency.
- Develop several measures, each with advantages and disadvantages:
  1. CAFE level minus predicted fuel economy (calculated based on pre-CAFE period)
  2. Level of CAFE standard (omit for today’s talk)
  3. Credit Balance (robustness check)
- Vehicles have a 3- to 5-year design cycle.

Primary Measure: Counterfactual Fuel Economy.

(CAFE level – Predicted fuel economy)

- Inspired by measure used in Small and Van Dender (2007)
- Coefficients from pre-1978 regression of mpg on gasoline price, GDP and a trend. (By automaker and fleet at vehicle level.)
- Central specification: average across, t-3, t-2, t-1, t, and t+1
- Concern: Are coefficients from 1960s applicable to 1990?

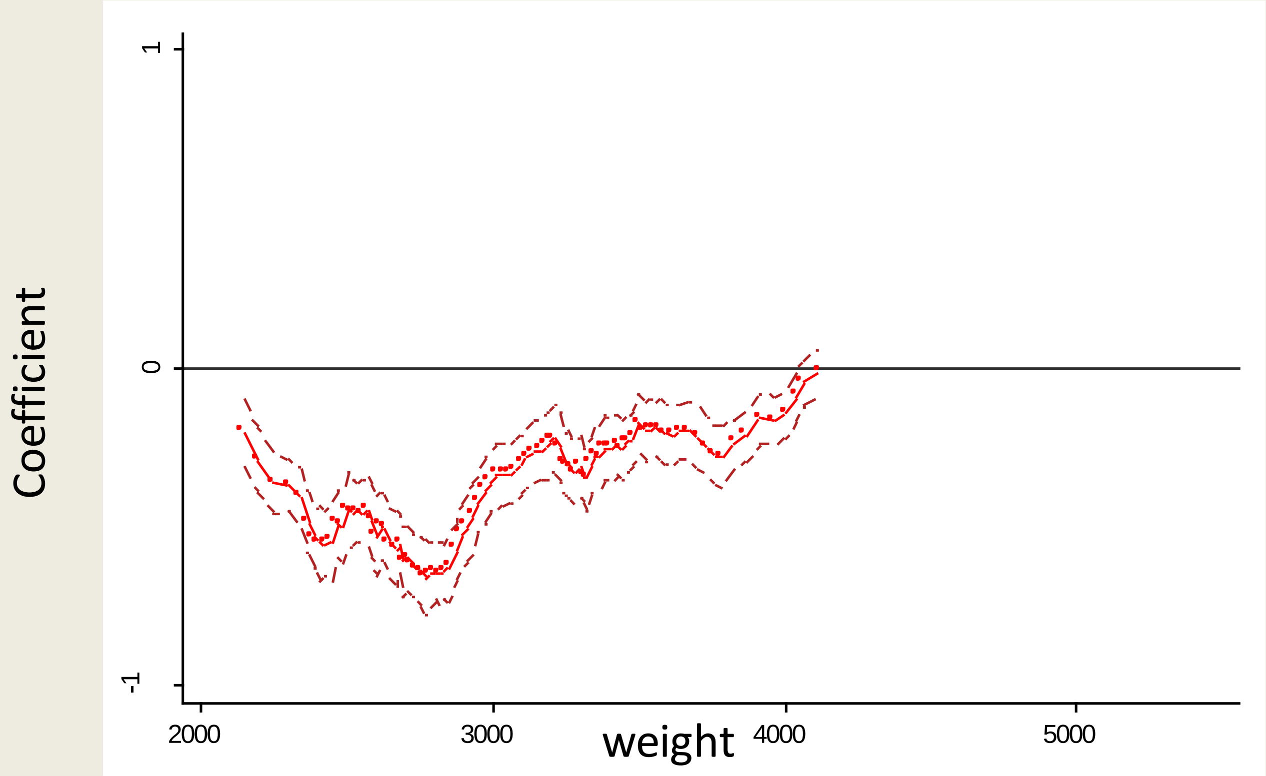


Other Controls

- Gasoline prices and GDP:
  - Central spec averages across 3 prior years: t-3, t-2, and t-1.
- Trend and trend-squared
- Firm fixed effects.
- Other tested covariates:
  - Firm-trend interactions
  - Model-year fixed effects
  - Prior year only of gasoline prices and GDP
  - Lagged firm-fleet weight.

Stringency Measure 1: Predicted MPG—Domestic Cars

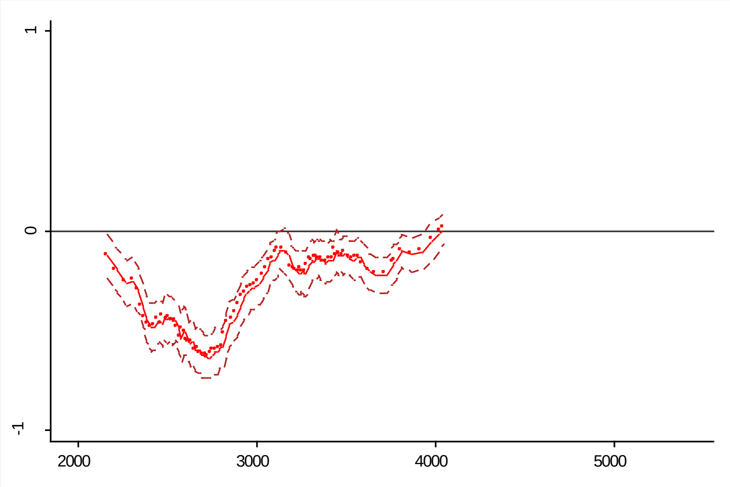
	OLS	Q10	Q25	Q50	Q75	Q90
	log(Predicted Fuel Economy - Standard)					
Stringency	-0.299***	-0.536***	-0.557***	-0.304***	-0.222***	-0.214***
	(0.027)	(0.049)	(0.059)	(0.054)	(0.048)	(0.044)
Weight in Quantile	3023.4	2280	2582	2989	3429	3803
Weight Change for 1MPG	-32.8	-44.4	-51.9	-33.2	-27.7	-29.6



Controls for gasoline price, GDP, firm fixed effects and trends. Bootstrapped std. err.

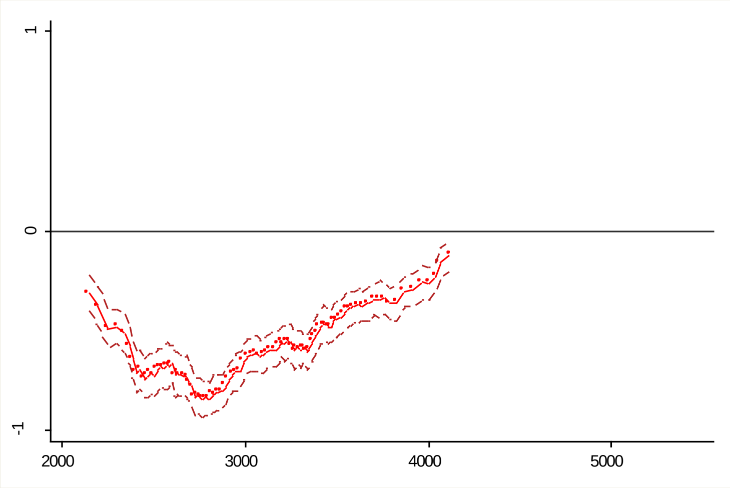
Stringency Measure 1: Robustness on Stringency

Coefficient



weight

More forward looking:
Average stringency across t-2, t-1, t, t+1, and t+2



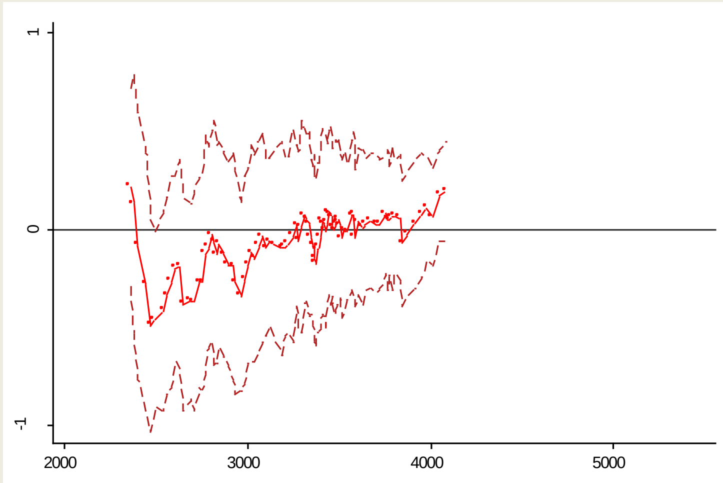
weight

Instantaneous:
Stringency in t-1

Controls for gasoline price, GDP, firm fixed effects and trends. Bootstrapped std. err.

Stringency Measure 1: Further Robustness

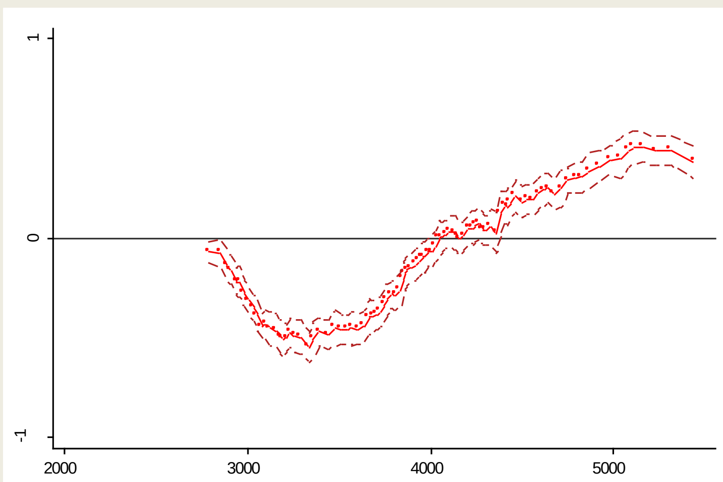
Coefficient



weight

Sales Weighted:
Model level observations

- Capture prevalence on the road with accident data.



weight

Light Trucks: Pickup Trucks, Vans, SUVs, CUVs

- Switching between 2WD and 4WD standards.
- Competition from Heavy-Duty Vehicles, which are unregulated.

Controls for gasoline price, GDP, firm fixed effects and trends. Bootstrapped std. err.

Non-Domestic Fleet

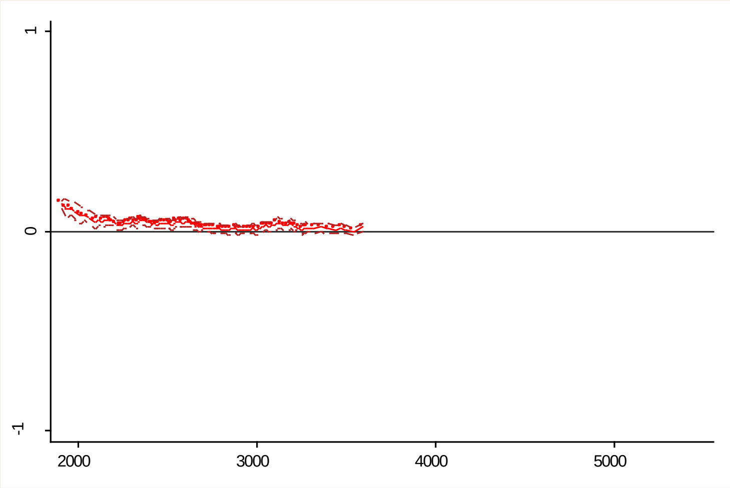
- Asian Vehicles:

  Manufactures are subject to, but not bound by CAFE

  Fuel economy exceeds mandate.
- While CAFE may not have a direct effect, it may have effects through a channel of competition.
- Examine the reaction to their own stringency.
- Examine the reaction to the stringency of the domestic manufactures.
- European Vehicles:

  Small market share. Pay fines to avoid compliance.

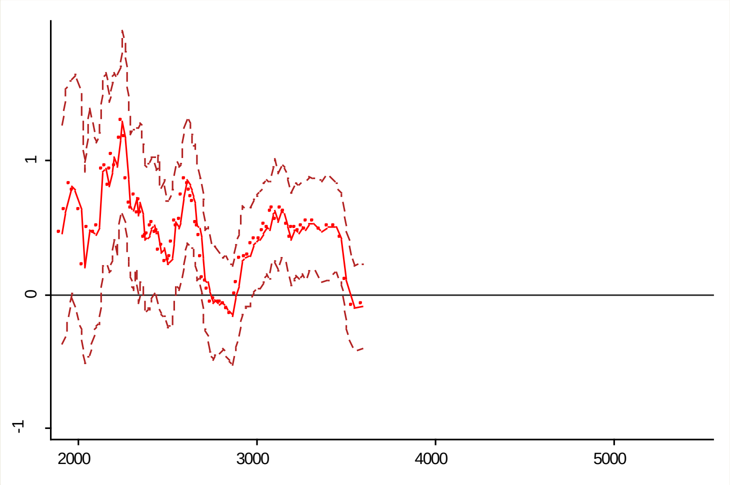
Stringency Measure 1: Asian Fleet



Own Firm Stringency

Coefficient

weight



Sales-weighted Domestic Firm Stringency

The Asian firms appear to offset the down-weighting of the domestic firms.

Will offset dispersion created in domestic fleet

weight

Additional controls for gasoline price, GDP, firm fixed effects and trend.

Summary: Non-Domestic Fleet

- Domestic Vehicles:
  - Down-weight light, economy vehicles
  - Lower mean, higher dispersion
- Asian Vehicles:
  - Do not seem to react much to their own stringency.
  - Upweighting in response to higher stringency on domestic firms.
  - Could offset some dispersion.

Implications for Fatalities

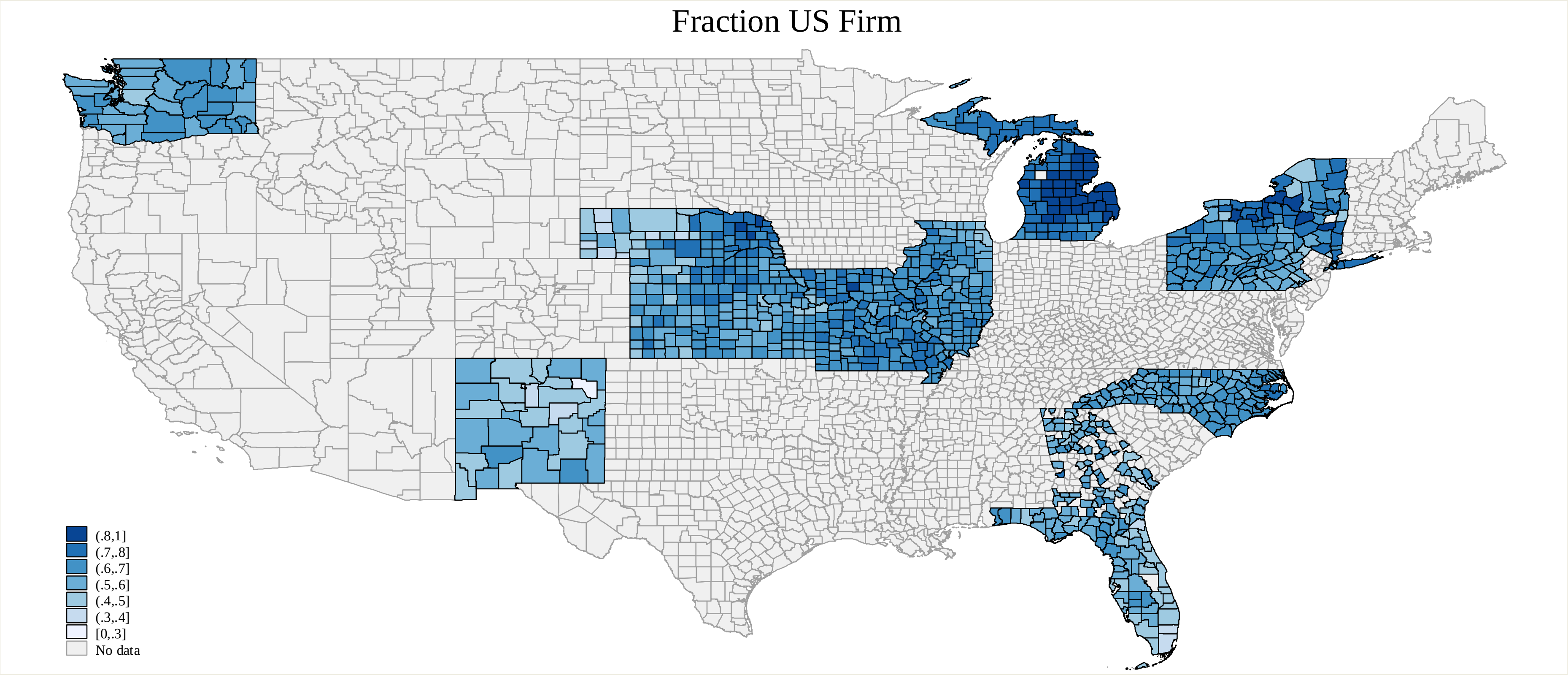
- Simulate how these weight changes influenced fatalities on existing set of accidents.
- Importance of footprint
  - Not a strategy for improving MPG
  - But has changed with weight; may affect fatalities

1. Estimate effect of mean and dispersion of weight and footprint on total fatalities.
2. Remove weight changes according to RIF regressions.

NHTSA State Data System of Accidents

- Population of all police reported accidents.
- Provides vehicle information and fatalities.
- Roughly 30 million accidents from various states between 1995-2009.
- Only examine 1-, 2-, and 3-vehicle crashes.
  - No pedestrians, motorcycles, heavy duty vehicles.
  - All vehicles must be identifiable
- Final sample of 17 million vehicles.

Fraction of Vehicles



- Regional variation in types of vehicles observed
- Lower coverage in Western US

Step 1: Probability of Accidents

- Estimate probability of a fatality in any vehicle based on:

$$P(f_i=1)=\beta^0+\beta^1\mu(\mathbf{wt}_i)+\beta^2\sigma(\mathbf{wt}_i)+\beta^3 s(\mathbf{fp}_i)+X_i\gamma+\varepsilon_i$$

  - $\mu(\mathbf{wt}_i)$: total weight in accident
  - $\sigma(\mathbf{wt}_i)$: dispersion of vehicle weights
  - $s(\mathbf{fp}_i)$: size of vehicles' footprints
  - X_i: Other regressors—Model year, trend, county of crash, speed, seatbelts

- Differentiate based on number of vehicles involved
  - 1-vehicle no dispersion measure
  - 2-vehicle dispersion $\sigma(\mathbf{wt}_i) = abs(wt_{1,i} - wt_{2,i})$
  - 3-vehicle dispersion $\sigma(\mathbf{wt}_i) = st.\ dev\ (wt_{1,i}, wt_{2,i}, wt_{3,i})$

One Vehicle Crashes

	I	II
Weight (1000 lbs)	0.00200***	0.00249***
	(0.00012)	(0.00030)
Footprint	-0.00005***	-0.00004***
	(0.00000)	(0.00001)
Speed and Seatbelts	N	Y
R-squared	0.01	0.06
N	7,345,202	1,639,271

Controls: County, Class (car, pickup, SUV/Van), Model Year, Trend

Lower weight is safer.

Larger vehicles carry more energy (Wenzel, 2013)

- Vehicle must absorb more energy
- Higher breaking demands,

Large footprint decreases fatality risk.

Speed and Seatbelts: small change in point estimate, small sample.

Multi-Vehicle Accidents

	Two Vehicle			Three Vehicle	
	III	IV		V	VI
Sum of Weights	0.00021***	0.00038***	Sum of Weights	0.00049***	0.00058**
	(0.00004)	(0.00011)		(0.00012)	(0.00028)
Abs(Weight Diff.)	0.00056***	0.00059***	Std. Dev. of Weights	0.00128***	0.00192**
	(0.00005)	(0.00011)		(0.00034)	(0.00078)
Smallest Footprint	-0.00001***	-0.00001*	Smallest Footprint	-0.00002**	-0.00001
	(0.00000)	(0.00000)		(0.00001)	(0.00002)
Largest Footprint	0.00000**	0.00000	Largest Footprint	0.00001**	-0.00001
	(0.00000)	(0.00000)		(0.00000)	(0.00001)
Speed and Seatbelts	N	Y		N	Y
R-squared	0	0.02		0.01	0.03
N	8956966	2125543		739020	190249

Controls: County, Class (car, pickup, SUV/Van), Model Year, Trend

Lower total weight is safer.

Weight dispersion is unsafe.

Step 2: Simulate Fatalities

Change the weights according to RIF regressions

- Set stringency equal to zero.
  - Stringency in 2005 is different than in 1995
  - Remove insignificant effects
  - Remove all competition effects (remove Asian firms).

Step 2: Simulate Fatalities

- Recalculate fatality rate in all 17 million crashes
  - Gives a percent change in fatalities
- Extend nationally
  - Apply average percent change to nation
  - Impute county level % change based on county characteristics:
    - county level: population and fatalities,
    - state level: % domestic, Asian fleet, % light truck, average vehicle weight and average vehicle age.

Role of Footprint

- New standard attempts to punish footprint reductions.
  - Historically weight and footprint were closely linked.
  - Elasticity of 0.7
  - Change footprint with weight.
    - Small vehicles have a small footprint.
    - Small footprint is fatal, particularly on smallest vehicle in a crash.

Simulation with Changing Footprint

	Removing Weight Changes due to CAFE			
	1995		2005	
	National Level	Imputed	National Level	Imputed
Using All Coefficients	700.6	514.1	585.0	427.0
Insignificant Values Assumed to be Zero	675.3	499.2	553.8	407.9
Remove Competitive Effects	499.2	390.5	127.4	99.9

- All indicate CAFE saved lives
  - More lives saved in 1995: low gas prices higher stringency
  - Not driven by insignificant RIF results.
  - Competition plays a larger role in 2005.
  - For perspective ~30,000 fatalities annually.

Results Holding Footprint Fixed

	Removing Weight Changes due to CAFE			
	1995		2005	
	National Level	Imputed	National Level	Imputed
Using All Coefficients	1230.7	887.7	713.5	479.7
Insignificant Values Assumed to be Zero	1283.4	936.3	832.3	592.0
Remove Competitive Effects	1343.4	1050.2	1038.2	812.7

- Keeping footprint fixed increases lives saved.

-> Maps

Discussion

- Benefits of simulations.
  - Transparent methodology
  - Preserves sorting of vehicles by city and by driver type
- Concerns
  - Driver or firm response to light-weight vehicles?
    - ➢ Changes in driver behavior (Peltzman, 1975)
    - ➢ Safety equipment by manufacture
    - ➢ Even if safer for society, small vehicles may be seen as less safe for occupants.
    - ➢ CAFE saved additional lives; estimates are too conservative.

Discussion

- Concerns.
  - CAFE will change total sales, VMT (rebound effect).
  - ➢ Fatality changes that are not due to weight changes.
  - Drivers would change vehicles. Quantity shifting.
  - ➢ Klier and Linn (2012) show this is an expensive compliance strategy.
  - ➢ Firms find it optimal to down-weight rather than preserve attributes using new technology.

Conclusion

- Ours is the first study to directly measure the effect of CAFE on weight dispersion.
- Link this dispersion with firm compliance strategy.
- CAFE saves >100 lives annually.
- New Footprint Standard.
  - Preserving footprint saves lives.
  - Unlikely to be optimal, but no evidence that it is harmful.

End

Appendix Slides

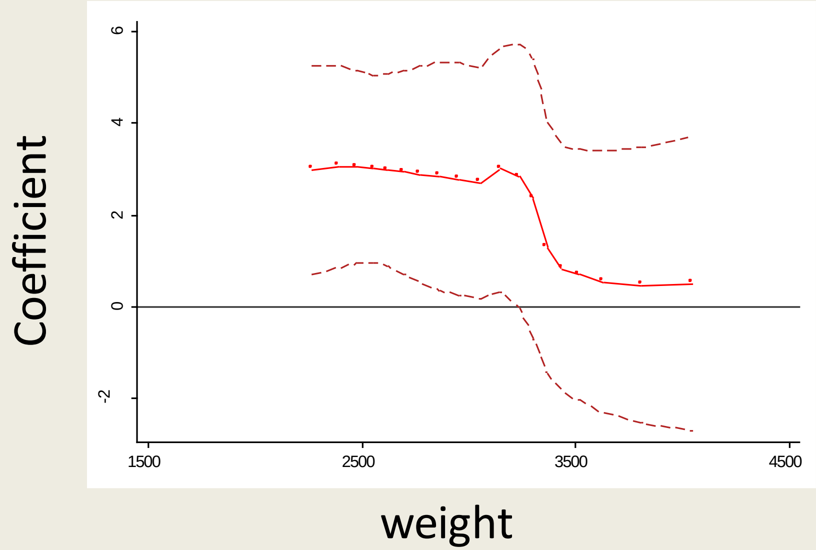
Summary Stats

Vehicle Weight

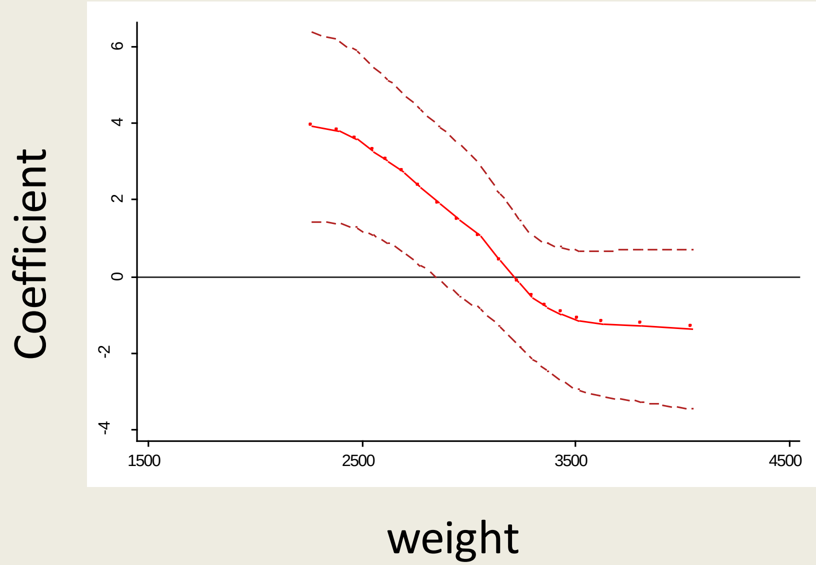
	Domestic			Foreign		
	Mean	Std. Dev.	N	Mean	Std. Dev.	N
1954 -1971	3,678	491	20,007			0
Cars	3,678	492	19,803			0
Light Trucks	3,668	434	204			0
1971 - 1981	3,591	701	10,016	3,337	875	2,002
Cars	3,583	703	9,278	3,339	872	1,942
Light Trucks	3,690	659	738	3,262	958	60
Post 1981	3,366	831	17,222	3,889	1,149	32,887
Cars	3,057	581	11,880	3,107	640	14,727
Light Trucks	4,052	889	5,342	4,523	1,077	18,160

Plot

What about a Panel?
Negative Binomial Regressions



Product Introductions



Product Terminations

Turnover is not random

Back

Other Measures

CAFE level

- Method adopted by all previous papers that directly measure effect on mean weight.
- Linear introduction as gasoline prices were falling.
- No cross-firm variation, no variation after 1990.

Credit Balance

- Unexpected deviations during stable period after 1990 are due to unforseen shocks to demand.
- Generates excess or shortage of credits in 3 year window.
- These adjustments appear to be too small but are similar to those presented here.
- Left for appendix

Results: Domestic Cars

	OLS	Q10	Q25	Q50	Q75	Q90
	log(Predicted Fuel Economy - Standard)					
Stringency	-0.299***	-0.536***	-0.557***	-0.304***	-0.222***	-0.214***
	(0.027)	(0.049)	(0.059)	(0.054)	(0.048)	(0.044)
Weight in Quantile	3023.4	2280	2582	2989	3429	3803
Weight Change for 1MPG	-32.8	-44.4	-51.9	-33.2	-27.7	-29.6
	log(CAFE standard)					
Stringency	-0.305***	-0.152	-0.436**	-0.624***	-0.341**	-0.183
	(0.075)	(0.145)	(0.142)	(0.132)	(0.120)	(0.108)
Weight in Quantile	3023.437	2280	2582	3001	3429	3803
Weight Change for 1MPG	-33.4	-12.6	-40.7	-67.8	-42.4	-25.2

Additional controls for gasoline price, GDP, firm fixed effects, and trend.

Stringency Measure 2: CAFE Level—Domestic Cars

	OLS	Q10	Q25	Q50	Q75	Q90
	log(CAFE standard)					
Stringency	-0.305***	-0.152	-0.436**	-0.624***	-0.341**	-0.183
	(0.075)	(0.145)	(0.142)	(0.132)	(0.120)	(0.108)
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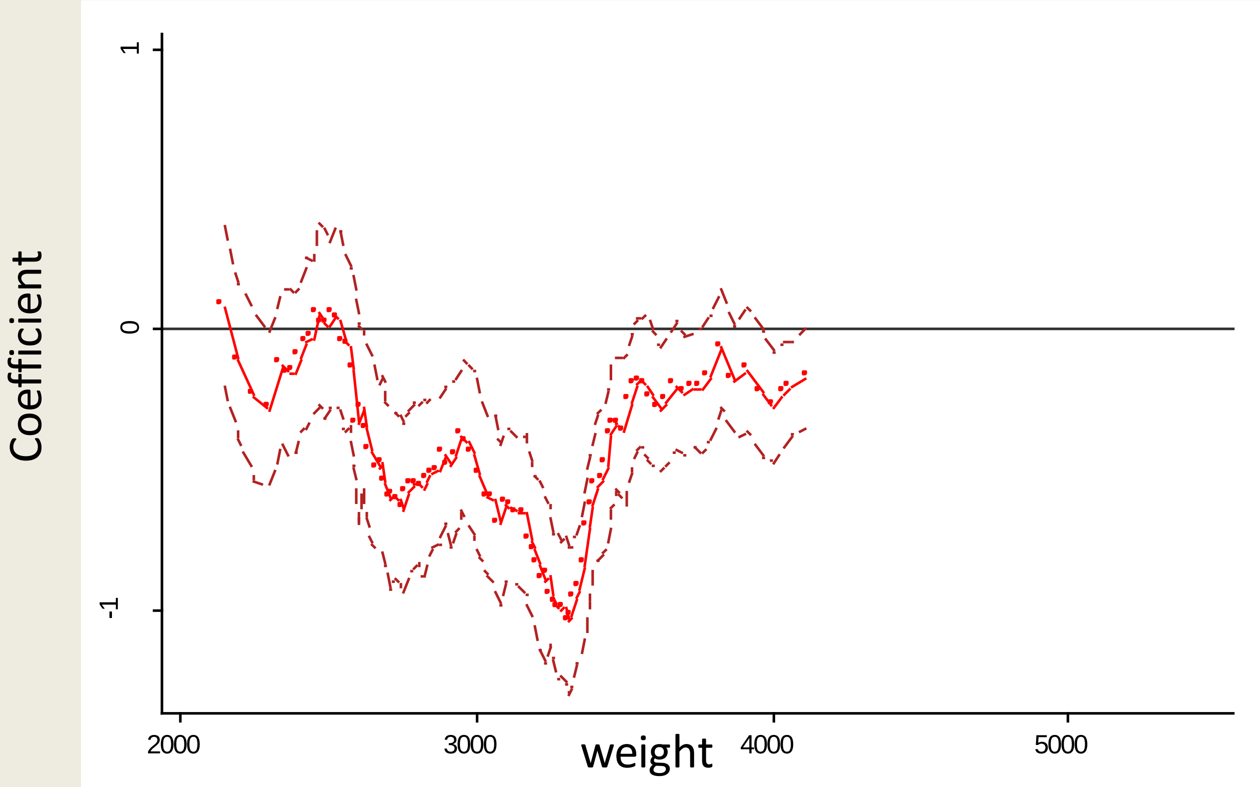
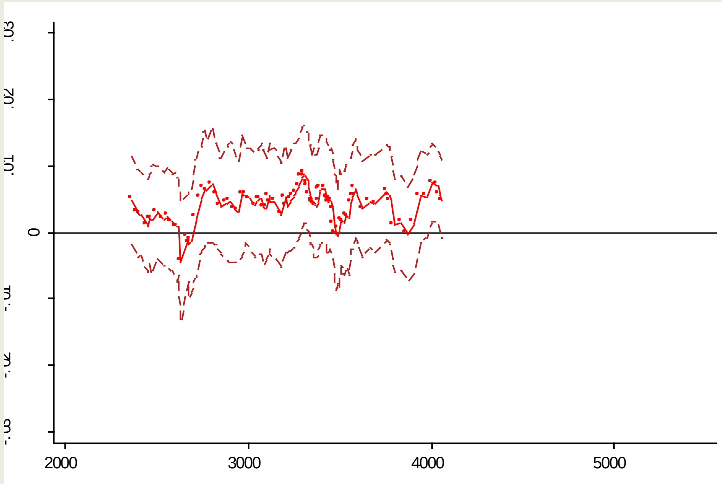


Additional controls for gasoline price, GDP, firm fixed effects and trend.

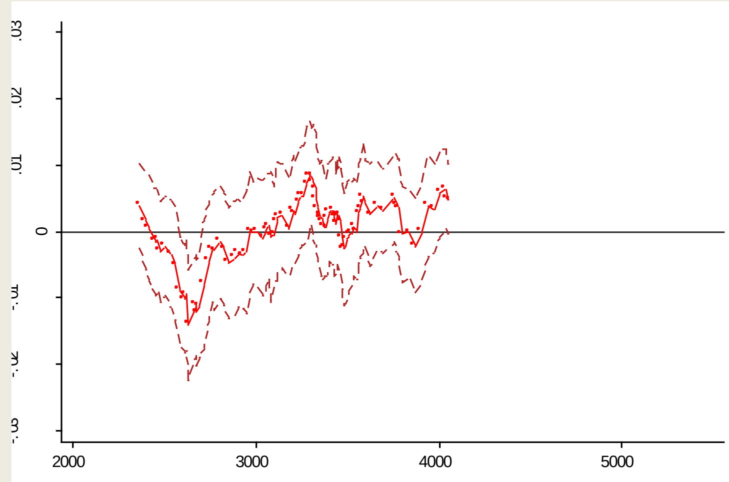
Stringency Measure 3: Balance of CAFE—Domestic Cars

Coefficient



weight

Standard specification



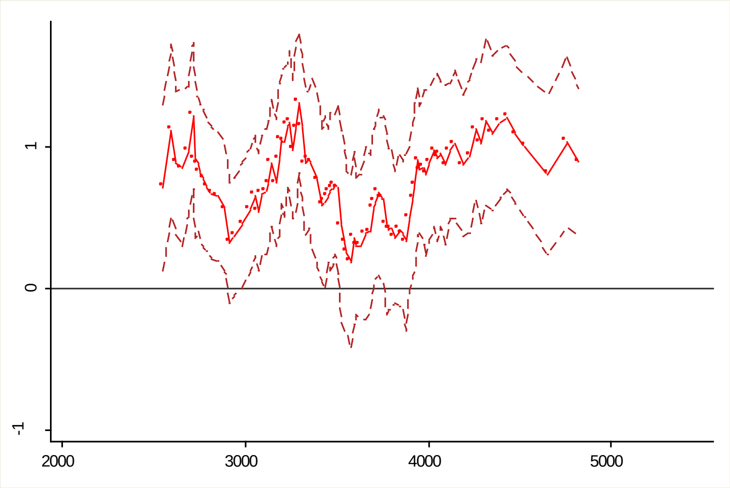
weight

With lagged weight

- Generally non-results:
  - Central specification no significant results
    - Adjustments are too small to be significant.
  - Occasionally some covariates show slight lowering of weight in the lower quantiles, in particular including lagged fleet weight
    - (fleet = car or truck)

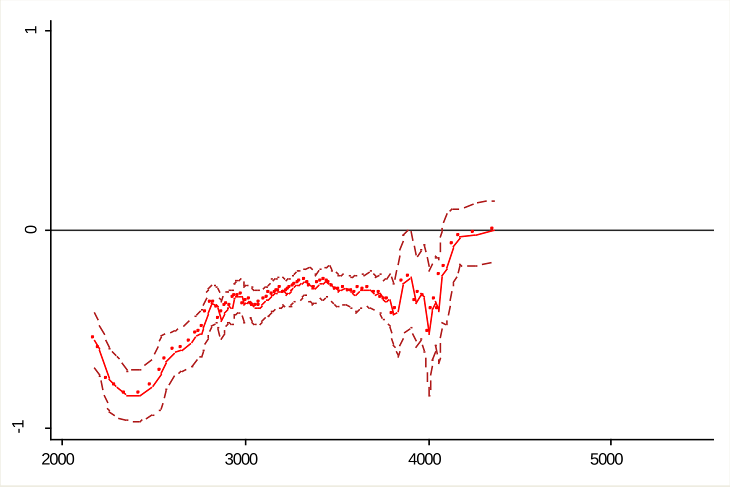
Stringency Measure 1: Misc.

Coefficient



weight

Asian Trucks (US Stringency)



weight

European Cars (US Stringency)

Additional controls for gasoline price, GDP, firm fixed effects and trend.

Other regressions

- Any other evidence?

    Domestic fleet regressions suggest firms avoid expensive technology improvements in economy cars.

    Expensive technology in luxury vehicles?

    Are they introducing or terminating vehicles in a strategic way?

Price Regressions

- Examine the effect of stringency on price

$$min\sum_{i}^{n}(P_{i,t}-(\beta\tau^{0}+\beta\tau^{1}S_{t}+\beta\tau^{2}X_{i,t}))g(|q_{i}-q_{\tau}|<bw)$$

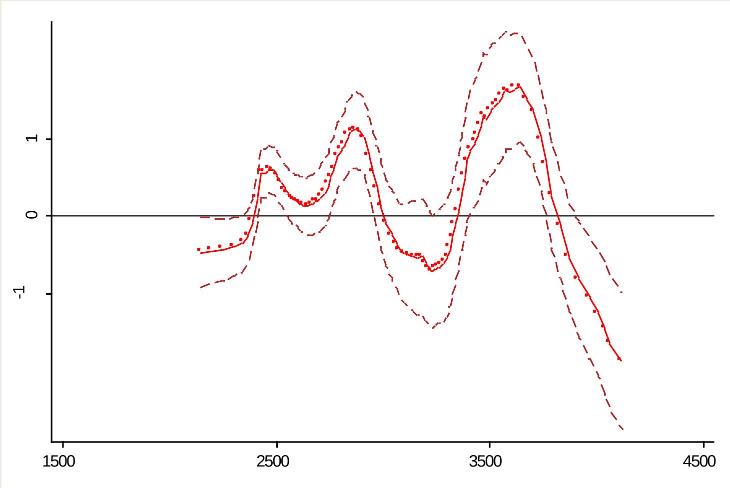
- P: Price
- S_t: Stringency of regulation
- X_t: Other Regressors

Regression of price on stringency for vehicles in a given weight quantile range.

Range is kernel weighted by bin using a bandwidth of 20 quantiles (not RIF-regression).

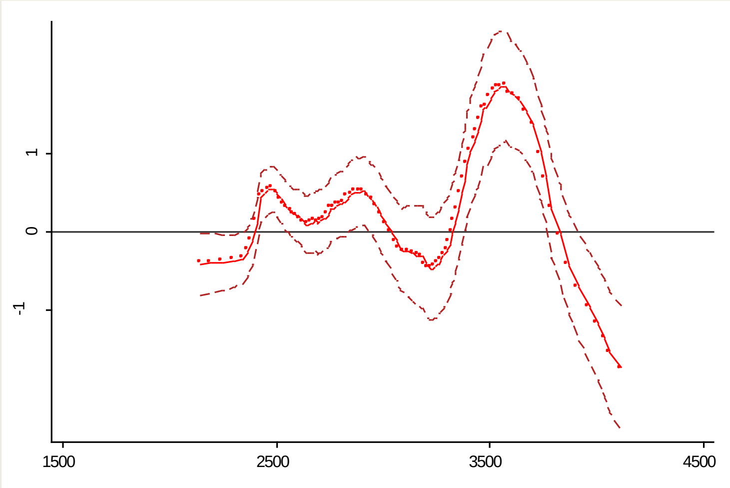
Price Regressions

Coefficient



weight

Stringency averaged from t-3 to t+1

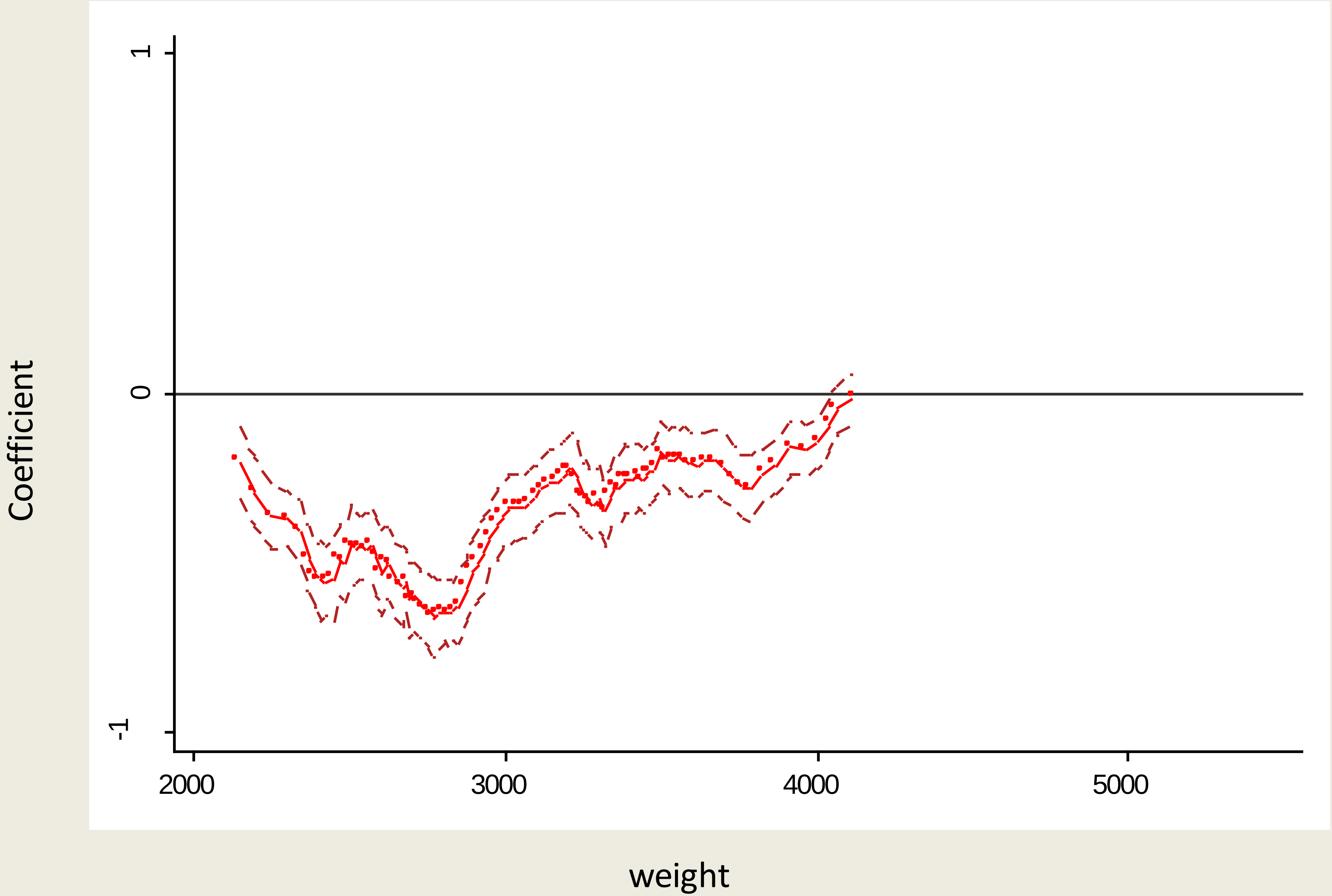


weight

Stringency t-1

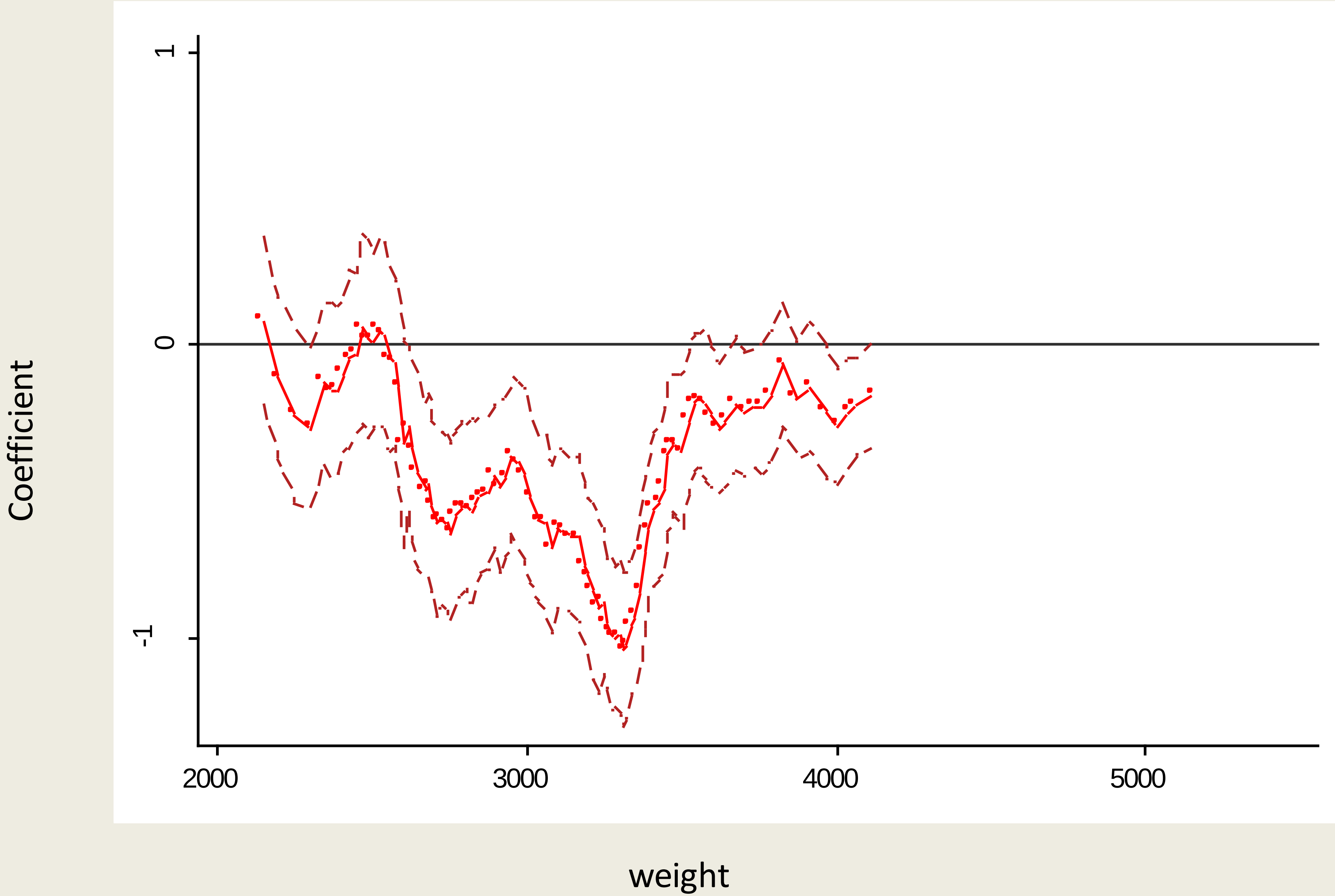
Additional controls for gasoline price, GDP, firm fixed effects and trend.
20 quantile bandwidth. Gaussian kernel.

Stringency Measure 1: Predicted MPG—Domestic Cars



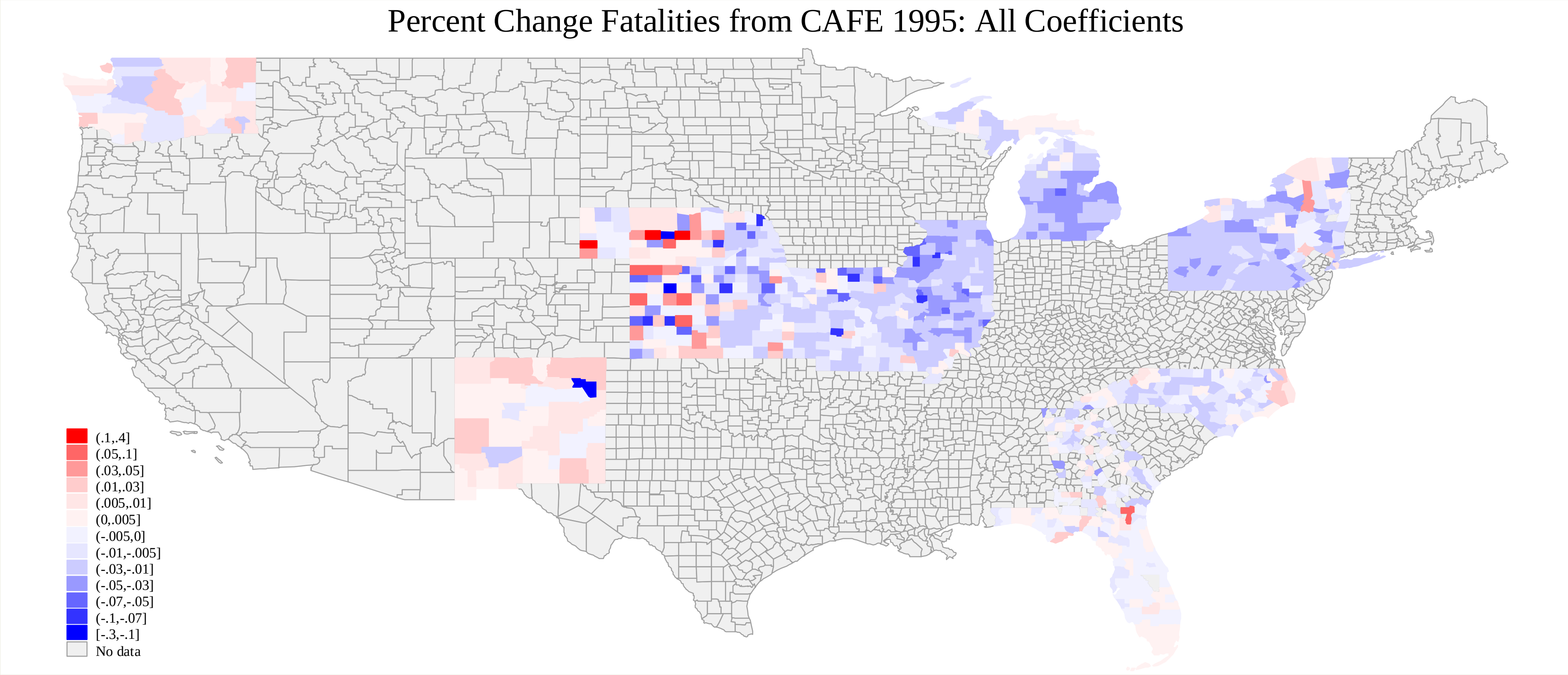
Additional controls for gasoline price, GDP, firm fixed effects and trend.

Stringency Measure 2: CAFE Level—Domestic Cars



Additional controls for gasoline price, GDP, firm fixed effects and trend.

Map 1: Actual Data 1995



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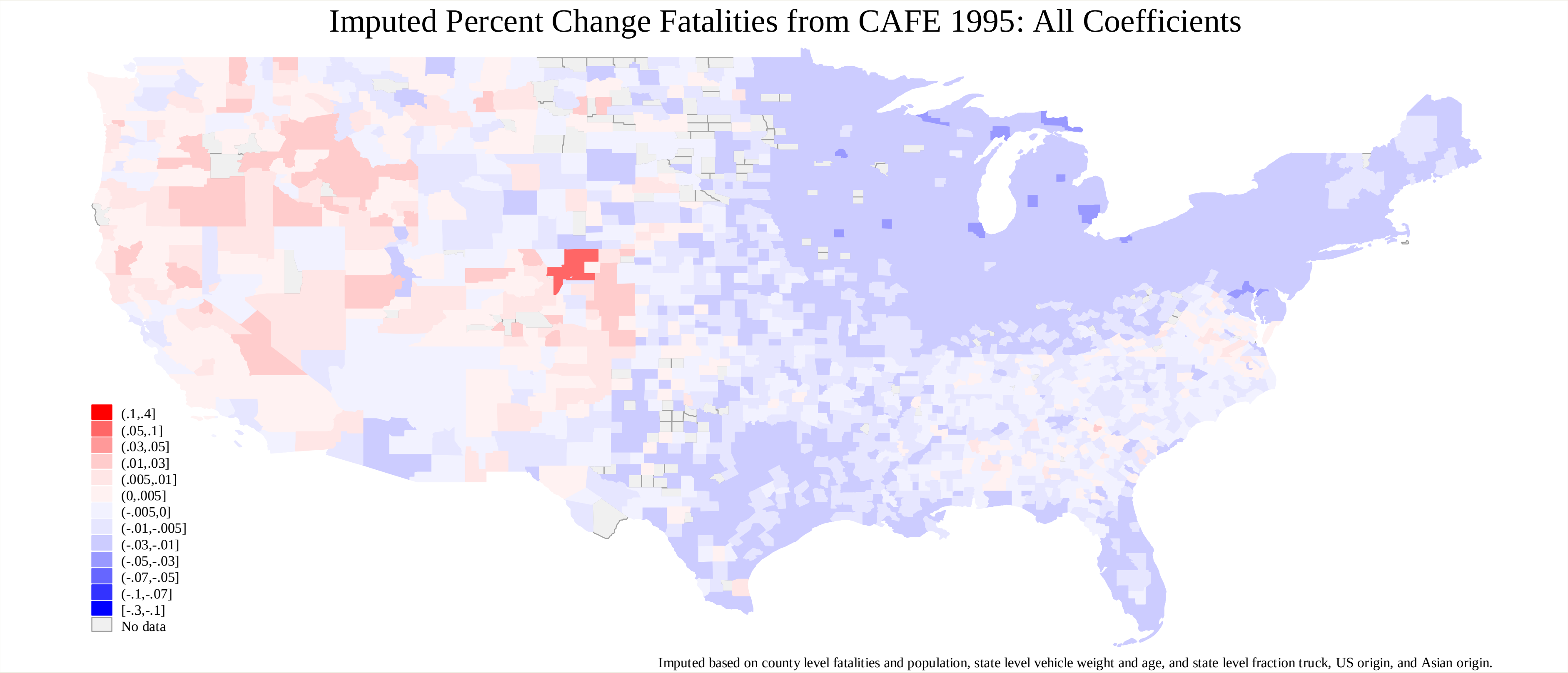
Map 2: Imputed 1995



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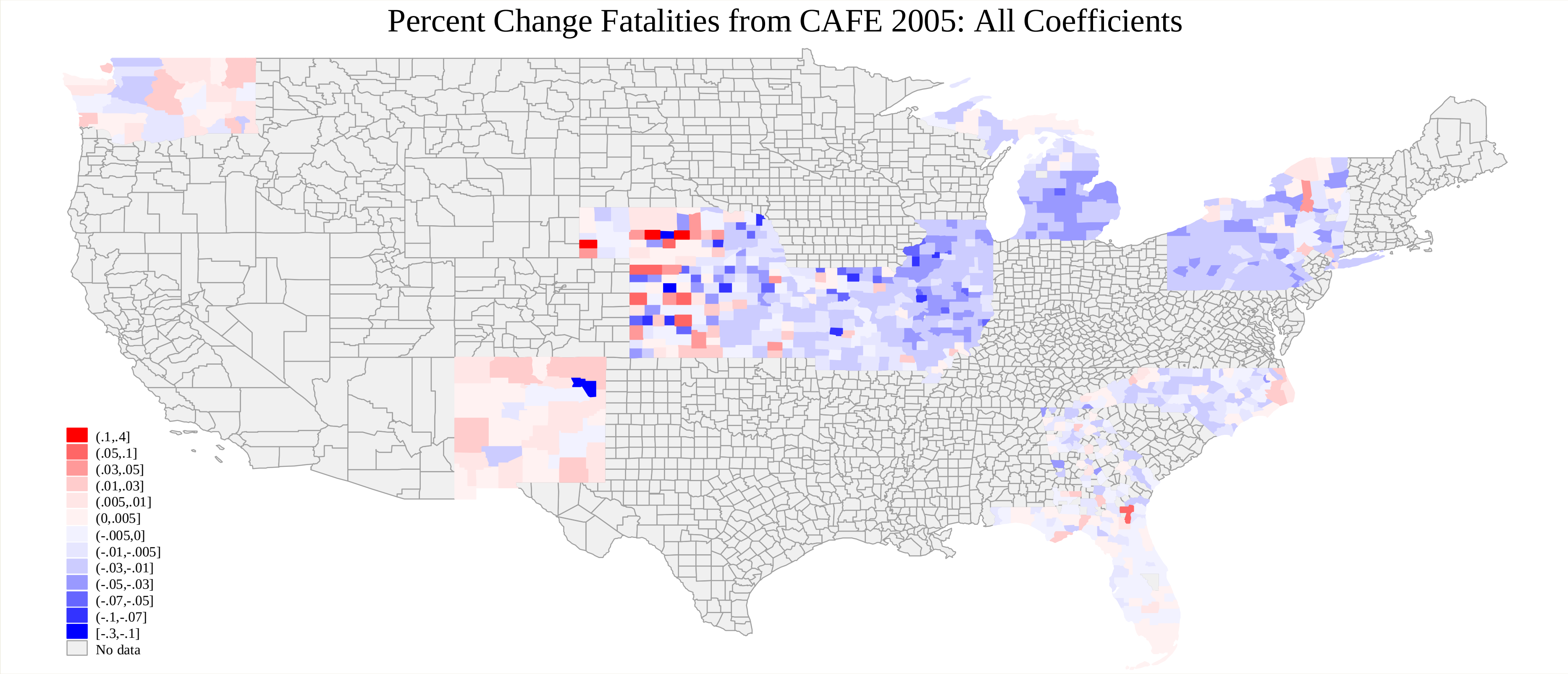
Map 3: Actual Data 2005



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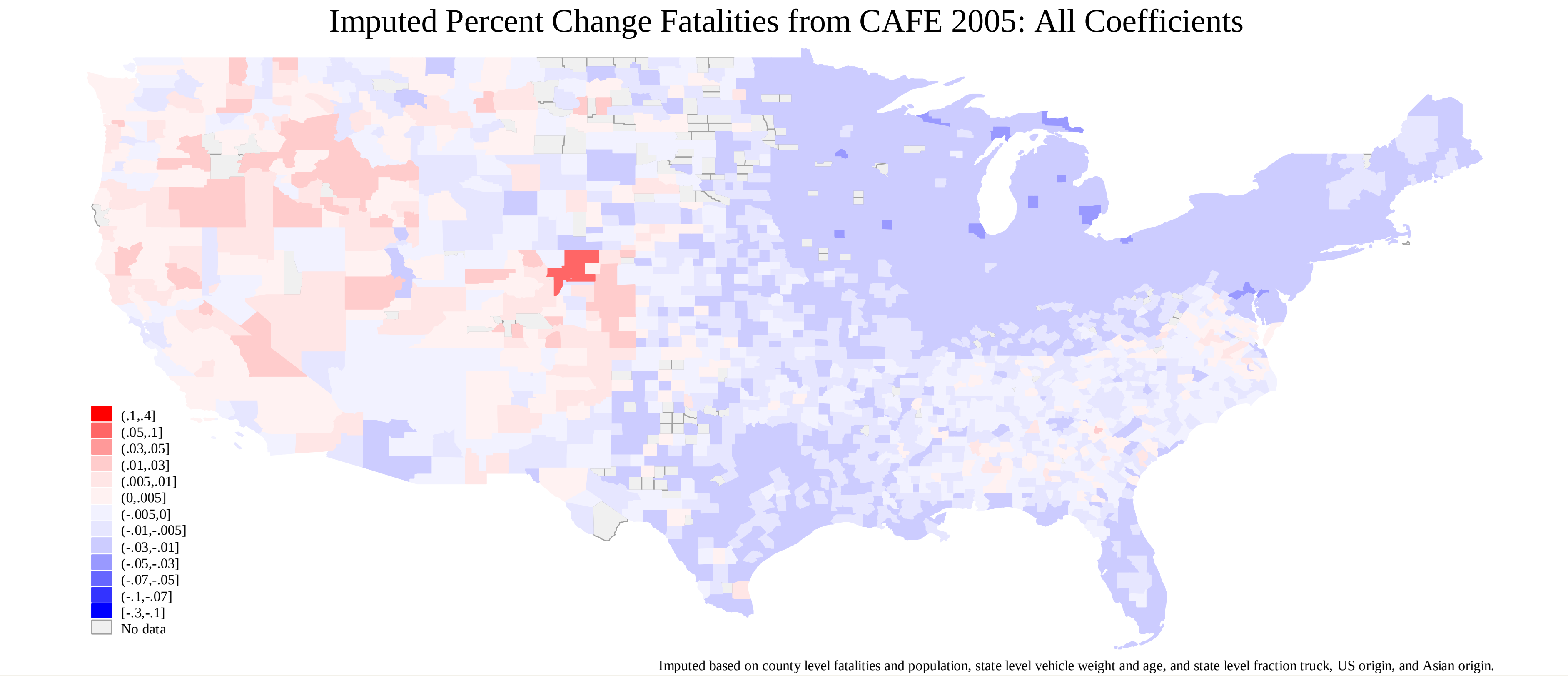
Map 4: Imputed 2005



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