Energy Consumption, Emissions and Modal Substitution in U.S. Freight Transportation

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Freight transportation, energy consumption and emissions

- Freight represents over 31% of U.S. transportation energy consumption
- Fuel costs are 30%-40% of freight costs
- Large differences in energy intensity across modes
  - Air $\sim$30 Btu/ton-mile
  - Truck $\sim$4 Btu/ton-mile
  - Barge and rail $\sim$0.5 Btu/ton-mile
- Differences in rates, travel times, accessibility
- Large literature on freight mode choice doesn't capture recent changes in freight operations
  - Friedlaender and Spady (1980), Levin (1978), and Winston (1981))
  - *E.g.* Intermodal rail service to compete with trucking

Research questions

- How do shipment and mode *characteristics* affect mode choice?
  - Value (inventory cost), distance and size (rates and fuel costs), etc.
- Which *modes* see increases (decreases) when fuel prices rise?
  - Given large differences in fuel efficiencies, modes and speeds
- Which types of *goods* or shipments are most affected by fuel price changes?
- What are the effects on *energy consumption and emissions*?
- Are there *secondary effects* on travel times, inventories or production decisions?

Proposed research design

2012 Commodity Flow Survey Public Use Microdata

- 4.5 million shipments
- Origin and destination state
- Transportation mode
- Good at NAICS or STCG level (about 40 types)
- Shipment value, weight and distance
- Weights to reconstruct population

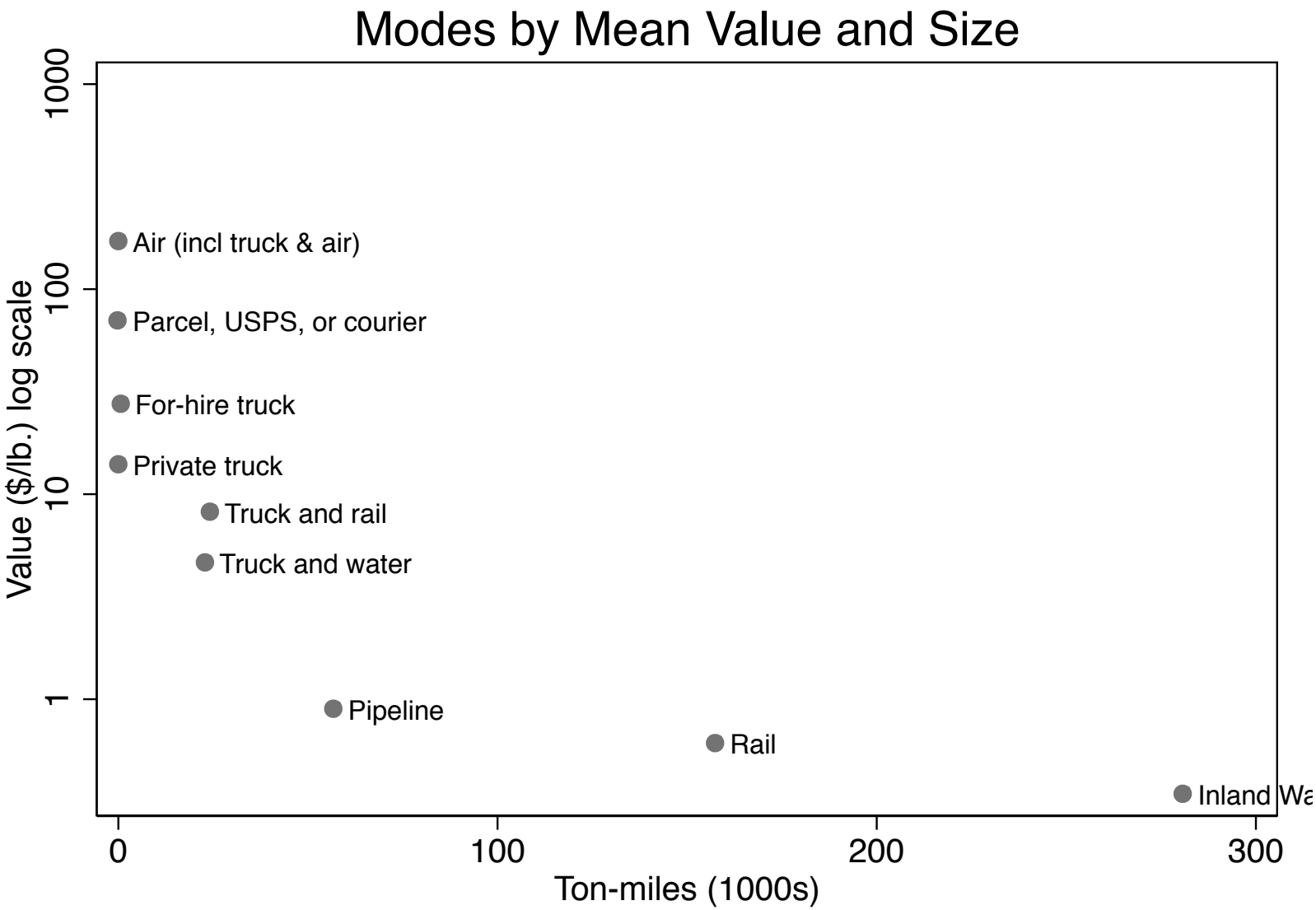
GIS data on transportation infrastructure

- Rail networks, roads and port infrastructure
- Estimate choice-specific characteristics for other modes

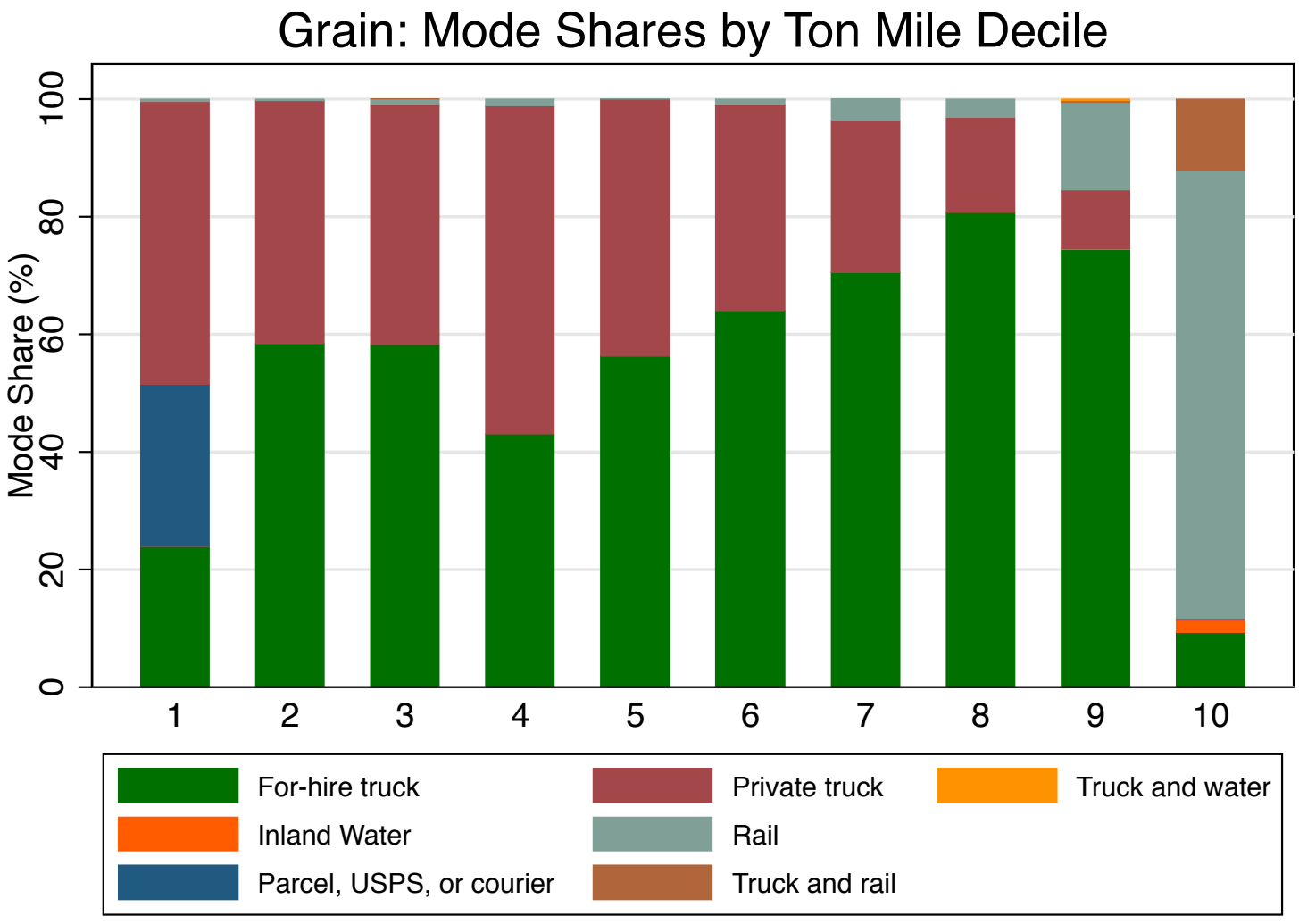
Mode and shipment characteristics

	Ton Mile Wgt. Avg			Mode Share					
Commodity Group	Value	Miles	Tons	Air	Pipeline	Rail	Truck	Water	Other
Basic Chemicals	0.6	1,148	420	0.00	0.01	0.54	0.34	0.10	0.01
Coal	0.01	1,165	17,160	0.00	0.00	0.95	0.02	0.04	0.00
Fertilizers	0.25	1,088	221	0.00	0.01	0.56	0.34	0.03	0.06
Fuel	0.41	680	4,709	0.00	0.24	0.26	0.38	0.01	0.11
Fuel Oil	0.44	454	3,030	0.00	0.26	0.02	0.59	0.13	0.00
Grain	0.14	1,156	4,703	0.00	0.00	0.74	0.10	0.09	0.07
Machinery	6.44	1,270	17	0.01	0.00	0.01	0.92	0.00	0.06
Metallic Ores	0.27	880	30,078	0.00	0.00	0.62	0.07	0.00	0.31
Mixed Freight	2.31	766	14	0.01	0.00	0.01	0.91	0.00	0.07
Non-Metallic Mineral Products	0.39	683	140	0.00	0.00	0.13	0.79	0.00	0.08
Pharmaceuticals	24.91	1,471	9	0.02	0.00	0.00	0.88	0.00	0.10
Primary Base Metal	0.98	955	52	0.00	0.00	0.19	0.71	0.00	0.10
Sand	0.03	688	173	0.00	0.00	0.37	0.54	0.00	0.09
Vehicles	4.52	1,250	30	0.01	0.00	0.06	0.78	0.00	0.15

Mode shares


Modes by Mean Value and Size
Value ($/lb.) log scale
1000
100
10
1
Air (incl truck & air)
Parcel, USPS, or courier
For-hire truck
Private truck
Truck and rail
Truck and water
Pipeline
Rail
Inland Wa
0
100
200
300
Ton-miles (1000s)

Grain mode shares



Model for mode choice of cost-minimizing shippers

Shippers choose mode j to minimize sum of rate, inventory (time) cost, and fixed cost per shipment

$$Cost_{ij} = \gamma_j \eta_j Pd_t \times Tonmiles_i + \frac{1}{\sigma_j} miles_i \times r_i \times value_i + \delta_j$$

Freight rate

- Fuel intensity (η_j) times ton-miles yields fuel consumption
- Times fuel price (Pd_t) yields fuel expenditure
- Markup to freight rate (γ_j)

Inventory cost

- Shipment distance ($miles_i$) divided by mode average speed (σ_j) yields travel time
- Times shipment value and discount rate (r_i) yields time cost

Fixed cost

- δ_j captures fixed cost of shipping via mode j

Model for mode choice of cost-minimizing shippers

- Estimate reduced form:

$$Cost_{ij} = \alpha_j Pd_t \times Tonmiles_i + \beta_j miles_i \times value_i + \delta_j + \epsilon_{ij}$$

- Fuel price-tonmile term captures *cross-sectional* differences in shipment sizes and (limited) *time-series* variation in fuel price
  - Use estimate α_j to conduct policy experiments for changes in fuel prices
- Miles-value term captures *cross-sectional* differences across goods and modes
  - May use GIS to estimate counterfactuals for alternative modes
- Estimate separately by commodity group
  - Pass-through, inventory, and setup cost parameters may vary by type of good shipped

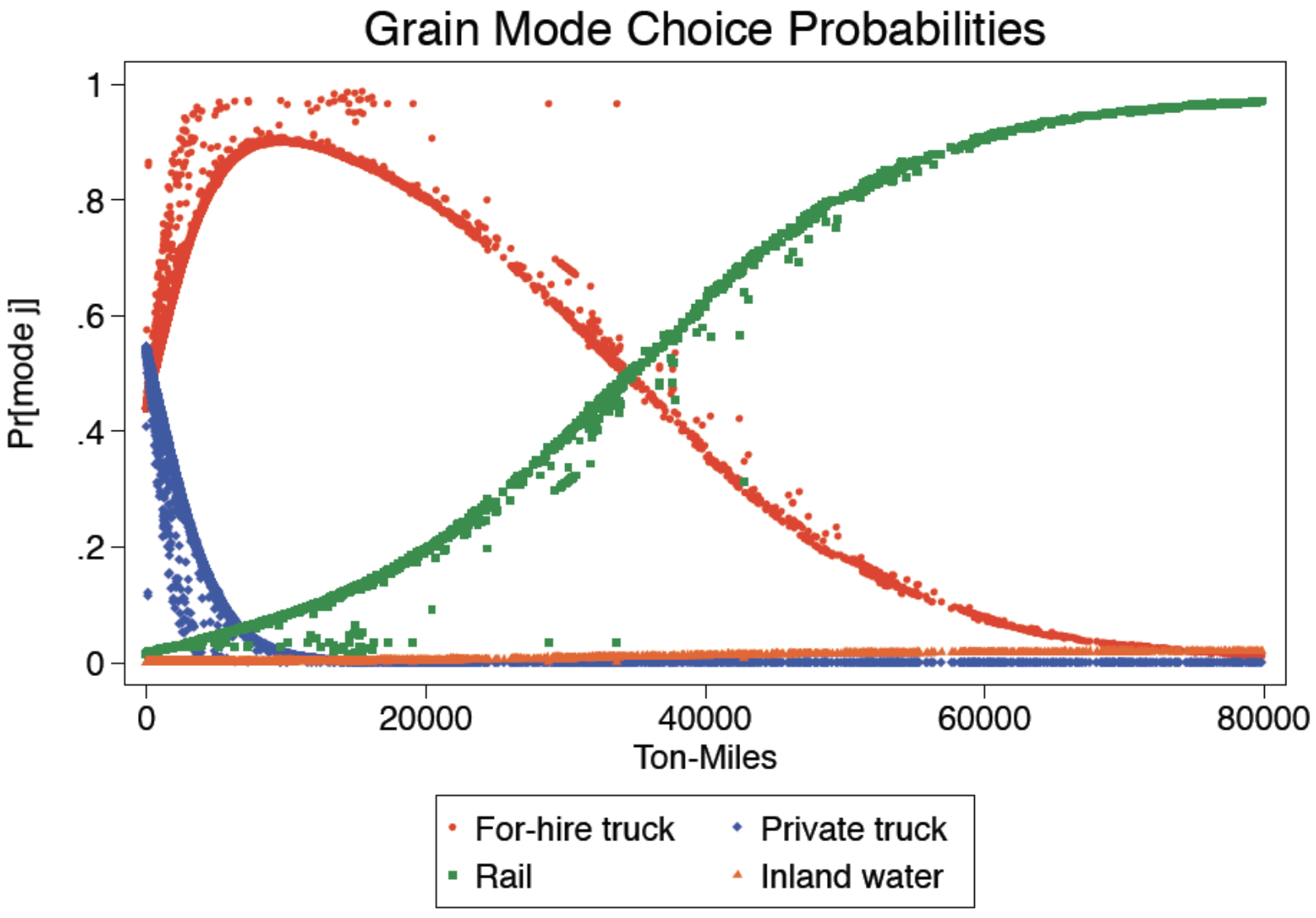
Marginal effects of fuel price change - grain shipments

Effect of Diesel Price on Freight Mode Choice Probabilities

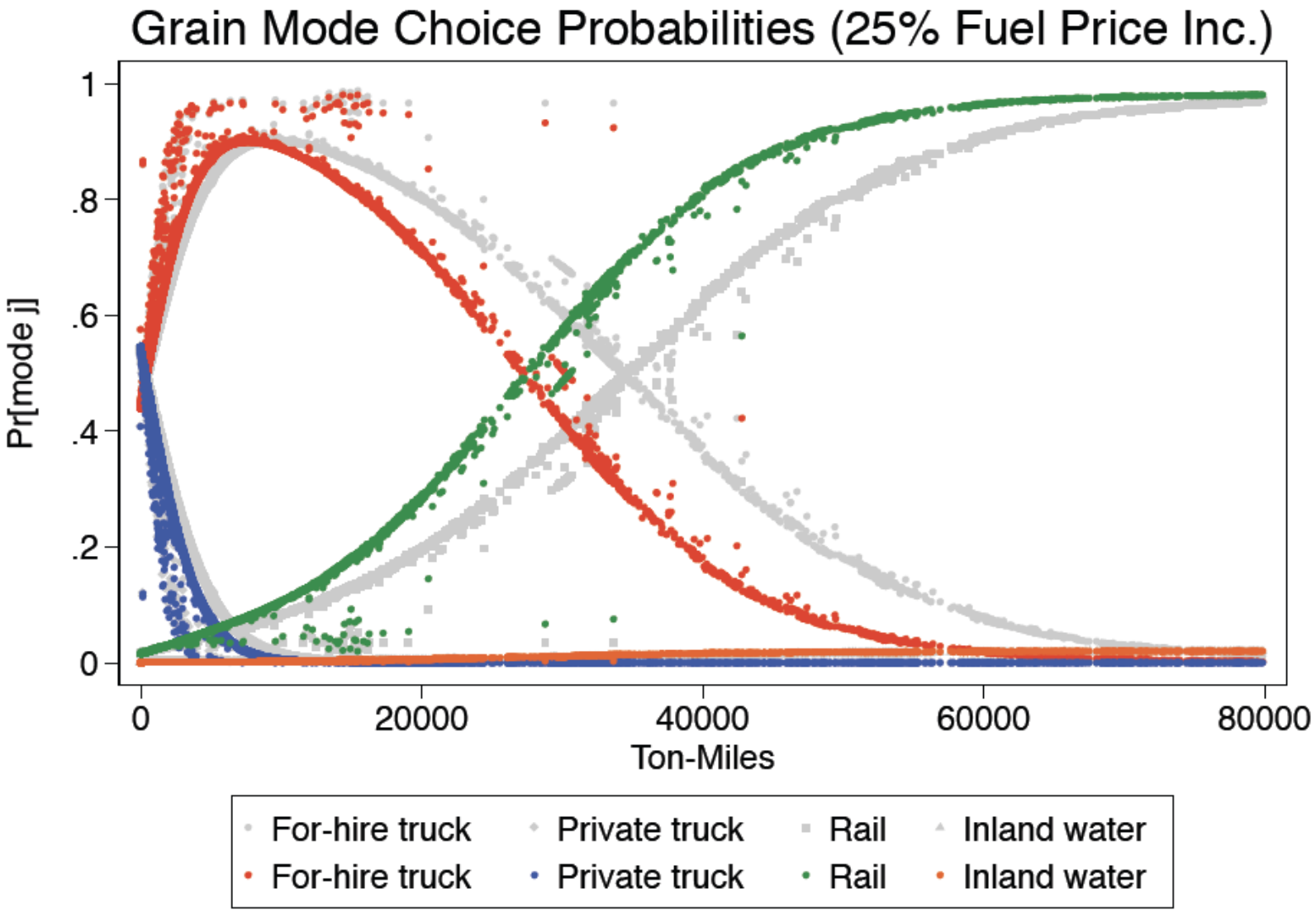
	For-Hire Truck	Rail	Inland Water
10,000 Ton-Miles	-0.007***	0.024***	0.001***
	(0.000)	(0.000)	(0.000)
20,000 Ton-Miles	-0.093***	0.092***	0.002***
	(0.000)	(0.000)	(0.000)
30,000 Ton-Miles	-0.193***	0.189***	0.004***
	(0.000)	(0.000)	(0.000)
40,000 Ton-Miles	-0.220***	0.217***	0.003***
	(0.000)	(0.000)	(0.000)
50,000 Ton-Miles	-0.149***	0.147***	0.002***
	(0.001)	(0.001)	(0.000)
60,000 Ton-Miles	-0.072***	0.088***	0.001***
	(0.001)	(0.000)	(0.000)
70,000 Ton-Miles	-0.031***	0.030***	0.000***
	(0.000)	(0.000)	(0.000)
80,000 Ton-Miles	-0.012***	0.012***	0.000***
	(0.000)	(0.000)	(0.000)
Observations	24744	24744	24744

Notes: Average marginal effects for a change in diesel price on mode choice probability evaluated at different shipments sizes (ton-miles). Marginal effect evalated at the means of shipment value and miles. ***, ** and * denote significance at the 1 percent, 5 percent and 10 percent levels.

Predicted mode choice probabilities - grain shipments



Predicted mode choice probabilities - grain shipments



Energy consumption and emissions - grain shipments

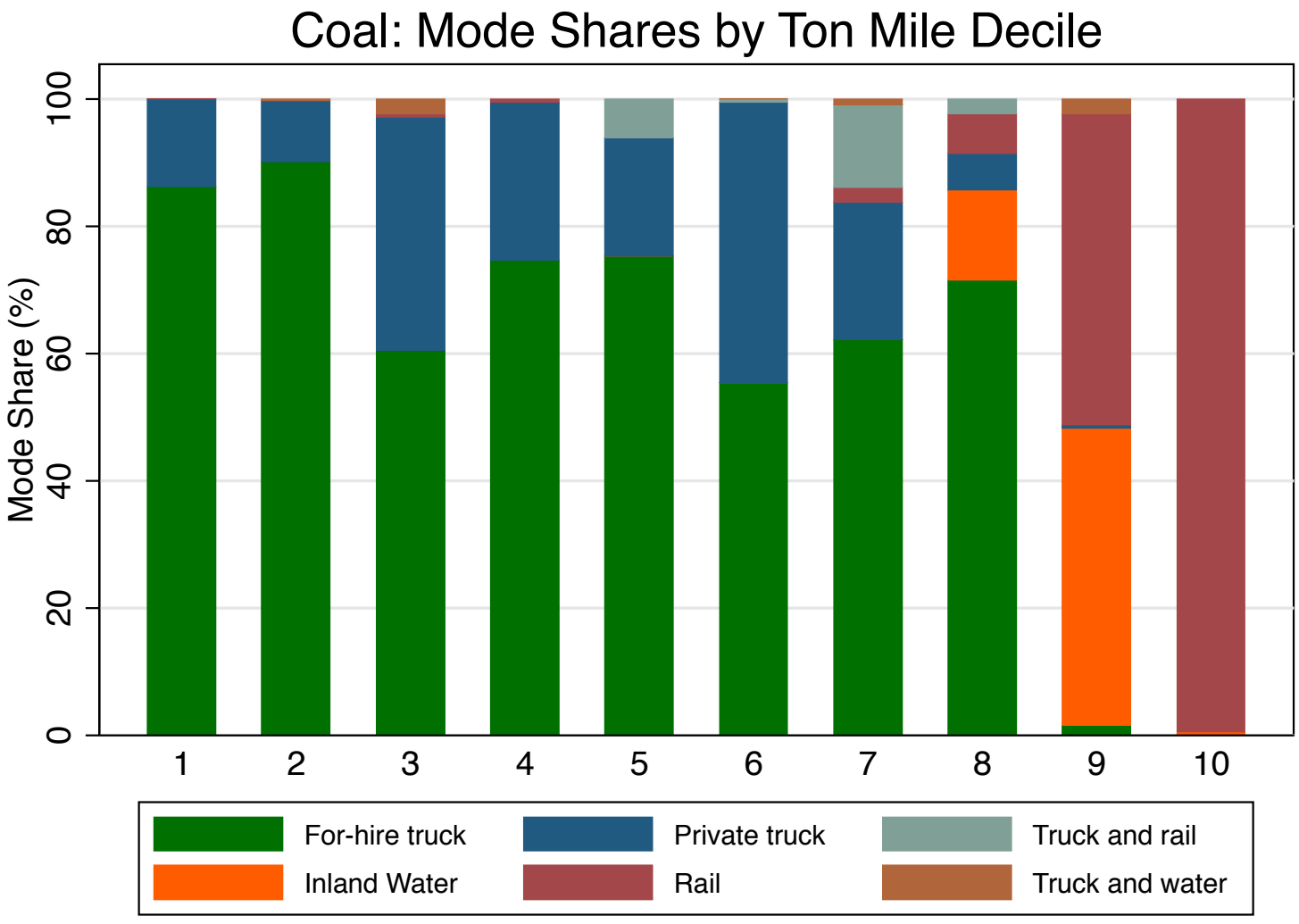
Fuel Prices, Grain Shipments, Fuel Use and Emissions

	BAU	10%	25%	50%	100%
Truck (billion ton-miles)	18.54	17.67	16.85	16.65	15.96
Rail (billion ton-miles)	147.09	151.18	152.00	152.85	153.54
Inland water (billion ton-miles)	3.91	0.69	0.69	0.04	0.04
Fuel (million gal.)	590.93	582.57	572.99	570.96	562.99
Emissions (MMT)	5.32	5.24	5.16	5.14	5.07
Percent change		-1.4%	-3.0%	-3.4%	-4.7%

Discussion

- Other commodity groups show similar patterns
  - Magnitudes, modes, and fuel reductions vary by good
- Data and MNL framework yield some limitiations
  - Geographic variables help (e.g. Mississippi Watershed)
  - GIS and alternative route/mode data may allow more flexible models
- Confidential data (Federal Data Center) likely outside scope of *this* project
- Explicitly a short-run approach
- Endogeneity of shipment size?

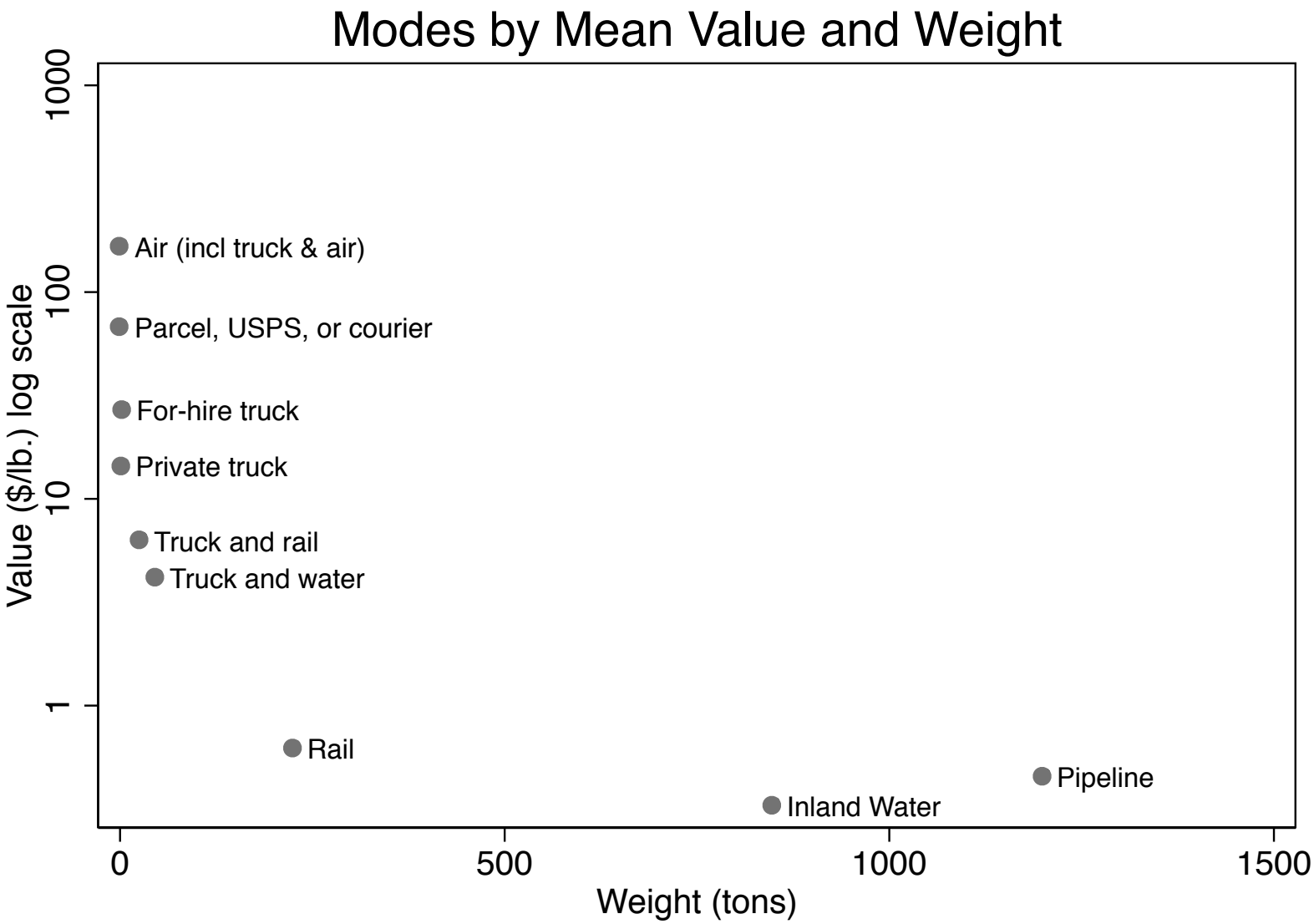
Coal mode shares



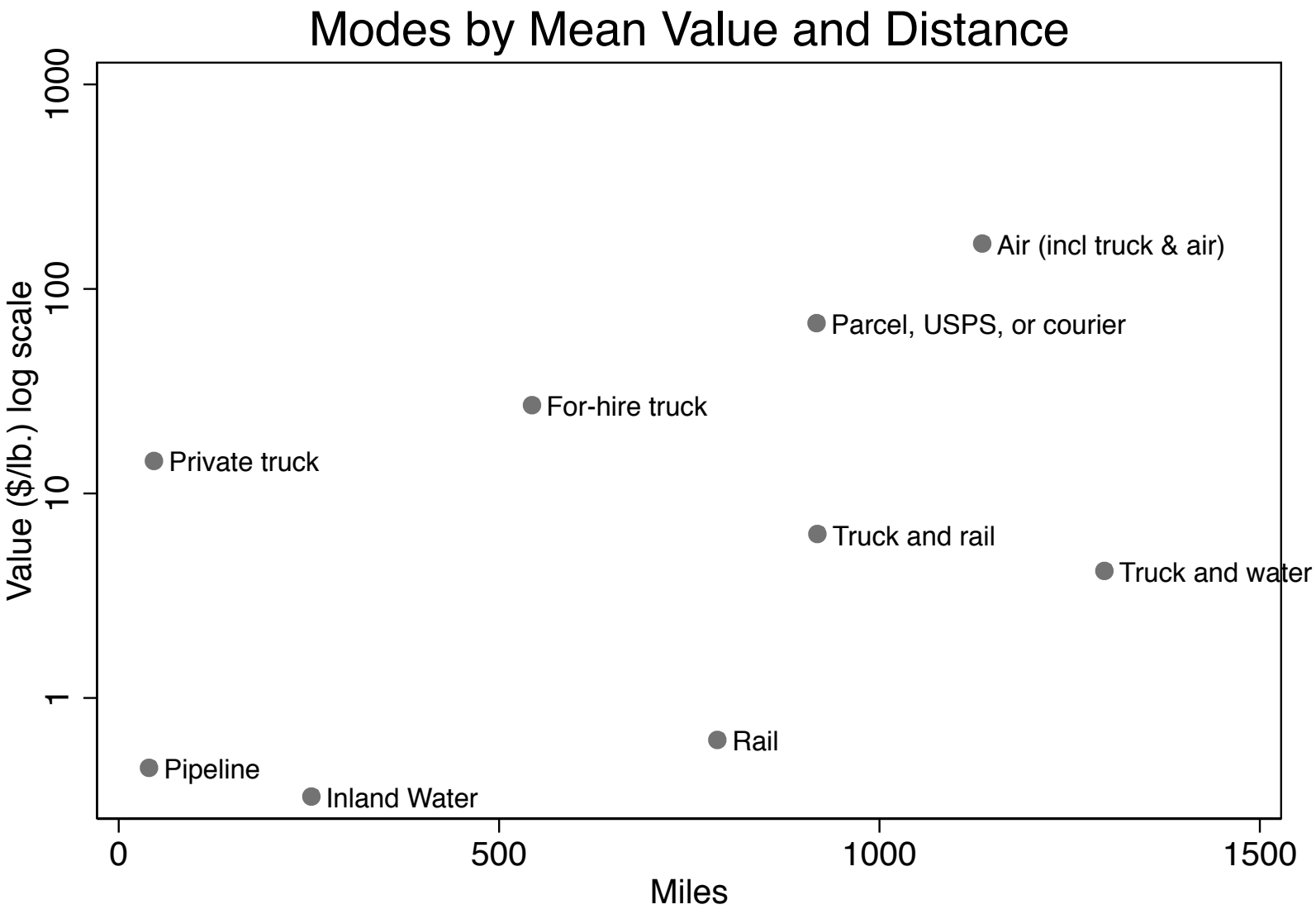
Mode and shipment characteristics

Mode	value ($)	value/lb.	distance (mi.)	weight (lb.)	tonmiles
Air (incl truck & air)	2,715	165.4	1,136	50	28
For-hire truck	4,084	26.8	544	5,378	648
Inland Water	405,685	0.3	253	1,695,861	225,628
Parcel, USPS, or courier	327	67.7	918	11	4
Pipeline	1,060,732	0.5	41	2,397,598	57,294
Private truck	1,460	14.4	47	3,058	79
Rail	56,938	0.6	788	449,252	170,008
Truck and rail	31,250	6.3	919	51,060	22,228
Truck and water	23,131	4.2	1,296	91,338	18,190

Mode and shipment characteristics



Mode and shipment characteristics



Coal mode choice probabilities

