Optimal Warranty Design for Durable Goods: Theory and Evidence

Work in progress

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Existing theories of warranties

Warranties specify what sellers do for buyers when product breaks – usually a commitment to pay for certain repairs – usually transferable

1. **Producer signals hidden quality with warranties (Courville and Hausman 1979; Grossman 1981; Gal-Or 1989; Balachander 2001)**
   - Warranties are cheaper for high-quality producer, so credible signal

2. **Warranties solve hidden producer underinvest (moral hazard) in quality (Lutz 1989; Mann and Wissink 1990; etc.)**
   - Overcome moral hazard by making producers liable for repairs

3. **Warranties as insurance from risk-neutral producers to risk-averse consumers (Spence 1977; Heal 1977; Kubo 1986; Soberman 2003)**

4. **But warranties may cause consumer moral hazard over maintenance (Cooper and Ross 1985; Emons 1989; Dybvig and Lutz 1993)**

History of car warranties

1925

- Ford masters assembly line production and consistent quality → introduced 90-day warranty
- This warranty soon becomes industry standard

1960s

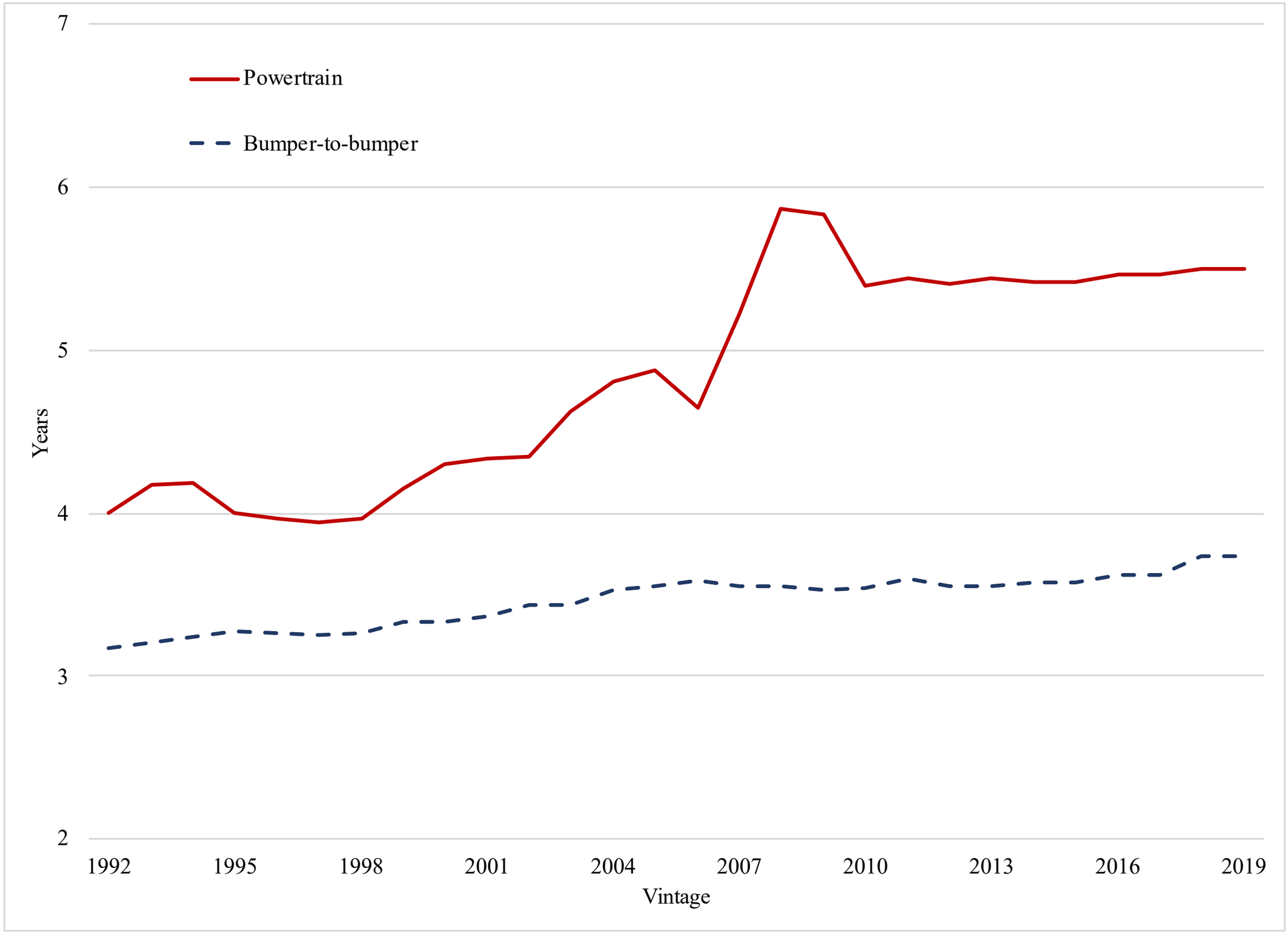
- Ford introduces first comprehensive warranty – 1 year / 12,000 mile
- Powertrain (engine, transmission, etc.) – up to 5 year / 50,000 mile
- Most carmakers soon follow

1980s

- Rise of Japanese imports with 3 year / 36,000 mile comprehensive
- Other carmakers soon increase warranty (and quality)

Quality signal and insurance theories of warranties very plausible

Since 1980s, warranty duration has continued to grow



Since 1980s, existing theories seem incomplete

Quality signaling seems less important

- Most carmakers now have well-known reputations over quality
- Third-party rating agencies like *Consumer Reports* publish car quality

Production moral hazard / underinvestment less an issue

- Car manufacturing increasingly standardized (e.g., lean production)

Insurance less important and moral hazard less a barrier

- Insurance less important – in population of younger cars, serious failure is rare and not “too” expensive
- Customer moral hazard still relevant – but cars need less maintenance / care – less a barrier to longer warranties

Premise of paper

We suggest a key purpose of warranties today is to limit adverse selection in the secondhand market

- Akerlof (1970), Gilligan (2004), Emons and Sheldon (2009), Peterson and Schneider (2014, 2017), etc.

Show theoretically how warranties can solve adverse selection

- But customer moral hazard somewhat restricts their use

- **Predictions of model (roughly) match current car warranty design**
- **Cars under warranty have more secondhand trade – consistent with warranties reducing adverse selection**
- **Valuation of warranties in used-car market far exceeds expected repair cost in population**
- **More generally, provide guidance for optimal warranty design**

Typical car warranty today

Powertrain – typically 4-8 years

- Covers engine and transmission

Bumper-to-bumper – typically 3-5 years

- Covers most other asymmetric information parts

Full information and wear-and-tear parts – no coverage

- Lights, brake pads, tires*, etc.

Luxury cars often include “free” maintenance for initial period

Basic model setup – builds on our earlier papers

Potential sellers ("sellers") have one used car each

Potential buyers ("buyers") have no cars

Sellers have taste for quality $\theta \sim U[1, \theta_H]$, total mass 1

All buyers have taste for quality $\theta = 1$, total mass > 1

Note

- Sellers originally bought their cars new and are considering upgrading now – so naturally they have higher taste for quality than buyers
- More buyers than sellers

Basic model setup

Car has two parts

Part Q has condition Q, non-repairable, full information

- (Non-repairable just means repair cost exceeds benefit for all drivers)
- E.g., wear and tear, rust, interior smell, aging technology and style

Part b is repairable (information properties to come)

- $b = \begin{cases} 0 & \text{if no defect} \\ 1 & \text{if defect} \end{cases}$
- Defect in population with probability $\lambda \in (0,1)$
- Defect reduces quality by $d > 0$ and costs $c > 0$ to repair

Total utility for driver θ is $\begin{cases} \theta Q & \text{if drive non-defective car} \\ \theta(Q-d) & \text{if drive defective car} \\ \theta Q - c & \text{if repair defective car and drive} \end{cases}$

Basic model setup

Sellers can upgrade their used car to new car

New cars have no defects and $Q_N > Q$

Assume new-car market is perfectly competitive

- Q_N and P_N are exogenous
- Avoids interaction between new- and used-car markets

Assume $\theta_H(Q_N - Q) > P_N - (Q - c)$ and $P_N > Q_N$, which guarantees that it's efficient for some but not all sellers to upgrade to new car

Scenario 1: Full information over b, must fix defect

Let $d > c$, i.e., benefit of repairing defect exceeds cost for all drivers

- E.g., flat tire, seat belt, starter motor

More buyers than sellers, so market price is buyer reservation price

$$P(Q, b) = Q - cb$$

Seller sells if new car gives higher utility than keeping used car

$$\theta Q_N - (P_N - (Q - cb)) \geq \theta Q - cb$$

Condition b doesn't affect selling decision → cost cb either way

<u>Result 1</u>: Under full information, the condition of the repairable part doesn't affect trade and the level of trade is efficient

Scenario 1: Full information over b, must fix defect

Now consider a transferable warranty that covers part b

- Before defect is realized, expected cost of warranty is $c\lambda$

Since warranty covers cost of defect cb, market price is now

$$P(Q, b) = Q$$

Seller calculation of whether to sell is same as before (cb drops out)

$$\theta Q_N - (P_N - Q) \geq \theta Q$$

<u>Result 2</u>: Warranties on observable, must-fix defects don't affect trade. Expected warranty cost is included in new-car price and warranty is not useful.

Scenario 2: Asymmetric information over b, must fix defect

No warranty for now

Market price is still buyer reservation price

$$P(Q, b) = Q - cg(Q)$$

where $g(Q)$ is buyer rational-expectation inference about b given Q

- $g(Q)$ is fraction of cars on used market with unobserved defect

Seller θ upgrades if $\theta Q_N - \left(P_N - \left(Q - cg(Q)\right)\right) \geq \theta Q - cb \rightarrow$

$$\theta \geq \frac{P_N - Q - cb + cg(Q)}{Q_N - Q}$$

which defines lower bound on θ among sellers who sell their car

- θ' is cutoff taste when $b = 1$; $\theta'' > \theta'$ is cutoff tastes when $b = 0$

Scenario 2: Asymmetric information over b, must fix defect

<u>Result 3</u>: Asymmetric information harms trade by preventing some efficient trades and inducing some inefficient trades

- Because actual condition of b is not incorporated into market price:
  - Sellers of cars with $b = 1$ see artificially high price and sell too much
  - Sellers of cars with $b = 0$ see artificially low price and sell too little
- Too few defect-free cars sell and too many defective cars sell

Now suppose warranty is in place before any defects occur

- Expected cost of servicing warranty is $c\lambda$, but increase in resale price is $cg(Q) > c\lambda$

<u>Result 4</u>: Increase in resale price created by warranty exceeds cost of servicing warranty, and is efficient to include

- Unobserved condition no longer affects trade → warranty returns trade to efficient level and solves adverse selection

Scenario 3: Full information over b, discretionary repair

Now some drivers prefer to forego repair, i.e., $d < c$, and no warranty

- E.g., cosmetic defects, A/C, infotainment, sunroof
- Introduces efficient motive for trade based on $b \rightarrow$ trade to lower-taste drivers who don't mind defect and forego discretionary repair

Now seller θ utility is $\begin{cases} \theta Q_N - (P_N - (Q - d)) & \textbf{if upgrade (and not repair)} \\ \theta Q - c & \textbf{if keep and repair} \\ \theta(Q - d) & \textbf{if keep and don't repair} \end{cases}$

High-θ sellers upgrade, mid-θ sellers keep and repair, low-θ sellers keep and don't repair

- High-θ sellers sell defective car to low-θ buyers who don't mind defect $\rightarrow$ avoids inefficient repair

Scenario 3: Full information over b, discretionary repair

Now suppose warranty over b, which again has expected value $c\lambda$

<u>Result 5</u>: For b with full information and $d < c$, no seller strictly prefers the warranty and some sellers strictly prefer no warranty

- For discretionary repairs, warranties are inefficient because they generate excess repairs
  - Sellers who would have sold defective car or kept defective car without repairing it are worse off
  - Sellers who would have repaired and kept car are indifferent

Warranty design under adverse selection

Warranty makes no difference for full-information, required repairs

- Sellers and buyers are indifferent about warranty

Warranty shouldn't cover full-information, discretionary repairs

- Induces some inefficient repairs
- Prevents efficient trades to low-θ buyers who don't mind defective car

Warranty should cover asymmetric information, required repairs

- Unobserved condition no longer affects trade → no adverse selection
- Warranty increases resale price by more than its expected cost

Warranty on asymmetric information, discretionary repair depends

- Some adverse selection benefit, but some inefficient repairs

Warranties and maintenance

Now let seller maintenance decision affect b

Seller can conduct maintenance at cost a, which decreases defect rate from λ_H to λ_L

Assume expected repair cost savings exceeds maintenance cost

$$c(\lambda_H - \lambda_L) > a$$

Timing

1. Warranty is present or not
2. Seller chooses whether to conduct maintenance
3. Condition b is realized
4. Used-car market occurs: seller observes b, decides whether to sell

Scenario 4: Full information over b and maintenance

No warranty

Full information over b, so seller internalizes full cost of repair whether keeps or sells car → seller chooses efficient maintenance

- No moral hazard

Warranty

Seller doesn't incur repair cost → never does costly maintenance

- Expected warranty cost is $\lambda_H c > a + \lambda_L c$
- Warranty is inefficient

Scenario 5: Asymmetric information over b and maintenance

No warranty

Result 6: Under adverse selection, moral hazard, no warranty:

1. Drivers $\theta < \theta'$ do maintenance and keep car
   - Always keep car, so internalize repair costs and do maintenance
   - Efficient
2. Drivers $\theta \in (\theta', \tilde{\theta})$ do maintenance and sell if defect
   - Benefit less from upgrading → do maintenance to avoid defect and selling
   - Adverse selection
3. Drivers $\theta \in (\tilde{\theta}, \theta'')$ don't do maintenance and sell if defect
   - Benefit more from upgrading car → skip maintenance
   - Adverse selection and moral hazard
4. Drivers $\theta > \theta''$ don't do maintenance and always sell
   - Maintenance and defect are unobserved by market so no maintenance
   - Adverse selection and moral hazard

Scenario 5: Asymmetric information over b and maintenance

Warranty

Result 7: Under adverse selection, moral hazard, warranty:

1. Sellers $\theta < \bar{\theta}$ prefer no warranty + doing maintenance, never sell
   - Prefer no warranty because they never sell
   - Prefer maintenance since repair cost saving exceeds maintenance cost
   - Warranty creates moral hazard over maintenance
2. Sellers $\theta \in (\bar{\theta}, \dot{\theta})$ prefer no warranty + doing maintenance, sell if defect
   - Warranty solves adverse selection, but creates moral hazard
3. Sellers $\theta > \dot{\theta}$ prefer warranty, skip maintenance, always sell
   - Sellers always sell, but market doesn't observe defect or maintenance, so skip maintenance
   - Warranty solves adverse selection, but creates moral hazard

Warranty design under adverse selection and moral hazard

Warranty on full-information parts is now harmful

- Seller has no incentive to do maintenance → induces inefficient under-maintenance and too many defects

Warranty on asymmetric-information parts still solves adverse selection – but increases moral hazard

- Without warranty, only sellers who are likely to sell choose to skip efficient maintenance
- With warranty, all sellers skip efficient maintenance

Trade-off

- Use warranty on parts with higher risk of adverse selection and lower risk of moral hazard
- Don’t use warranty on parts with lower risk of adverse selection and higher risk of moral hazard

Efficient warranty

Full coverage

- Parts with asymmetric information, must repair, little maintenance
    - E.g., engine, transmission

Limited coverage

- Parts with asymmetric information and (1) discretionary repairs or (2) maintenance / care is important
    - E.g., A/C, suspension

No coverage

- Parts with full information or high wear-and-tear (maintenance/care)
    - E.g., tires, lights, brake pads, wipers, external vehicle body

Maintenance

- Car brands whose sellers prefer to upgrade frequently and hence have moral hazard over maintenance – i.e., luxury brands

Car warranties today

Powertrain – 4-8 years

- Covers engine, transmission
- Expensive to fix, asymmetric information → cause of adverse selection
- Not too much moral hazard over longer duration

Bumper-to-bumper – 3-5 years

- Covers most other asymmetric information parts
- Shorter duration perhaps because
    - Some of repairs are discretionary (e.g., A/C, infotainment) or
    - Moral hazard (e.g., terrain / driving style can harm suspension)

No coverage on full information and/or wear-and-tear parts

- Lights, brake pads, tires*, etc.

Maintenance included for luxury cars

Data for time period 1991-2006

Consumer Expenditure Survey

- Rolling panel data set – up to four quarters of data per households
- Data on household cars, car purchases, and repairs
- Detailed household characteristics
- Unit of observation is a car in a quarter

Intellichoice

- Bumper-to-bumper and powertrain warranty durations on all model-vintages – mileage and age

Consumer Reports

- Defect rates on all parts by model-vintage

Overview of repair frequencies and expenditures

		Expenditures conditional on repair		
	Repair rate (%)	90th percentile ($)	Mean ($)	SD ($)
Transmission	1.6	1436	562	691
Engine	2.6	1171	525	686
Bodywork	1.5	935	470	560
A/C	1.1	747	307	342
Steering	1.3	687	312	302
Rear end	0.4	686	331	449
Brakes	5.4	495	235	229
Shocks	0.5	486	247	218
Cooling	2.4	468	208	230
Electrical	3.2	457	217	216
Exhaust	1.7	375	203	198
Motor tune-up	5.8	408	183	195
Oil change	36.9	64	39	32

Warranties and turnover (adverse selection)

Main warranty variation (panel and cross-section) is powertrain

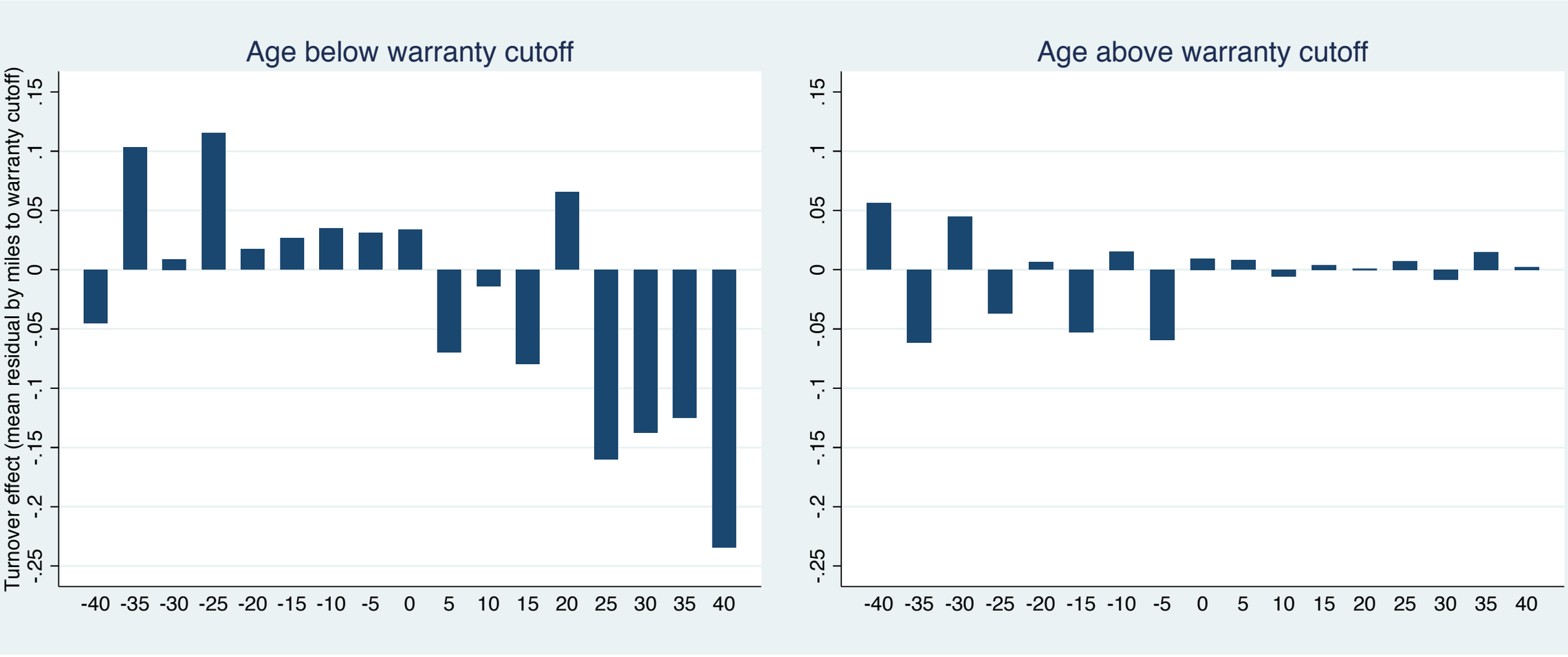
Cars age 4-8; OLS; all specifications include dummies for nameplate, vintage, mileage intervals, age, intercept

	(1) Indicator for turnover	(2) Indicator for turnover	(3) Indicator for turnover	(4) Indicator for turnover
Powertrain warranty dummy	0.125***	0.068***	0.126***	0.127***
	[0.023]	[0.022]	[0.029]	[0.029]
Defect rate -- all parts				0.297***
				[0.061]
Defect rate -- transmission				-0.418**
				[0.184]
Defect rate -- engine				-0.169
				[0.240]
Nameplate x age dummies	X		X	X
Nameplate x mileage dummies		X	X	X
Observations	20,492	20,492	20,492	20,492
R-squared	0.075	0.091	0.097	0.098

Warranties and turnover (adverse selection)

Main warranty variation (panel and cross-section) is powertrain

Turnover effect below and above powertrain mileage cutoff



Warranties and price (adverse selection)

Cars age 4-8, OLS

Powertrain warranty effect is large compared to value in population

	(1) Price ($)	(2) Price ($)	(3) Price ($)	(4) Log price	(5) Log price	(6) Log price
Powertrain warranty dummy	2,060***	1,934***	1,720**	0.133**	0.123**	0.113*
	[698]	[672]	[714]	[0.064]	[0.062]	[0.066]
Purchased from dealer	2,618***	2,489***	2,481***	0.317***	0.306***	0.312***
	[275]	[265]	[283]	[0.025]	[0.024]	[0.026]
Purchased with trade-in	2,062***	2,038***	1,963***	0.186***	0.182***	0.176***
	[258]	[249]	[261]	[0.024]	[0.023]	[0.024]
Vintage (year)	130	108	105	0.004	0.002	0.003
	[131]	[127]	[134]	[0.012]	[0.012]	[0.012]
Mileage at purchase (x 10^{-3})	-558***	-530***	-569***	-0.051***	-0.048***	-0.050***
	[107]	[103]	[108]	[0.010]	[0.009]	[0.010]
Car age at purchase (years)	-1,458***	-1,433***	-1,396***	-0.146***	-0.144***	-0.140***
	[101]	[98]	[104]	[0.009]	[0.009]	[0.010]
Air conditioning		537	416		0.058	0.038
		[603]	[649]		[0.055]	[0.060]
Sunroof		1,037***	1,194***		0.083**	0.086**
		[365]	[389]		[0.034]	[0.036]
Automatic transmission		1,673***	1,753***		0.154***	0.175***
		[373]	[398]		[0.034]	[0.037]
Number of cylinders		719***	724***		0.062***	0.060***
		[127]	[133]		[0.012]	[0.012]
Four-wheel drive		1,364***	1,181***		0.155***	0.143***
		[367]	[381]		[0.034]	[0.035]
Female			637***			0.076***
			[229]			[0.021]
Black			367			-0.007
			[390]			[0.036]
Region dummies		X	X		X	X
Buyer dummies			X			X
Observations	2,524	2,520	2,333	2,524	2,520	2,333
R-squared	0.779	0.797	0.810	0.779	0.797	0.810

Main takeaways

New evidence of adverse selection in durable-goods markets

Older theories of warranties seem to give incomplete picture

AS and MH may help explain durable-goods warranty design today

Guidance for warranty design based on information properties and necessity of repair of good

Future work

- Complementary role of leasing – also involves AS and MH
- Absence of deductibles in car warranties (AS vs. MH effects)
- Role of extended warranties