Keynote Lectures on Industrial Organization:

Ben Handel (Berkeley): *Complex consumer choices and health care markets: methodology and applications*

Michael Schwarz (MICROSOFT): *Carpooling and the economics of self-driving cars*

Chaired by Andre Boik (UC Davis)
Complex Consumer Choices and Health Care Markets: Methodology and Applications

Ben Handel (Berkeley)
June 24, 2018

North American Summer Meeting of the Econometric Society
Behavioral Consumers and Health Care Markets

• Health care markets have consumers making important decisions in complicated settings

• Many cases where consumer treatment choices seem misguided, with implications for contract design

• Growing body of work on medical provider decisions and implications for incentive design and quality regulation

• Substantial literature on behavioral consumers in insurance markets, with implications for firms and regulators as well
  -- Demand analysis
  -- Supply-side / regulatory implications
  -- Unanswered questions
Insurance Markets: Demand Analysis
Behavioral Economics and Health Insurance Choice

• Health insurance markets are fantastic “laboratories” for studying consumer-decision making when choices are:
  • Complicated
  • Boring
  • Important

• Key additional ingredient: inherent uncertainty

• Market designers have substantial input into choice architecture and product regulation
  • Great context to translate behavioral economics research into policy
  • Fantastic micro-level data with ability to judge right and wrong
  • Many different environments to study
Expected Utility with Behavioral Consumers

- Expected utility is baseline model of demand for insurance. Papers in literature modify this to account for informational / behavioral issues

- Model in Handel and Kolstad (2015, AER):

\[
\hat{u}_{ij} = \int_{0}^{\infty} f_{ij}(s|\hat{\psi}_{i,j}, \hat{\mu}_i) u(W_i - P_{ij} + \hat{\pi}_{i,j}(\hat{\psi}_{i,j}, \hat{\mu}_i) - s, \gamma_i) ds
\]

\[
\hat{\mu}_i = \mu_i + \delta^\mu + \epsilon_i
\]

\[
\hat{\psi}_{i,j} = \psi_j + \delta^\psi_j + \epsilon_{i,j}
\]

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Ex ante distribution of out-of-pocket medical spending in j  
V-NM utility given one health spending realization s
Expected Utility with Behavioral Consumers

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- Model in Handel and Kolstad (2015, *AER*)

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\]

- Biased perceptions:
  - $\hat{\mu}_i = \mu_i + \delta^\mu + \epsilon_i$
  - $\hat{\psi}_{i,j} = \psi_j + \delta^\psi_j + \epsilon_{i,j}$
  - $\hat{\pi}_{i,j} = \pi_j + \delta^\pi_j + \epsilon_{i,j}$

$\pi$: Doctor Prefs
$\mu$: Health Status
$\Psi$: Plan characteristics
Empirical Implementation: Handel + Kolstad (2015, AER)

- Easy to write down model, harder to quantify consumers’ departure from *homo economicus*

- Data from large employer with 150,000 consumers and 2 primary plan choices

- One method: use comprehensive survey data on consumer information about (i) health status (ii) provider network preferences and (iii) plan characteristics

- **Identification Strategy:** rational / fully informed consumers make choices with baseline expected utility, biased / uninformed consumers leave money on the table

- Empirical implementation is middle ground between fully structural behavioral model and reduced form model

\[
U_{ij} = \int_0^\infty f_{ij}(s)u_i(x_{ij}(P_{ij}, s, j_{t-1}, Z_i))\,ds
\]

\[
u_i(x) = -\frac{1}{\gamma_i(D_i)} e^{-\gamma_i(D_i)x}
\]

\[
x_{ij} = W_i - P_{ij} - s + \eta(D_i)1_{j_t = j_{t-1}} + Z_i'\beta I_{HDHP} + \epsilon_{ij}
\]

- Clear that, using data alone, consumers are losing meaningful sums of money in choice, model quantifies this and paper analyzes implications

Z- Indicator of mis-specified beliefs and/or limited information
Key Results: Handel + Kolstad (2015, AER)

- Average consumer with limited information / biases willing to leave almost $2,000 on table relative to fully informed rational consumer

- Consumer choice issues:
  - Provider networks
  - Plan Characteristics
  - Projected Health Spend
  - Hassle Costs

- Implications for Risk Preference Estimates:
  - Consumers estimated to be much less risk averse once precise signals on information sets considered
  - Important implications for welfare analysis of insurance market policies
Bhargava, Loewenstein, Sydnor (2017, QJE)

- Study large employer with 24,000 employees where employees choose from flexible menu with up to 48 possible plans

- For almost all employees, choosing low deductible options are *strictly dominated* by high-deductible options

- Most employees choose dominated option, losing on average $400

- Good evidence that something apart from standard expected utility model must be in play: no degree of standard risk aversion can rationalize choices
Bhargava, Loewensteine, Sydnor (2017, QJE) 

• Series of online experiments to disentangle different explanations:

1. **Menu complexity**: as number of plans $N$ increases or number of attributes per plan increases, menu becomes more complex. As this increases, consumers less likely to find / choose best plan.

2. **Alternative preferences**: Consumers gain financial value from not making out-of-pocket payment, above and beyond financial implications. Liquidity constraints, desire for budget predictability or just don’t like act of paying.

3. **Insurance literacy**: May follow expected utility model but have incorrect beliefs about key decision inputs. E.g., consumers may not understand OOP maximum or own health risk.
Bhargava, Loewenstein, Sydnor (2017, QJE)

- Series of online experiments to disentangle different explanations:

  1. **Menu complexity**: not much impact when reducing menu from 12 plans X 2 attributes to 4 plans X 1 attribute

  2. **Alternative preferences**: Intensive information treatment leads to great reduction in dominated plan choices, suggesting alternative preferences play a minor role

  3. **Insurance literacy**: Seems primary explanation: with intensive information / comprehension treatment incidence of dominated plan choice falls from 48% to 18%
Active Choice Issues: Additional Evidence

- Literature now has quite a few empirical papers studying active choice issues in health insurance markets.

- **Medicare Drug Insurance:** Abaluck and Gruber (2011, 2016), Heiss et al. (2010), Ketcham et al. (2012) all show seniors in the U.S. leaving substantial sums of money on table in initial choices.

- **Information Provision:** Kling et al. (2012) show that information provision to seniors in part D improves choices and value from insurance, Abaluck and Gruber (2017) study similar questions.

- **Choice Set Regulation:** Abaluck and Gruber (2016) study plan choices of employees in Oregon school districts. Employees leave substantial sums of money on the table in active / passive choices. Choice set curation / regulation is only intervention that has impact on choice quality (not information provision or forced active choice).
Inertia

• Quite a few empirical papers studying inertia, many potential underlying mechanisms:
  -- Handel (2013), modeled as switching cost
  -- Ho et al. (2016), modeled with rational inattention
  -- Search costs, naïve present bias, endowment effect, switching providers other explanations

• Typical identification:
  -- Natural experiment where all consumers make active choice in one year, passive choices after
  -- Also, compare new enrollees to similar existing enrollees

• Though certain strategies used to suggest which mechanisms are in play, papers typically lump mechanisms together. Matters for some policy questions but not others
Inertia: Potential Micro-Foundations

- Potential mechanisms underlying inertia include:

  1. Switching costs
  2. Search costs
  3. Inattention
  4. Naïve present bias
  5. Switching providers

- Literature in general does not distinguish between these mechanisms: there are some policies / cases for which disentangling the mechanisms is crucial, and others for which it is less important. See Handel and Schwartzstein (forthcoming, *JEP*) for a discussion.
Inertia: Some Results

• Handel (2013) – Consumers on average willing to leave $2,000 on table to stay in default option
  -- Evidence from new entrants compared to old
  -- Evidence from dominated plan choice

• Ho et al. (2016) – Consumers switch 10% of time, similar likelihood of paying attention in rational inattention model
  -- More likely to switch with shocks to (i) current plan premium change (ii) current plan cost-sharing change
  -- Amount of money left on table due to inertia is significant

• Other papers also document significant losses from inertia:
Insurance Markets: IO Implications
Key Themes

What are the implications of behavioral consumers for market design and competition policy?

-- Regulation and welfare analysis

-- Adverse selection and choice quality

-- Firm pricing with behavioral consumers

-- Paternalistic policies and competition
Regulation and Welfare Analysis

- With behavioral consumers, demand and welfare-relevant value are separate objects that need to be quantified for policy analysis.
Regulation and Welfare Analysis

• With behavioral consumers, demand and welfare-relevant value are separate objects that need to be quantified for policy analysis.

• How do you do this empirically [Handel and Schwartzstein (2018)]?
  
  -- Use decisions of experts to determine welfare curve for “similar” consumers.

  -- Survey consumers and use informed consumers to determine welfare curve for “similar” consumers.

  -- Implement “fully debiasing” intervention and use results to determine welfare curve.
Example: Handel & Kolstad (2015)

- With behavioral consumers, demand and welfare-relevant value are separate objects that need to be quantified for policy analysis.
Adverse Selection and Choice Quality

- In insurance markets, costs depend on who chooses the product.

- This can lead to adverse selection, which can lead to inefficient provision and even market unraveling.

- Improving consumer choices can lead to worse outcomes for the market overall by exacerbating adverse selection.

- Relationship between adverse selection and choice quality depends on choice environment / market foundations.
Example: Handel (2013)

- Population is worse off overall after choices improve with reduced inertia
- Polyakova (2016) shows example where reverse is true
Adverse Selection and Choice Quality

- Handel et al. (2017) studies systematically, in active choice environment, when improved choices do or do not improve consumer welfare

**Corollary 1** In a competitive market with under-insurance, the marginal welfare gain from reducing information frictions is lower (and potentially negative) if (i) the mean friction value (i.e., $E_{P(\alpha)}(f)$) is higher, (ii) the re-sorting on costs (i.e., $-\text{cov}_{P(\alpha)}(c,f)$) is stronger and (iii) the re-sorting on surplus (i.e., $-\text{cov}_{P(\alpha)}(s,f)$) is weaker.

- When choices improve, if consumers resort along the demand curve according to cost then welfare impact is lower (or negative); if they resort according to surplus more than welfare impact is greater
Firm Pricing with Behavioral Consumers

• Insurers could take advantage of consumer frictions / biases systematically in their pricing / markups

• Not many papers on this: but a few that study invest-then-harvest pricing when consumers have inertia

• Ho et al. (2017) low pricing at outset of Medicare Part D market, fast price rises afterwards. In counterfactual analysis, predict government savings of $550 million per year due to reduced subsidies if inertia removed entirely

• In many insurance settings, prices heavily regulated so this may be less of a concern here than in other sectors
Paternalistic Policies and Competition

• Several papers suggest that information provision to consumers alone is not enough to markedly improve choices.

• What about more paternalistic policies:
  -- Curating choice sets
  -- Smart / Targeted Defaults

• Abaluck and Gruber (2017) empirical work showing that curating choice set leads to welfare improvement: greater benefit from reduced errors relative to heterogeneous prefs.

Targeted Defaults: Example

**Figure 1.**

Smart Default Example

**Input: Individual-Level Health Information**
- Modified claims data from insurer
- Demographic information
- Consumer inputs about health risk

**Input: Consumer Financial Preferences**
- Consumer inputs
- Choices by well-informed, similar consumers

**Proposed Default Plan**
- Expected financial benefit of plan switch greater than $XXX
  - Yes

  - Primary providers included in new plan, network has enough key providers in zip code
    - Yes

    - Expected financial benefit of plan switch greater than $XXX
      - Yes

    - Default Consumer into Candidate Plan
Paternalism and ACA / Competition

FIGURE 2.
Choice Policies: Consumer Agency and Choice Effectiveness
Targeted Defaults: Some Questions to Answer

- What forms of agency-preserving interventions are most effective? What is the upper bound on effectiveness?

- When consumers now have a default option, is forced active choice a welfare improving policy?

- Targeted defaults: impact on choices, social objectives, and impact on competitive markets

- How can choice sets be curated to maximize welfare?

- Redistributive impacts
Some Unanswered Questions
Insurance: Some Areas Where Research is Needed

1. More nuanced understanding of behavioral foundations for poor choices. A decent amount of work done, but much still to be learned in this area.

2. Link between behavioral choice and behavioral utilization

3. Model-motivated assessments of policies to improve choices


5. Behavioral Insurers or Insurers With Frictions
Wrap Up

• Insurance literature has been one of best settings to study behavioral consumers and behavioral IO

• A lot of evidence on demand, still relatively few papers on different IO questions of interest

• Other areas related to health insurance or health care markets with some behavioral work, but more needed:
  1. Consumer treatment choices and interesting implications for contract design [Baicker et al. (2015)]
  2. Other areas: physician decision-making, incentive payments, and contract design [Handel et al. (2018-?)]
  3. Residency match [Rees-Jones and Skowronek (2018)]
Carpooling and the Economics of Self-Driving Cars

Michael Ostrovsky    Michael Schwarz
Three emerging technologies that will transform transportation:

- Self-driving cars
- Frictionless time-dependent tolls
- Convenient, efficient carpooling

What will a market powered by these technologies look like?

How should it be designed and organized?
Outline of the talk

• Emerging technologies and interactions among them

• Main model and results

• Auxiliary result: The benefits of higher utilization
Tolls – current technology
Tolls – coming soon (2020)
Carpooling

Tap into your local Waze community
See friends, neighbors & coworkers going your way

Convenient and enjoyable carpooling
Autonomous transportation and carpooling

In the world with self-driving cars, carpooling will blur the line between solo driving and public transportation. Currently, the cost of drivers is a significant component of public transit costs ⇒ large vehicles, frequent stops, slow and often inconvenient service. Eliminating this cost ⇒ smaller vehicles, fewer stops, door-to-door transit at reasonable cost. Some of the reasons for carpooling becoming much more attractive:

- No-hassle coordination: the self-driving car has to know its destination, and so coordinating carpooling does not require effort on the part of riders.

- No loss of flexibility.

- It is easy for an automated system to make carpooling matches in real time (i.e., when the car is already moving) and adjust its route accordingly.
• Detours are much less costly: it costs much less to sit in the car as a passenger and read/sleep/work/watch movies while the car is making a five-minute detour than to drive during that time.

• One of the key challenges in creating a carpooling platform is getting to a critical mass where on-demand carpooling is reliable enough to be practical. With transportation services powered by self-driving cars, this issue is resolved automatically.

• With several people sharing a ride, it does not have to be the case that the same person is the first one getting in the car and the last one getting out of it.

• No need to depend on a potentially unreliable carpool driver.

• Consistency of experience. E.g., no need to worry about being matched with an unsafe driver.
Autonomous transportation and road pricing

- Equilibrium effect of self-driving cars on road demand (in the absence of road pricing). Disutility of being stuck in traffic goes down $\Rightarrow$ demand goes up $\Rightarrow$ more traffic.

  “A lot of people think that once you make cars autonomous that they’ll be able to go faster and that will alleviate congestion and to some degree that will be true. But . . . the amount of driving that will occur will be much greater with shared autonomy and actually, traffic will get far worse.”

  – Elon Musk, Tesla CEO (2017)

In this case, intelligent road pricing becomes even more valuable.
- A self-driving car's system will have exact data on what route the car is taking, and at what time ⇒ that data can also be used to compute tolls.

- A passenger of a self-driving car needs to enter her destination when she begins the trip, and it is convenient to present road prices at that moment, and/or let her choose among several options. Similarly, if the passenger’s departure time is flexible, the system can present her with various options to travel at a lower price at a different time. In other words, it is convenient to incorporate road pricing directly into the user interface for autonomous transportation.
Complementarity between carpooling and road pricing

Example based on Vickrey (1969). Consider a congested road: twice as many drivers want to go over the segment over a certain period of time as what the road allows.

- Suppose carpooling becomes very convenient: its disutility (vs. driving solo) is some small $\Delta > 0$. This has no effect on outcomes.

- Suppose there is no carpooling and tolls are set at the socially optimal level. With homogeneous drivers, *none of the drivers are better off*: they simply pay in dollars what they used to pay in time. Also, the cost of suboptimal arrival times is not eliminated.

- Now suppose we both have convenient carpooling and set tolls optimally. We now fully relieve congestion, all riders arrive at their most preferred times, and are now much better off than they were before.
Main model and results
Model

- Finite set of riders $m = 1, \ldots, M$.

- Finite set of road segments $s = 1, \ldots, S$. Each road segment $s$ identifies both a physical road segment and a specific time interval.

- Each road segment $s$ has an integer capacity $q_s > 0$.

- A trip is a feasible combination of one or more riders and one or more road segments. There is a finite number $T$ of possible trips $t = 1, \ldots, T$.

- Each trip $t$ has a physical cost $c(t)$ associated with it.
• Each rider $m$ has a valuation for every trip $t$ that involves him: $v_m(t)$. Monetary transfers enter $m$’s utility additively.

• For each $m$, there exists an “outside option”: a trip that involves only one rider ($m$) and no road segments, gives $m$ the value of zero, and costs zero.

• An assignment is a set of trips $A$ such that each rider is involved in exactly one trip in $A$.

• Assignment $A$ is feasible if for each road segment $s$, the number of trips in $A$ that include road segment $s$ does not exceed its capacity $q_s$.

• The social surplus of assignment $A$ is equal to the sum of the valuations of all the riders from the trips to which they are assigned in $A$ minus the sum of the costs of the trips in $A$. 
Monetary transfers and outcomes

- A non-negative vector \( p \in \mathbb{R}^M \) specifies the price paid by each rider \( m \).

- A non-negative vector \( r \in \mathbb{R}^S \) specifies the tolls imposed by a regulator.

- An *outcome* is a triple \((A, p, r)\) that specifies an assignment, the payments made by the riders, and the tolls imposed by the regulator.
An outcome \((A, p, r)\) is

- **feasible** if the corresponding assignment \(A\) is feasible,

- **budget-balanced** if the sum of prices paid by the riders for their trips is \(\geq\) to the sum of the total physical costs of those trips and the total tolls on the road segments involved in those trips,

- **stable** if it is not possible to organize a trip \(t\) that makes all the riders involved in it strictly better off than they were under \((A, p, r)\),

- **market-clearing** if for every road segment \(s\) that has “excess capacity” in \(A\), the corresponding toll \(r_s\) is equal to zero.
Theorem 1:

If an outcome \((A, p, r)\) is feasible, stable, budget-balanced, and market-clearing, then assignment \(A\) has the highest possible social surplus among all feasible outcomes.
Proof:

Take a feasible, stable, budget-balanced, and market-clearing outcome \((A, p^A, r^A)\). Suppose feasible assignment \(B\) generates a higher social surplus than assignment \(A\).

Take any trip \(t\) in \(B\), and all riders \(m\) involved in \(t\). By stability of \((A, p^A, r^A)\), this coalition cannot benefit from organizing trip \(t\) by themselves, given prices \(p^A\) and tolls \(r^A\) in outcome \(A\). Thus, summing the utilities of all riders involved in trip \(t\):

\[
\sum_{m \in t} (v_m(t^A_m) - p^A_m) \geq \left( \sum_{m \in t} v_m(t) \right) - c(t) - r^A(t).
\]

Adding up equations (1) across all trips \(t\) in assignment \(B\), we get

\[
\sum_{m=1}^{M} v_m(t^A_m) - \sum_{m=1}^{M} p^A_m \geq \sum_{m=1}^{M} v_m(t^B_m) - \sum_{t \in B} c(t) - \sum_{n=1}^{N} r^A(s)k^B(s),
\]

where \(k^B(s)\) denotes how many trips in assignment \(B\) use segment \(s\).
Since the outcome is by assumption budget-balanced, we have

\[ \sum_{m=1}^{M} p_m^A \geq \sum_{t \in A} c(t) + \sum_{s=1}^{S} r^A(s)k^A(s). \]

Thus, equation (2) implies that

\[ \sum_{m=1}^{M} v_m(t_m^A) - \sum_{t \in A} c(t) - \sum_{s=1}^{S} r^A(s)k^A(s) \geq \sum_{m=1}^{M} v_m(t_m^B) - \sum_{t \in B} c(t) - \sum_{s=1}^{S} r^A(s)k^B(s). \]

The social surplus of \( A \) is equal to \( \sum_{m=1}^{M} v_m(t_m^A) - \sum_{t \in A} c(t) \), while the social surplus of \( B \) is equal to \( \sum_{m=1}^{M} v_m(t_m^B) - \sum_{t \in B} c(t) \). To show that the former is greater than or equal to the latter, it is now sufficient to observe that

\[ \sum_{s=1}^{S} r^A(s)k^A(s) \geq \sum_{s=1}^{S} r^A(s)k^B(s), \]

which follows from the market-clearing property of \((A, p^A, r^A)\).
Issue: a feasible, stable, budget-balanced, market-clearing outcome may fail to exist. For example, suppose we have 101 riders and each car fits at most two passengers.

Approximation: allow trips to be “divisible”. Formally, a “quasi-assignment” $A$ is a measure on the set of trips such that overall, each rider is involved in measure 1 of trips. The definitions of an outcome and of feasibility, stability, budget-balancedness, and market-clearing extend naturally.

Theorem 2:

A feasible, stable, budget-balanced, and market-clearing quasi-outcome is guaranteed to exist. Any such quasi-outcome is socially efficient.
Idea of the proof:

Construct an auxiliary economy. Consumers in this economy are new agents called “trip organizers”. There are $T$ types of those agents, one for each trip. There are 2 trip organizers of each type.

The goods are the $M$ riders and $S$ road segments from the original model. Price vector $\rho \in \mathbb{R}^{M+S} \geq 0$ assigns a price to every good in the economy.

Trip organizers can consume bundles of goods $b \in [0, 1]^{M+S}$. Their utility is

$$\tilde{V}_t(b) = \left( \sum_{m \in t} v_m(t) - c(t) \right) \times \min_{g \in t} b(g) - \rho^T b.$$
Competitive equilibrium: set of prices $\rho$ and profile of consumption bundles $b$ such that every consumer is optimizing and markets clear.

Existence of CE: For each $\rho$, take optimal bundles $b$, and add them up to get aggregate demand $D \in \mathbb{R}^{M+S}$. Let $Q \in \mathbb{R}^{M+S}$ denote the available supply of all items. Define the tâtonnement price adjustment function $\tau(\rho, D) = \max\{0, \rho + (D - Q)\}$.

Correspondence $\varphi$: for each $\rho$, take all possible $D$, and compute all possible $\tau(\rho, D)$.

Correspondence $\varphi$ satisfies all the requirements of Kakutani’s fixed-point theorem: $\varphi(\rho)$ is non-empty and convex for all $\rho$; and $\varphi(\rho)$ has a closed graph. Thus, correspondence $\varphi$ has at least one fixed point. Any fixed point $\rho^*$ of $\varphi$ and a profile of consumer-optimal bundles with aggregate demand $D^*$ such that $\rho^* = \tau(\rho^*, D^*)$ form a competitive equilibrium.
Last step: observe that in every CE, the utility of every consumer (trip organizer) is zero, because by construction, there is “excess supply” of trip organizers.

This observation allows us to go from a CE in the auxiliary market to a feasible, stable, budget-balanced, and market-clearing quasi-outcome:

• For each segment $s$, toll $r(s)$ is equal to the competitive equilibrium price $\rho^*(s)$.

• For each rider $m$, the utility $u(m)$ in the original market is set equal to $\rho^*(m)$.

• To construct the quasi-assignment $G$, take all riders $m$ whose utility $u(m)$ is greater than zero and “read off” the volumes of various trips from these riders.
Additional observations and results
The world without self-driving cars

The model and the main results can be easily adapted to the world without self-driving cars. Each “trip” would simply needs to specify which of the people involved is the driver (with the rest being passengers), and we also need to make some minor modifications to our modeling assumptions.

However, the model does not apply directly to the world with professional drivers (taxis, Uber, Lyft, and so on). The reason for this distinction is that in the world with professional drivers, one of our assumptions is no longer accurate: “each trip $t$ has a physical cost $c(t)$ associated with it.”

Why do we make this assumption in our main model?
Basic model of car utilization

A car costs $C$ and dies after $N$ miles or $A$ years, whichever comes first. The annualized real interest rate is $r$. A car is driven $K$ miles per year. Fuel, maintenance, and insurance are variable costs, $m$ per mile. Note: car will die at $T = \min\{A, \frac{N}{K}\}$.

Proposition

For $r > 0$, the cost per mile $G$ is equal to $m + \frac{Cr}{K(1-e^{-rT})}$. For $r = 0$, the cost per mile is $G = m + \frac{C}{KT}$.

Proof:

$$C + \int_0^T mKe^{-rt}dt = \int_0^T GKe^{-rt}dt.$$ 

\[\square\]

Note that there is no discontinuity at $r = 0$ (because $\lim_{r \to 0} \frac{r}{1-e^{-rT}} = \frac{1}{T}$).
Corollary

*If cars die from usage (rather than old age) and the real interest rate is equal to zero, the increase in annual mileage yields no cost savings.*

Numerical example

- Cars die after 200,000 miles or 15 years, whichever happens first
- New cars cost $30,000, real interest rate is 3% per year
- Gas, maintenance and insurance are variable costs, 30 cents per mile

<table>
<thead>
<tr>
<th>Annual mileage</th>
<th>5,000</th>
<th>15,000</th>
<th>25,000</th>
<th>35,000</th>
<th>75,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost per mile (¢)</td>
<td>80</td>
<td>48</td>
<td>47</td>
<td>46</td>
<td>46</td>
</tr>
</tbody>
</table>
Implications

- Limited cost reduction of using “Transportation-as-a-service” vs. personal ownership for many people (e.g., those driving 15,000 miles per year or more and living in areas with low parking costs), so personal self-driving cars may easily co-exist with various transportation services. Our framework accommodates this possibility.

- “High utilization” in the form of putting more people in the car (carpooling) is likely to be much more important than “high utilization” in the form of putting more miles on a car. E.g., potential cost savings from doubling car occupancy are an order of magnitude higher than the savings from doubling car usage.

- Note: with self-driving cars, the economic return from making cars more durable will increase, so the economics of utilization may change. We’ll deal with it when we get there . . .
Conclusion

A lot still to be done ...