

Congestion and Incentives in the Age of Driverless Cars

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Motivation

Automation and artificial intelligence are rapidly changing the structure of the automobiles market and the organization of traffic

- Autonomous vehicles (AVs)
 - ▶ vehicles driven by a software that does not require human intervention (5 levels of automation; Level-4 AVs are just behind the corner)
- AVs entail relevant technological, legal, and moral issues (Awad et al. 2018)
- But significant, and often underappreciated, economic aspects as well.
- Widespread use of software for traffic management allows for greater traffic coordination, due to
 - ▶ reliable real-time information on traffic flows
 - ▶ opportunity for cars to make/change their travel plans contingent on other vehicles behavior



ROBOTAXI

THE END OF THE STEERING WHEEL?



Centralization of urban traffic

- Robotaxis, i.e., taxis operated by ride service companies through AVs
 - ▶ Partnership Waymo-Lyft to offer robotaxi services in selected urban areas in the US
 - ▶ General Motor's subsidiary Cruise expected to roll out its robotaxis fleet soon
 - ▶ Tesla will soon stop selling cars to private owners, and use them for - comparatively more profitable - robotaxis fleet instead
- Investment into private cars is bound to shrink (Fagnant and Kockelman, 2015)
- Fleets are cheaper (labor cost saving thanks to AVs) and with higher utilization rate
- Transition from private vehicles to fleets of AVs - centralization of urban traffic

Congestion externality

- Congestion big issue (congestion costs > 100 bln \$ per year in US)
- Likely to remain important (even more so) when AVs will be in place
 - ▶ more rational use of infrastructure \rightarrow higher road capacity \rightarrow less congestion
 - ▶ travelers may spend more productively their time on vehicles \rightarrow less congestion costs
 - ▶ induced demand for travel \rightarrow more congestion
- When private (traditional or autonomous) vehicles are *not* organized in fleets, congestion externalities emerge: a driver driving on a congested road is contributing to increasing the congestion
 - ▶ this not only affects the driver, but it affects the other drivers as well
 - ▶ drivers are atomistic, and, unless they are taxed appropriately, they do not consider the extra cost that their decisions to drive in congested hours/places imposes on their fellow drivers
- When AVs are organized in fleets and centrally managed, they do not behave atomistically
 - ▶ each company managing a set of AVs has an incentive to consider the impact of congestion costs on its profit
 - ▶ depending on market structures, there may be incentives to (at least partially) internalize congestion externalities

What we do

- We analyze and the welfare effects of the transition from a decentralized market with atomistic travelers to a centralized market with a single company managing a fleet of vehicles, including the analysis of the transition period where AVs managed by a company will coexist with privately owned AVs
 - ▶ It may seem intuitive that, as a result of the internalization of congestion under centralization, welfare increases. We show that this intuition is incomplete
- We characterize optimal tax scheme throughout the centralization process
 - ▶ We show that the optimal tax under decentralization - a congestion charge - differs markedly from the optimal tax under centralization - a tax to correct quality distortions

Heterogeneity

- Heterogeneity in disutility from congestion costs is substantial (Small, 2012) and reflects heterogeneity in individuals' value of time, as well as in value of reliability
 - ▶ Difference in value of time between the 75th and the 25th percentile is about half of the median value for the value of time (with the median being about 21 \$ per hour, and the interquartile range being about 10 \$ per hour)
 - ▶ Value of reliability varies between the third and the first quartile by more than 100% of the median value (with a median of approximately 12 \$ per hour, and the interquartile range about 13 \$ per hour)
- With heterogeneous travelers, reduction in aggregate congestion costs (as well as welfare maximization) requires to act also on the efficient sorting of travelers
 - ▶ Consider a highway with two lanes. With heterogeneous disutility from congestion, efficiency may require to differentiate the speed across the two lanes, with a faster lane for fewer travelers that dislike congestion a lot, and a slower lane for the others

Sorting

- Efficient sorting is economically very relevant
- A little less than the average hourly disutility from congestion can be mitigated by efficiently sorting travelers, without any increase in infrastructure capacity or travelers rationing
 - ▶ AVs and other recent technological advancements are dramatically decreasing the cost of the sorting technology, thereby making it a viable and important alternative to manage congestion
- Our stylized framework will allow for both margins to mitigate congestion:
 - ▶ rationing
 - ▶ sorting
- Welfare effects of the transition depends crucially on what margin is dominant

Travelers and lanes

- An origin A and a destination B are connected by one road with *two segregated and congested lanes*
- Continuum of heterogeneous travelers, denoted by parameter $\theta \sim U[0, 1]$, using AVs to go from A to B
- Lanes ex ante identical and ex post potentially different in terms of congestion and in the price and/or taxes that are charged in each of them
- A traveler chooses
 - ▶ whether or not to travel
 - ▶ if she travels, in which of the two lanes to do so
- An outcome is an assignment of each type θ to a lane, or to not traveling

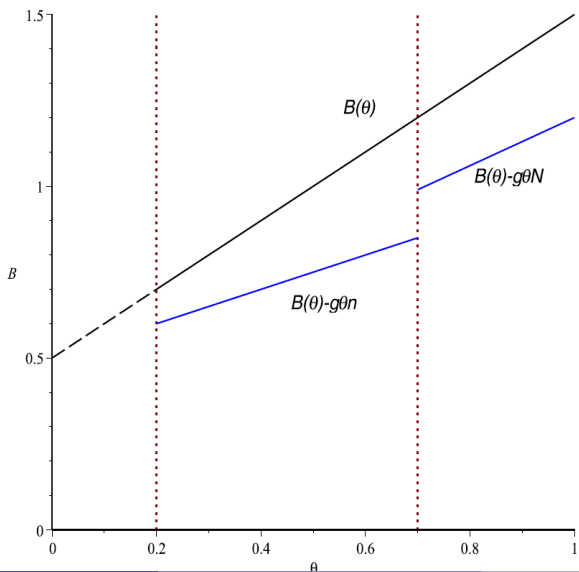
Travel options

- Net utility for a traveler with preference parameter θ when travelling in a lane with n other travelers

$$B(\theta) - \theta gn$$

- θ affects the utility of traveling, $B(\theta) \geq 0$, with $B' > 0$, and the idiosyncratic component θ of the congestion disutility θgn
 - ▶ Consistent with evidence pointing to a positive relation between wage and value of time (see, e.g., Small, 2012)
- g , common component of the congestion disutility θgn , sufficiently low so that $\frac{\partial(B(\theta) - \theta gn)}{\partial \theta} > 0$ for any θ and n : utility is increasing in θ

Utility



First best

- Social planner maximizes:

$$\max_{\substack{s \geq 0, f \geq 0 \\ s+f \leq 1}} W = \int_{1-s-f}^{1-f} [B(\theta) - \theta g s] d\theta + \int_{1-f}^1 [B(\theta) - \theta g f] d\theta$$

- Notation:

- ▶ s : proportion of travelers traveling in slow lane
- ▶ f : proportion of travelers traveling in fast lane

- At the social optimum, there is differentiation across the 2 lanes

$$s_{FB} > f_{FB}$$

- Travelers with very low θ may not travel (when g high relative to $B(0)$)
- Travelers with low θ travel in the low quality/high congestion lane: slow lane
- Travelers with high $\theta \in [1 - f_{FB}, 1]$ travel in the high quality/low congestion lane: fast lane

Sorting

- We first focus on the sorting problem, and analyze welfare in the transition between decentralized and centralized travel assuming the market is fully covered in all circumstances
- This turns out to happen, given our parameters, when

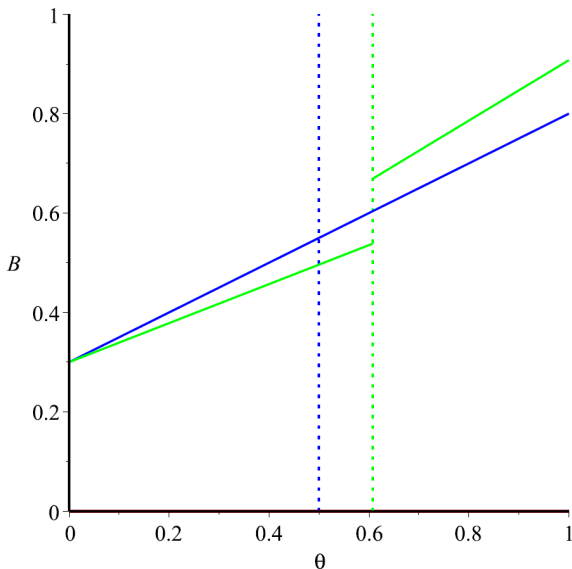
$$\frac{B'(0)}{B(0)} \leq 1$$

- g sufficiently low relative to $B(0)$ so that the planner wants to dispatch all travelers
- the value of traveling sufficiently flat so that a firm does not want to screen some consumers out of the market

Fully decentralized market

- Market is populated with atomistic travelers only (= private cars)
- No internalization of congestion externality
- No charges in each lane (no fares, no taxes)
- Each traveler maximizes individual utility
- Features of the equilibrium
 - ▶ atomistic travelers split equally in the two lanes (no matter their type), so that $s_A = f_A = \frac{1}{2}$
- Distortion with respect to first best:
 - ▶ there is no differentiation across lanes (or underdifferentiation): fast lane is too slow, slow lane is too fast

Utility in decentralized market vs first best



Centralized market

- All travelers are corporate, $\mu = 1$
- They all use a single firm that manages a fleet
- Firm's problem

$$\max_{s,f} ps + Pf$$

$$\text{s.t. } p = B(0) \quad (\text{participation of type-0 traveler})$$

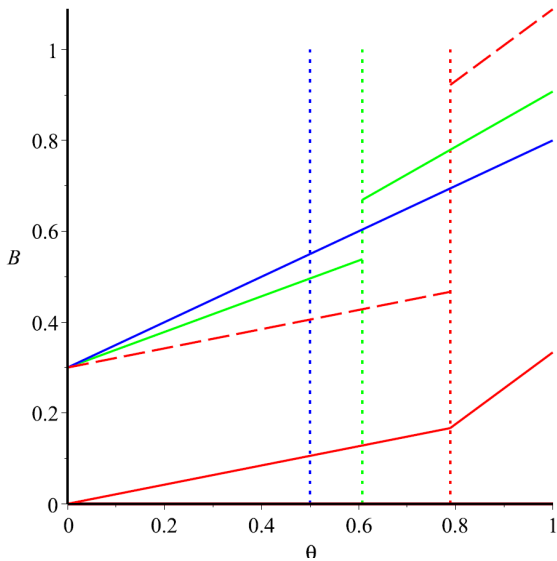
$$P = p + (1 - f)g(s - f) \quad (\text{incentive compatibility of marginal traveler})$$

- ▶ firm uses fares to direct travelers across lanes
- ▶ it uses differentiation across lanes to extract value from high θ -travelers

In equilibrium

- Firm differentiates more than social planner (overdifferentiation): fast lane is too fast ($f_M < f_{FB}$), slow lane is too slow ($s_M > s_{FB}$)
- Intuition: monopolist distorts quality

Utility



Welfare effects

- While, as the level of market centralization μ increases, the firm is increasingly able to internalize the congestion externality, this does not reflect into an increase in welfare. To the contrary, welfare goes down.
- Two distortions. One involves the mass of travelers traveling and the resulting level of differentiation across lanes:
 - ▶ Overdifferentiation with centralization more pronounced than underdifferentiation with decentralization
- A second one involves the identity of travelers, during the transition period
- With high μ , all the atomistic travelers, including low θ , travel in the fast lane. This misallocation reduces welfare severely.
- Distributional effects:
 - ▶ Centralization makes corporate travelers with high θ , as well as travelers that remain atomistic, better off. Low θ corporate travelers stand to lose from centralization.

Rationing

- Social planner rations when congestion cost g is high relative to value for traveling for marginal type $B(0)$
- Firm rations when $B'(0)$ is large relative to $B(0)$
 - ▶ standard monopoly tradeoff
 - ▶ firm can screen too many or too few travelers out of the market with respect to social planner
- With fully decentralized market, all consumer always travel
- Effect of centralization ambiguous
 - ▶ scope for welfare improving centralization when g is high relative to $B(0)$ - so that planner would ration - and $B'(0)$ large relative to $B(0)$ - so that firm would ration.
 - ▶ but parameters must ensure that firm is not rationing too much.

Welfare with rationing

- Welfare may improve with centralization when rationing occurs.
- This requires two circumstances:
 - ▶ Rationing under centralization occurring with a high enough g (so that the planner would also ration)
 - ▶ Parameter values ensure not too much restriction ($B'(0)$ not too high)

Taxes with atomistic travelers

- We design first-best restoring taxes in the polar cases $\mu = 0$ (decentralized travel) and $\mu = 1$ (centralized travel, only corporate travelers)
- Government sets a per-vehicle tax equal to t in the slow lane, and equal to T in the fast lane

$$t_{AT} \leq B(0)$$

$$T_{AT} = t_A + \frac{g}{18} (5 - \sqrt{7})$$

- With atomistic travelers only, taxes that restore first best are congestion charges: each traveler internalizes the congestion externality she imposes on fellow travelers
- Taxes are welfare-improving, but, in the absence of compensation, low θ 's stand to lose because they travel in a more congested lane

Taxes on monopoly

- Timing
 - ▶ first, tax authority announces a per-vehicle tax equal to t in the slow lane, and equal to T in the fast lane
 - ▶ second, firm sets fares p and P
 - ▶ third, travelers make their travel decisions
- First-best-restoring tax scheme:

$$t = gs$$

$$T = gf$$

- Very different tax than that on atomistic travelers
 - ▶ gs and gf restore first-best differentiation (i.e., first-best relation between s and f)
 - ▶ since $s > f$, tax is larger in the slow lane and discourage the monopolist to overcrowd it, thus reducing differentiation across lanes
 - ▶ a congestion charge, but a tax on quality (Cremer and Thisse, 1994)

Taxes with rationing

- First best restoring taxes under full centralization when rationing occurs in the equilibrium without taxes:

$$t = gs - d$$

$$T = gf - d$$

- ▶ where d is a subsidy.
- When congestion is sufficiently severe (g is large), subsidies exceed taxes
- They would absorb funding from general taxation. Politically unappealing?
 - ▶ possibly, to be compensated with an ex ante license

Conclusions

- We analyze welfare effect of transition from decentralized to centralized traveling under heterogenous travelers
- We show that they differ depending on whether the main issue is sorting or rationing
- In spite of a better ability to internalize congestion externality, centralization fails to be welfare-improving when the issue is rationing
- When the main problem is rationing (because the congestion costs are severe enough with respect to utility from traveling), centralization may be welfare-improving.
- Taxes that restore first best are starkly different in the decentralized and in the centralized world
- With full centralization, restoring first best may require a subsidy

Extensions

- Oligopoly competition
- Not only competition, but market design, for instance...
 - ▶ ...exclusive lanes
- Endogenous choice of owning the car
 - ▶ fares and, more in general, transport menus need to be incentive compatible across transport modes
- Acceptability
 - ▶ are we ready to surrender our individual decision making for a public good (such as the reduction of aggregate congestion disutility)

THANKS

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