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Pricing curb parking

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ABSTRACT

Where traffic is congested and all the curb spaces are occupied, some drivers are probably cruising for parking. Cities can eliminate this cruising by charging demand-based prices for curb parking to ensure one or two open spaces on every block. Drivers will then usually find convenient places to park within a short walk of their destinations. But if cities charge demand-based prices for curb parking, how will drivers choose where to park, and what will they pay? To answer these questions, I have examined how four variables—parking duration, number of persons in the car, walking speed, and value of saving time spent walking—determine parking choices when prices increase as drivers approach their destinations. Short-term parkers, carpools, slow walkers, and drivers with a high value of saving time will park closer to their destinations. Long-term parkers, solo drivers, fast walkers, and drivers with a low value of saving time will park farther away. This spontaneous, self-organizing pattern of parking choices responding to demand-based parking prices will minimize the collective cost of the time drivers spend walking to and from their destinations. Demand-priced curb parking will also reduce uncertainty about travel times. Drivers delayed by traffic congestion can save time at the end of their trips by paying a higher price to park closer to their destinations. Demand-priced curb parking at the end of a trip can serve as a buffer allowing late-arriving drivers to buy time when they need it most.

> *I will begin with the proposition that in no other major area are pricing practices so irrational, so out of date, and so conducive to waste as in urban transportation. Two aspects are particularly deficient: the absence of adequate peak and off-peak differentials and the gross underpricing of some modes relative to others… our rubber-shod sacred cow is a ravenously space-hungry, shall I say, monster?* William Vickrey (1954)

1. Introduction

Dubious statistics that are cited frequently enough can become widely believed. Here are a few citations for the dubious statistic that 30% of traffic is cruising for parking:

> Studies have found that an estimated 30 percent of all drivers currently on the road are actively looking for parking (Marcotorchino 2018).
> The literature contains estimates that the proportion of cars traveling on downtown city streets during the business day that are cruising for parking is 30% or even higher (Arnott and Williams 2017).
> It is estimated that nearly 30% of urban congestion is created by drivers cruising for parking (Bayless and Neelakantan 2012).
> Thirty percent of congestion is caused by people looking for parking spaces (Biggs 2015).

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> In the United States, 30% of traffic congestion on road networks is caused by people circling around for parking (Yan et al., 2020).[1]

Where did this apocryphal 30% meme come from? Apparently from me. In *The High Cost of Free Parking*, published in 2005, I summarized the results of 16 studies of cruising:

> "Table 11–5 summarizes the results of 16 studies of cruising in 11 cities. Between 8 and 74 percent of traffic was searching for parking, and it took between 3.5 and 13.9 min to find a curb space. But these studies dating back to 1927 are mainly of historical interest. The data were probably not very accurate when they were collected, and the results depended on the time of day, the specific place, and the season when the observations were made. Still, cruising today is similar to what drivers have done since the 1920s, and the studies at least show that searching for underpriced curb parking has wasted an enormous amount of time and fuel for many decades. The studies are selective because researchers study cruising where they expect to find it—on streets where curb parking is underpriced and overcrowded." (Shoup 2005, 290).

Table 1 presents the results of these 16 studies.

The share of cars cruising for curb parking ranged between 8% and 74% of the cars driving on downtown streets where curb parking was underpriced and overcrowded. The average of 30% cruising in these studies does *not* refer to all traffic, as Paul Barter (2017) explained:

> With repeated mentions of that 30% figure, it seems to have morphed into a misleadingly precise and general claim about the percentage of overall traffic or congestion due to parking search. It would be annoying if debunking the sloppy use of this 30% average undermines the important point that cruising for parking can cause a huge mess in busy areas, at busy times, when parking is mismanaged.

Perhaps the 30% meme has simply become a shorthand way to say that underpriced curb parking can create serious problems.[2] The next section surveys the research on cruising and the problems it creates. I then develop a model of how drivers will choose parking spaces if cities price curb parking to ensure one or two open spaces on every block. I conclude by examining the equity, efficiency, and practicality of using prices to manage curb parking.

Table 1
Cruising for parking, 1927–2001.

Year	City	Share of traffic cruising (percent)	Average search time (min)
1927	Detroit (1)	19%	
1927	Detroit (2)	34%	
1933	Washington		8.0
1960	New Haven	17%	
1965	London (1)		6.1
1965	London (2)		3.5
1965	London (3)		3.6
1977	Freiburg	74%	6.0
1984	Jerusalem		9.0
1985	Cambridge	30%	11.5
1993	Cape Town		12.2
1993	New York (1)	8%	7.9
1993	New York (2)		10.2
1993	New York (3)		13.9
1997	San Francisco		6.5
2001	Sydney		6.5
Average		**30%**	**8.1**

Source: Shoup (2005, Chapter 11)

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[1] There are three misconceptions in this one sentence. First, stating that the 30% figure refers to the United States is wrong because the 2006 article reported studies of cruising in countries around the world, including Australia, Germany, Israel, South Africa, and the UK. Second, stating that the 30% figure refers to traffic congestion is wrong because it refers to the share of cars in the traffic flow that are cruising for parking, which is not the same thing as congestion. Third, 30% is also wrong, as explained in this article. These misconceptions do no harm if the 30% figure is simply being used to call attention to the serious problems caused by mismanaging the curb.

[2] Millard-Ball, Hampshire, and Weinberger (2020) also debunked the 30% meme, and suggested that cruising is a rare phenomenon. They cited several studies that found no significant cruising, including one in the Netherlands that found cruising time was only 36 s per trip (van Ommeren, Wentink, and Rietveld 2012). But the Dutch study measured the cruising time for all traffic in the nation, not in the local hot spots of cruising. Just as the share of traffic that is cruising in hot spots doesn't describe all cruising in the nation, the share of all traffic that is cruising in the nation doesn't describe what happens in local hot spots. Cruising presents no problem in most places, but huge problems in some places. Millard-Ball, Hampshire, and Weinberger also distinguished between (1) parking *search*, which is the time from the driver's decision to start looking for an open curb space until the car is parked, and (2) *cruising*, which is excess vehicle travel after reaching the destination without having found an open curb space. Search, but not cruising, begins before reaching the destination.

Table 2
Cruising for parking, 2005–2020.

Year	City	Share of traffic cruising (percent)	Average Search Time (min)
2005	Los Angeles	68%	3.3
2006	New York	28%	
2007	New York	45%	
2008	New York		3.8
2011	Barcelona	18%	
2012	Abu Dhabi		7.3
2015	Brisbane		15.4
2018	Stuttgart	15%	
2020	Ningbo		6.0
Average		**35%**	**6.0**

Source: Shoup (2005), Schaller (2006), Transportation Alternatives (2007), Transportation Alternatives (2008), Ruh (2017), Lee et al. (2017), Hampshire and Shoup (2018), Zhu et al. (2020), Bagloee et al. (2012).

2. Choosing to cruise

Drivers usually want to park right in front of their destination. If more drivers want to park at the curb than there are spaces available, however, searching for an open space resembles a motorized game of musical chairs. As Thomas Sowell (2010) put it, “What everyone wants adds up to more than there is.” And when too many drivers want to park at the curb, they add to traffic while they search for a space.

Cruising for parking accounts for between 0% and 100% of the traffic, depending on the place and time of day. For example, drivers won’t cruise if open curb spaces are available or curb parking is prohibited. No drivers on freeways are cruising. But on a busy street with crowded curb spaces and congested traffic, many or even all the drivers may be cruising for parking.

Table 2 shows the results of nine more recent studies of cruising. The cruising share ranged from 15% to 68%, with an average of 35%. In New York City, researchers who interviewed drivers stopped at traffic lights found that 28% of drivers on a street in Manhattan were cruising for parking (Schaller 2006) and 45% on a street in Brooklyn (Transportation Alternatives 2007). Using the same method, researchers in Barcelona found 18% of drivers were cruising (Ruh 2017). Another method of measuring cruising involves observing the number of cars that pass a newly vacated parking space before a driver parks in it. Using this method, Hampshire and Shoup (2018) estimated that 15% of the cars in traffic in downtown Stuttgart were cruising for parking.

When drivers cruise, they worry about how long it will take to find a curb space, not what share of the traffic is cruising. The studies in Table 2 found an average search time of six minutes. In the survey of drivers who parked in central Brisbane, for example, all respondents reported having searched for on-street parking as their first choice. After unsuccessfully cruising for up to 16 min, some drivers parked off-street (Lee, Agdas, and Baker 2017). Therefore, the cruising time before parking on the street understates the total cruising time, which includes time spent cruising by drivers who park off-street. Mannini et al. (2017) found the average search time for on-street parking is about 11% of the total travel time for trips to the center of Rome.

Cao, Menendez, and Waraich (2019) used a macroscopic model with data from central Zurich to estimate the cruising share. All curb spaces were occupied from 11 am to 4 pm (Fig. 1). Between 20% and 70% of traffic was cruising for parking during those five hours (Fig. 2). Drivers averaged between 6 and 14 min searching to find a curb space (Fig. 3). The cruising share and the average search time varied substantially from one minute to the next. An *average* cruising share does not predict the cruising share at any moment.

Inci, van Ommeren, and Kobus (2017) estimated that each hour a driver parked at a crowded curb in Istanbul induced between three and four more drivers to cruise. By congesting traffic, this added cruising increased travel times and fuel costs for all drivers, and increased air pollution and safety risks for everyone.

Commercial delivery vehicles also cruise frequently because they park frequently. Using a sample of 2,900 delivery trips in downtown Seattle, Dalla Chiara and Goodchild (2020) found an average cruising time of 2.3 min per delivery. Because the average delivery took 8.2 min for each delivery, cruising represented 28% of the delivery time. Because the drivers averaged 30 deliveries per day, they cruised an average of 1.15 h per day.

Cruising for curb parking also slows public transit. Krishnamurthy and Ngo (2020) found that after San Francisco began to price curb parking to provide one or two open spaces on every block, buses ran faster and transit ridership increased by between 5% and 11%.

Beyond these academic studies of cruising, drivers know about their own cruising. Calvin Trillin (2001) and Anna Quindlen (2018) even wrote novels about it.

3. Search costs

Underpriced curb parking gives a small, temporary benefit to a few lucky drivers, but it creates large social costs for everyone else. Consider a study of cruising for the 470 curb parking spaces in Westwood Village, a 15-block business district near UCLA (Shoup 2005,

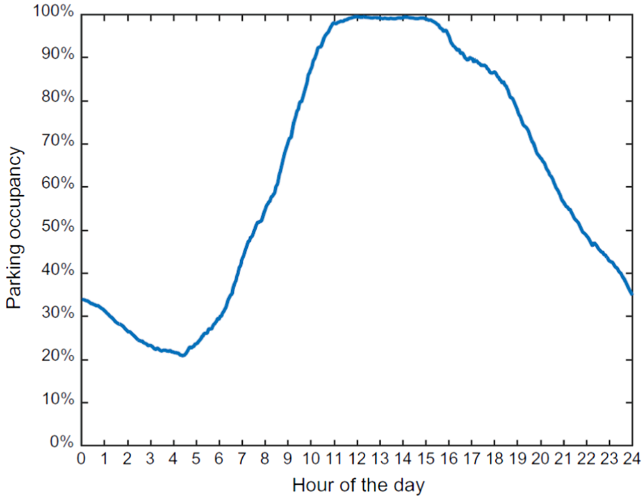

Fig. 1. Curb space occupancy rate in central Zurich.

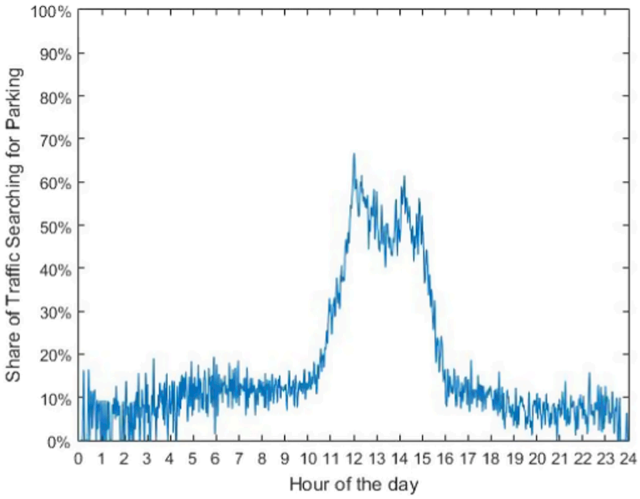

Fig. 2. Share of traffic cruising for curb parking in central Zurich.

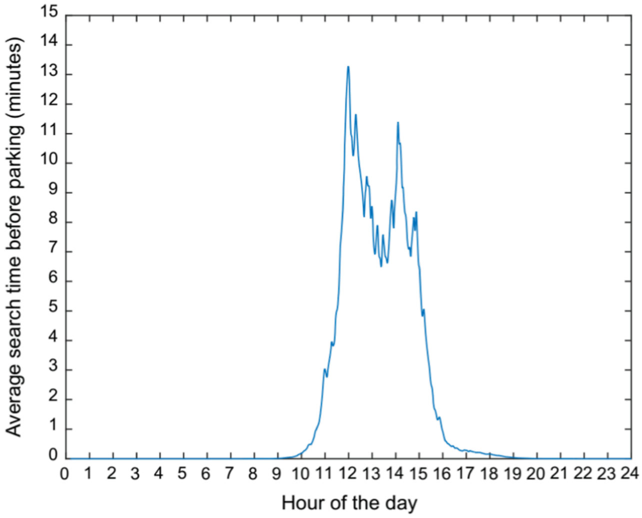

Fig. 3. Average search time for curb parking in Central Zurich. Source: Cao, Menendez, and Waraich (2019).

Chapter 14). The average time to find a curb space was 3.3 min and the average distance cruised was half a mile. While 3.3 min is not a long time for one driver to cruise, the minutes add up quickly because the parking turnover rate was 17 cars per meter per day. The average cruising time per meter was 54 min per day, and the average cruising distance per meter was 7.7 miles per day.[3]

For the 470 parking meters, cruising created 3,633 vehicle miles traveled per day, greater than the distance across the continent (Shoup 2005, 352). Over a year, cruising for parking in Westwood created 945,000 VMT, equal to 38 trips around the earth or four trips to the moon. This cruising was not real travel, however, because the drivers weren't going anywhere; they had already arrived and were hunting for an open curb space.

Thirty-eight trips around the earth every year in a 15-block business district? That is more than two trips around the earth for each block! Simple arithmetic shows that cruising can easily create this excess vehicle travel. The result depends on only four variables:

1. cruising time before finding a curb space
2. turnover rate for the curb spaces
3. cruising speed, and
4. number of curb spaces.

Consider a commercial district with 500 curb spaces. On a day that is the average for the year, the spaces turn over 10 times, and drivers cruise for 3 min at 10 miles an hour (the average speed observed in Westwood for cars cruising for parking) before finding an open curb space. We can calculate the total VMT per year for cruising in four steps:

1. Cruising for 3 min 10 times a day creates 30 min of cruising per space per day.
2. Cruising for 30 min at 10 miles an hour creates 5 VMT per space per day.
3. Cruising 5 VMT a day for 365 days creates 1,825 VMT per space per year.
4. Cruising 1825 VMT per space per year for 500 spaces creates 912,500 VMT per year.

Four realistic assumptions and four multiplications predict 912,500 VMT per year, close to the observed value for Westwood Village. Common sense and careful counting show that cruising can create an astonishing amount of unwanted and unnecessary vehicle travel. INRIX, a leading firm in crowd-sourced traffic data, estimated that drivers waste $73 billion a year in the time, fuel, and emissions costs of searching for parking in the United States (Cookson and Pishue 2017).

The curb occupancy rate strongly affected search times. Fig. 4 shows the average occupancy rate and the average search time for each hour between 8 am and 8 pm. No one cruised between 8 am and 10 am when most stores were closed, but search times rose sharply when stores opened and the occupancy rate rose above 90%. When all curb spaces are occupied, an increase in parking demand increases the average search time but not the number of parked cars. In this case, even the most intelligent parking guidance system will not eliminate cruising.

Subsequent studies on cruising times and curb occupancy have found similar results. Using parking simulation models, Levy, Martens, and Benenson (2013) found cruising times increase rapidly when curb occupancy rises above 92%. Using data from Seattle, Dowling (2019) found cruising times increase rapidly when curb occupancy rises above 85%. If finding a curb space resembles winning a lottery, drivers pay for the lottery tickets with the time they spend cruising.

Using a computer simulation of downtown parking and traffic congestion, Arnott and Inci (2006) estimated that setting the price of curb parking high enough to eliminate cruising would eliminate 98% of the cost of traffic congestion in downtown and convert 100% of the deadweight loss caused by underpriced curb parking into public revenue.

If drivers pay for curb parking with money, the cash can clean the sidewaklks, plant street trees, and remove grafitti. When drivers cruise for parking, they pay in minutes rather than money, wasting not only their own time but also congesting traffic, polluting the air, and putting bicyclists and pedestrians at risk. Free curb parking tells drivers to waste time, foul the environment, and starve public services. Properly priced curb parking transforms the value of this wasted time into better public services.

Beyond telling drivers to cruise, crowded curb parking also leads drivers to double park, park in bus stops, and block fire hydrants. A study in New York found when all the legal curb spaces were occupied, reducing the legal occupancy by 5% (to 95%) led to a 50% reduction in illegal parking (Transportation Alternatives 2007). In Manhattan, when all the legal curb spaces are occupied and a tow-truck is removing a car parked at a fire hydrant, sometimes a desperate driver is waiting to claim the vacated space. The best way to prevent illegal parking is to keep a few legal spaces open.

Where double parking is a problem, curb prices that leave one or two open curb spaces per block will effectively widen the street by another traffic lane that can be used either for cars or for a bus or bike lane. For example, a study of curb parking on Santa Monica Boulevard in West Hollywood, CA, found that when the curb lane had no vacancies, double-parked cars stopping to load or unload passengers blocked a travel lane 65 percent of the time (Lu 2018).

Only a few drivers will have to change their behavior to create one or two open spaces on each block. Drivers can (1) park off-street,

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[3] The cruising distance per meter was calculated for each of the 12 metered hours and summed to yield the average cruising distance per meter of 7.7 miles per day. The average cruising distance in each hour was weighted by the number of cars that parked in that hour. Because there was a high turnover rate between 8 am and 10 am when most stores were closed and there were ample open spaces and little cruising, the weighted average cruising distance per meter of 7.7 miles per day was lower than the product of the average turnover rate (17 cars per day) and the average cruising distance (0.5 miles). See Shoup (2005, 352).

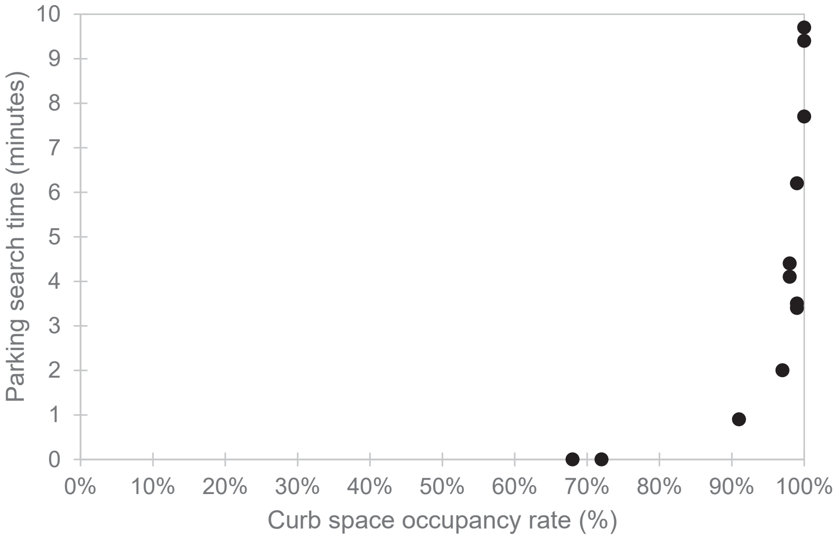

Fig. 4. Curb space occupancy and parking search time in Westwood Village. Source: Shoup (2005, 359).

(2) carpool, (3) shorten their parking duration, (4) divert some trips to off-peak hours, and (5) make more trips by public transit, cycling, or walking. A few changes by a few drivers will ensure curb parking availability and reduce traffic congestion.

4. Space, time, and money

That parking prices influence travel choices is about as debatable as gravity. In 1954, William Vickrey (who won the Nobel Prize in economics in 1996) proposed that cities should set the prices for curb parking to “keep the amount of parking down sufficiently so that there will almost always be space available for those willing to pay the fee.”

Vickrey’s simple proposal sounded outlandish and impractical in the 1950s, but demand-based parking prices are now taken seriously and modern technology makes them eminently practical. But how will on-street parking markets work? How will prices vary among spaces? How will drivers decide where to park?

If the goal is to ensure one or two open curb spaces per block, cities can set the price of curb parking to yield this result. At higher prices the curb lane will be underused, and at lower prices it will be overcrowded (Shoup 2005, Chapter 12; 2018, 21–41). This is the Goldilocks of Principle of parking prices. Prices will be higher near popular destinations and cheaper farther away.

A parking space is an intermodal facility that allows travelers to change between two travel modes—driving and walking. The optimal parking spot is the one that minimizes the total time and money cost of parking and walking. Parking closer to the destination will cost more money but will save time walking from the car to the destination and back. So how far away from their destinations will drivers park?

In Shoup (1999 and 2005, Chapter 18 and Appendix D), I presented a model of how parking prices influence drivers’ choices and have condensed it here. Consider these variables

d	the distance from a parking space to the final destination (miles)
$p(d)$	the price of parking at distance d from the final destination ($ per hour)
t	parking duration (hours)
n	number of persons in the car (persons per car)
w	walking speed between the parking space and the final destination (miles per hour)
v	value of saving time spent walking ($ per hour per person).

The *total* cost of parking at any location is the *money* cost of parking the car plus the *time* cost of walking the rest of the way to the destination and back. Fig. 5 illustrates a driver’s options. Suppose parking costs $1 an hour at the destination and declines with increasing distance from it. The driver wants to park four hours ($t = 4$), is alone in the car ($n = 1$), walks four miles an hour ($w = 4$), and values walking time saved at $8 an hour ($v = \$8$). The value of time, v, is not a generic value for all uses of time, but is specific to the driver’s time spent walking to and from the destination on a specific trip.

The money cost of parking four hours is $4 at the destination and it declines with distance from the destination (the downward

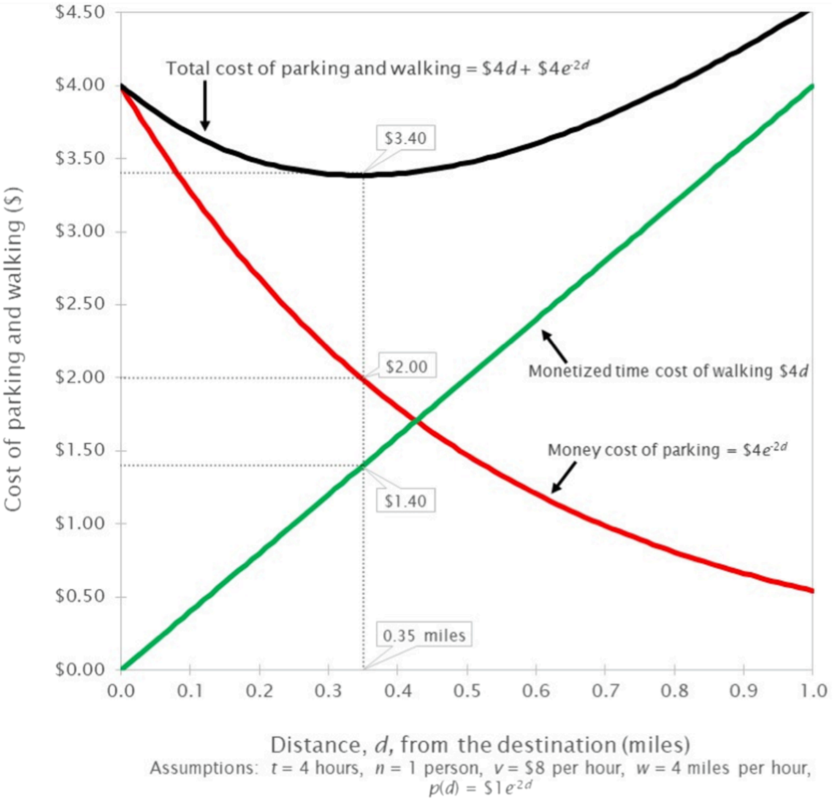

Fig. 5. The money and monetized time costs of parking as a function of distance from a destination.

sloping curve). The monetized time cost of walking ranges from zero at the destination to $4 one mile away (the upward sloping curve).[4] The sum of the parking and walking costs (the top curve) reaches its minimum value of $3.40 at 0.35 miles from the destination. Here, the money cost of parking for four hours is $2.00 and the time cost of walking is $1.40. The time to walk from the car to the destination (d/w) is 5.25 min and then another 5.25 min walking back to the car, for a total walking time of 10.5 min.

Compared to paying $4 to park at the destination, parking 0.35 miles away saves $2 on parking and costs $1.40 for 10.5 min of walking time. Parking closer doesn't save enough time to justify the extra money, while parking farther away doesn't save enough money to justify the extra time. Parking closer costs too much and parking farther away takes too long.[5]

We can also examine how the five variables—the price of parking, parking duration, number of people in the car, walking speed, and value of time spent walking—affect parking choices.

Multiplying the parking duration, t, by the price per hour, $p(d)$, gives the money cost of parking as a function of distance from the destination, $tp(d)$.

Dividing the distance walked, d, by the walking speed, w, gives walking time to the destination, d/w hours. The time for the round trip to the destination and back is $2d/w$. The value of time, v, is the price the driver is willing to pay to save time spent walking, so the monetized cost of a solo driver's time spent walking is $2vd/w$.

The total cost of walking depends on the number of people in the car, n, because everyone spends the same time walking from the car to the destination and back.[6] Multiplying the number of people in the car by the average value of their time gives a carpool's total cost of walking time, $2nvd/w$.

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[4] If the driver walks four miles an hour, walking one mile will take 0.25 h, and the round trip will take 0.5 h. If the driver values walking time saved at $8 an hour, the total cost of walking time is $4 for a parking spot one mile from the destination.

[5] This calculation neglects the driver's payment at the meter during the walking time. The Appendix includes this payment in determining the optimal parking spot.

[6] I have neglected the strategy of dropping passengers at the destination and parking farther away, so only the driver will walk.

The money cost of parking and the monetized time cost of walking are thus:

$tp(d)$	money cost of parking
$2nvd/w$	monetized time cost of walking to and from the destination

The sum of the money cost and the monetized time cost is the total cost of parking at any location.

$tp(d) + 2nvd/w$	total cost of parking and walking.

The walking distance that minimizes the total cost of money and time gives the optimal parking location. We can obtain this cost-minimizing location by differentiating the total cost with respect to *d* and setting the result equal to zero.

$$\frac{\partial[tp(d) + 2nvd/w]}{\partial d} = t\frac{\partial p}{\partial d} + \frac{2nv}{w} = 0 \tag{1}$$

$$\frac{\partial p}{\partial d} = -2nv/tw \tag{2}$$

The parking price gradient, number of persons in the car, their walking speed, the value of their time, and the parking duration determine the optimal parking spot. You can spend more money to save time by parking closer, or spend more time to save money by walking farther. The optimal parking spot balances the desire to save money (greed) with the desire to avoid walking (sloth).

The slope of the parking price gradient, $\partial p/\partial d$, governs the location choice. For example, suppose the price of curb parking is $1 an hour at your destination and declines with distance from the destination according to the negative exponential formula used to graph the price of parking in Fig. 5 (above):

$$p(d) = \$1^{e-2d} \tag{3}$$

We can find the optimal walking distance, *d**, that minimizes the total cost of parking and walking by substituting the formula for parking price as a function of distance (Equation (3)) into the formula for the minimum total cost of parking and walking (Equation (2)) and solving for d^*.

$$\frac{\partial(\$1e^{-2d})}{\partial d} = -2nv/tw \tag{4}$$

Solving Equation (4) for *d* gives the optimal walking distance, d^*.

$$d^* = -\tfrac{1}{2}log_e\left(\frac{nv}{tw}\right) \tag{5}$$

Given the prices in Equation (3), Equation (5) shows how the ratio *nv/tw* determines the optimal distance from the parking space to the destination. Fig. 6 graphs Equation (5) and shows that a higher ratio of *nv/tw* (on the horizontal axis) leads to shorter walking distance (on the vertical axis).

In the numerator of *nv/tw*, more people in the car (*n*) and a higher value of their time (*v*) will lead drivers to park closer to their

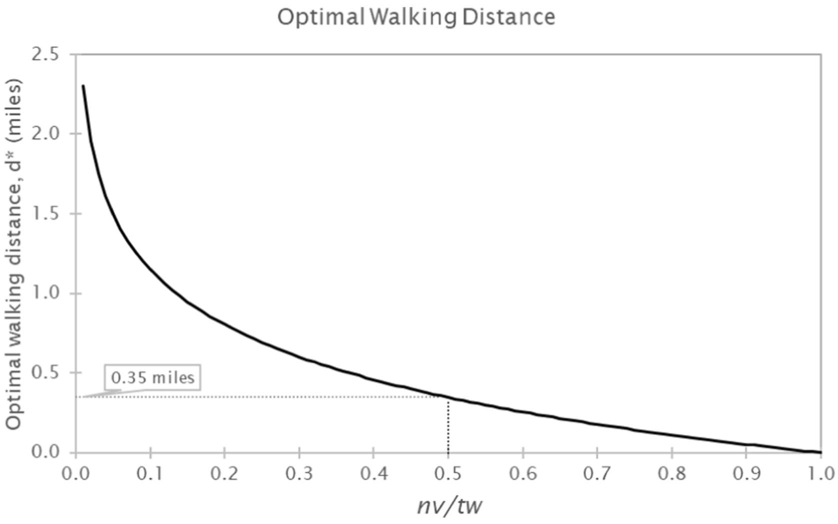

Fig. 6. The optimal walking distance as a function of *nv/tw*.

Table 3
Partial derivatives and elasticities of d^* as a function of t, w, n, and v.

Variable	Partial derivatives of d^*	Elasticity of d^*
t (parking duration)	$\frac{\partial d^*}{\partial t} = +\frac{1}{2t} > 0$	$\eta_t = +\frac{1}{2d^*} > 0$
w (walking speed)	$\frac{\partial d^*}{\partial w} = +\frac{1}{2w} > 0$	$\eta_w = +\frac{1}{2d^*} > 0$
n (number of persons)	$\frac{\partial d^*}{\partial n} = -\frac{1}{2n} < 0$	$\eta_n = -\frac{1}{2d^*} < 0$
v (value of time)	$\frac{\partial d^*}{\partial v} = -\frac{1}{2v} < 0$	$\eta_v = -\frac{1}{2d^*} < 0$

destination. In the denominator, a longer parking duration (t) and a faster walking speed (w) will lead drivers to park farther away.

As nv/tw increases, the walking distance declines until $nv/tw = 1$ and $d^* = 0$, so the driver parks right at the destination.[7] If we enter into Equation (5) the values for n, v, t, and w used to construct Fig. 4, $nv/tw = 0.5$ and the optimal walking distance d^* is 0.35 miles, the same as the distance shown in Fig. 4. If the optimal walking distance for a car trip is longer than the total trip distance, as with short trips in the neighborhood, the best choice is to walk all the way.

5. Causes and effects

The model's results are unsurprising, even obvious, but few drivers consciously consider any of the model's variables when deciding where to park. Most drivers don't think about parking until they can't find a space or have to pay for it, but when drivers do expect to pay for parking with either money or time, a model can help us understand their intuitive decisions.

How strongly do the model's variables affect how far drivers (and their passengers) will walk from their parking spots to their destinations? Given the parking prices in Equation (3), Table 3 shows the elasticity, η, of the optimal walking distance, d^*, with respect to parking duration, walking speed, number of persons in the car, and the value of time.

The derivative of d^* is positive with respect to t and w, which means you will park farther from your destination if you park longer or walk faster. The derivative of d^* is negative with respect to n and v, which means you will park closer to your destination if you have more people in the car or place a higher value on time.

Because all four elasticities are equal in absolute value, all four variables have equal effects on parking location.[8] For example, the number of people in a car is as important as the value of their time. A solo driver who values time at $20 an hour and a carpool of four persons who each value time at $5 an hour will both park the same distance from their destination, all else equal. Similarly, a two-person carpool who park eight hours will choose the same location as a solo driver who parks four hours, all else equal.

6. The value of saving travel time

The value of saving time spent walking is specific to each trip. For example, if you enjoy walking and have plenty of time, you may park a mile away. If you are in a hurry, you may park right at the destination. The same traveler can value time differently, and park differently, on different trips to the same destination.

The value of time spent walking also depends on the walk's quality. In *Walkable City Rules*, Jeff Speck (2018) wrote that, at its best, walking is simultaneously useful, comfortable, safe, and interesting. In a walkable city, drivers might not pay much to avoid walking, but where the sidewalks are dirty and unsafe, drivers might pay much more.[9]

Both average travel time and its variability are important to drivers planning their trips. Cruising for underpriced and overcrowded curb parking at the destination increases both the average travel time and its uncertainty. Where travel times are uncertain, drivers may depart early to reduce the risk of arriving late (U.S. Department of Transportation 2017). The studies in Table 2 found the average cruising time before parking ranged from 3.3 to 15.4 min, and Fig. 3 shows that the cruising time varies sharply from minute to minute. Charging market prices for curb parking will reduce both the average time it takes to find a curb space and the uncertainty of this time.

Drivers who are delayed by unexpectedly heavy traffic can spend money at the end of their trips to park closer to their destination and reduce walking time. Market prices for curb parking will serve as a buffer allowing late-arriving drivers to buy time when they need it most. Also, drivers who arrive early because of unexpectedly light traffic can park farther away and save money by spending more time walking.

How much is time worth when you are late? For example, suppose you face a high cost if you arrive late for an important appointment. To estimate the value of saving travel time in urgent situations, Bento, Roth, and Waxman (2020) used data from Los Angeles to analyze why some solo drivers pay surprisingly high tolls to use the high-occupancy lanes. They found that the urgency of travel, not the high income of drivers, explained the high prices that many drivers were willing to pay. They estimated that the urgency of travel accounted for 87 percent of total willingness to pay for time savings on the tolled lanes.

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[7] If $nv/tw > 1$, the walking distance is less than 0, which means parking at the destination.

[8] These elasticities depend on the price gradient assumed in Equation (3), and will vary according to the specific gradient.

[9] In Los Angeles even the sidewalks have potholes, and 4600 of the city's 10,750 miles of sidewalks need repair (Shoup 2010). The 2028 Olympics could use LA's broken sidewalks as an obstacle course.

Paying a toll to enter a high-occupancy lane allows desperate solo drivers to "jump the queue" and buy the time needed to meet their schedule constraints. Similarly, paying a higher parking price to save walking time at the end of a trip provides a valuable option in urgent cases. Saving time in urgent travel is yet another collateral benefit of market-priced curb parking. Despite all the research on the driving time saved by congestion prices for roads, transportation planners have ignored the walking time saved by market prices for curb parking.

7. All models are wrong but some are useful

Parking models are a good example of statistician George Box's maxim that all models are wrong but some are useful. A market-based parking model cannot predict where all drivers will park or how much they will pay, but it is useful for thinking about public policy.

This model neglects several complications. The time spent walking increases the time paid at the meter, which will shift the optimal parking location closer to the destination. Congested traffic reduces the speed and increases the vehicle operating cost of driving toward the destination, which will shift the optimal parking location farther away. The Appendix presents a more complete model that includes both of these complications in the parking decision.

The model is more mathematical than practical, but its results confirm common sense. A high price per hour is no problem if you park for a short time or split the cost among several people. A high price per hour *is* a problem if you drive solo and park for a long time. Drivers who buy time in the parking market will sort themselves out according to how long they want to stay, how many people are in the car, how fast they walk, how they value time, and many other factors that differ from one trip to another and that only individual drivers can know. Are they carrying heavy packages? Is it raining? As John Cassidy (2000, 44) wrote,

> "By allowing millions of decision-makers to respond individually to freely determined prices, the market allocates resources—labor, capital, and human ingenuity—in a manner that can't be mimicked by a central plan, however brilliant the central planner."

Or to paraphrase Pascal, parking has reasons that reason will never know.

If the price of parking increases as drivers approach their destinations, the almost gravitational pull of shorter walking times for the more convenient spaces will attract carpools, short-term parkers, slow walkers, and drivers with a high value of time. Lower prices for more distant parking spaces will lure solo drivers, long-term parkers, fast walkers, and drivers with a low value of time to park farther away. This spontaneous, self-organizing pattern of behavior will minimize the collective cost of all drivers' walking time to and from their destinations. The best individual choices will lead to the right collective choices. If cities charge market prices for curb parking, drivers (or their parking guidance systems) will do the rest of the planning.

The length of time a driver parks will probably vary much more than the other three variables. For example, a driver who parks 10 h will occupy a space 60 times longer than a driver who parks only 10 min.[10] For this reason, the most convenient and therefore more expensive parking spaces will turn over faster than the cheaper, distant spaces, and this rapid turnover of the convenient spaces will reduce the drivers' total walking time. Convenient parking spaces for quick trips will also increase the number of customers for local businesses. Popular places will have higher parking prices but no one will have to search for parking like panning for gold.

Although drivers don't use a model to decide where to park, this model's assumptions are reasonable and its predictions are testable. Suppose you are driving to a site where the price of curb parking increases as you approach your destination. Will you park closer to your destination if you intend to park for a short time? If you have passengers in the car? If you walk slowly? If you are in a hurry? If your answers are *yes*, the model correctly predicts your choices.

To create a few open spaces everywhere, parking prices need to vary and the resulting price gradients will shift throughout the day as demand shifts. The peak prices might occur in commercial districts during the day, entertainment sites during the evening, and high-density residential neighborhoods at night. Individual gradients will form around many dispersed centers, much like anthills forming on a terrain that itself has peaks (the central business districts) and flat plains (low-density neighborhoods). Parking prices at any location will rise and fall, and the local peaks will shift around like kittens fighting under a blanket.

The model assumes that prices increase regularly as drivers approach their destinations, but even if this isn't the case drivers probably consider both the money cost of parking and the time cost of walking in choosing where to park. The same four variables (parking duration, number of people in the car, walking speed, and value of time spent walking) will influence the choice of parking location. For example, if parking prices decline as you drive toward your destination, you may drive past the destination to get cheaper parking on the other side and walk back.

8. Efficiency and equity

Demand-based prices will reveal the fair market value of the curb lane. Cities will be able to compare the value of curb parking to the value of other uses, such as loading zones, bus lanes, bike lanes, wider sidewalks, or outdoor dining. The curb lane can host all these uses, but not all at once. Charging market prices for the curb lane will help city planners find the best uses for the land.

Cities can charge demand-based parking prices in loading zones. Camera technology now allows cities to charge for parking according to both the duration of parking and the length of delivery vehicles. If a 50-foot truck pays five times more per minute than a 10-

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[10] Using the responses to an internet-based questionnaire, van der Waerden, Timmermans, and de Bruin-Verhoeven (2017) found that the longer car drivers stay at a destination, the higher the probability they will walk a longer distance from the parking space to the destination.

foot cargo bike, both will pay the same price per curb foot. If delivery drivers pay for parking per minute per curb foot, electric cargo bikes may become the cheapest vehicles for short trips with small packages.

Cities can use the revenue per curb foot to identify underperforming uses and to rebalance the curb space to increase productivity and revenue. Many trucks and rideshare vehicles paying a high price per minute for short parking sessions can yield higher revenue than a few cars paying a low price per hour for long sessions. Charging the right prices for parking will also provide valuable information for managing the curb, such as who uses it, when they use it, and how they use it (Shoup, 2020). Cities can then use the data to better manage the curb, such as by re-sizing or re-timing the loading zones.

Pricing the curb to guarantee open spaces will also reduce illegal parking by commercial vehicles. In a study of Seattle's commercial loading zones, Girón-Valderrama et al. (2019) found that 40% of commercial vehicles double-parked or parked in transit lanes, tow-away zones, no-parking zones, and passenger loading zones. Making legal loading zone parking space available will reduce this illegal parking.

Demand-based prices for curb parking can also show where the city might shift a curb parking lane to a bike or bus lane. If the price of parking is low, bike and bus lanes will cost little in lost meter revenue compared to the time and money savings on safer bike rides and faster buses.

If reducing prices for curb parking when many spaces are empty is fair, increasing prices when all the spaces are full is also fair. To ensure that demand-based prices do not burden low-income residents, cities can give low-income residents a discount on curb parking, just as they give discounts on electricity and water bills. But if cities subsidize parking for low-income car owners, they should also give an equivalent subsidy to low-income residents who do not own a car and instead walk, bike, or ride public transit. The subsidy should be for people, not parking.

9. Practicality

Charging the right prices for curb parking is not only efficient in theory but also workable in practice. Planners won't get the prices right all the time, but with some practice they will probably be able to get close enough most of the time. The parking location model unrealistically assumes that drivers have perfect knowledge of parking prices and perfect foresight, but new technology now makes those assumptions more realistic.

License-plate-recognition cameras now enable flexible pricing, frictionless payments, and effective enforcement (Shoup 2005, Chapter 12; 2018, Chapters 28, 29, 36, and 37). Many drivers already pay for parking with cell-phone apps (such as ParkMobile, Passport, and RingGo) and some cars' guidance systems already come equipped with these apps on the dashboard (INRIX 2019, 2020). Drivers can use a voice command to begin paying for curb parking, and the car automatically stops paying when it leaves the curb space. If parking is priced by the minute, drivers pay only for the time they use. The on-dash technology can interpret all the city's confusing regulations and give turn-by-turn directions to the nearest available spaces (Bliss and Small 2019). In the future, the prices of all parking spaces and their availability will probably be on the web, and drivers may be able to input to their guidance systems their value of saving time for a trip, so an algorithm (as in Equation (5)) can recommend the optimal parking spot (Berg 2020). Artificial intelligence will probably make smarter parking decisions than humans do, and parking-optimizing guidance systems may be available long before anyone gets a self-driving car.

A distributed, bottom-up, driver-centered system of parking choices that takes into account each driver's information about each trip will inevitably be more practible than a centralized, top-down system for planning the optimal allocation of curb parking spaces (Mladenovic 2021).

Dashboard payments for parking may eventually become so simple, touchless, and ubiquitious that drivers will cease to think about them, as with so many other once-surprising technologies from automatic transmissions to automatic braking. Weiser (1991, 94) explained this process: "The most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it."

Can demand-based prices for curb parking work in practice? The first government study of congestion pricing, the famous Smeed Report, proposed nine essential criteria for a successful system of congestion prices (United Kingdom Ministry of Transport 1964). These criteria are also appropriate for judging a system of curb parking prices:

1. Charges should be closely related to the amount of use made of the roads.
2. It should be possible to vary prices for different roads (or areas), at different times of the day, week, or year, and for different classes of vehicle.
3. Prices should be stable and readily ascertainable by road users before they embark upon a journey.
4. Payment in advance and by credit should be possible.
5. The costs for individual road users should be accepted as fair.
6. The system should be simple for road users to understand.
7. The equipment for charging should possess a high degree of reliability.
8. The system should be reasonably free from the possibility of fraud and evasion, both deliberate and unintentional.
9. The system should be capable of being applied, if necessary, to the whole country.

Demand-based parking prices can satisfy these nine criteria. The necessary technology is already available and some cities are using it. In 2011, San Francisco began charging demand-based prices at 7,000 parking meters (Pierce and Shoup, 2013). Each block has different prices during three periods of the day (before noon, from noon to 3 p.m., and after 3 p.m.). In 2018, the program expanded to all 28,000 meters citywide. San Francisco was the first city to apply this principle for pricing curb parking and SFMTA (2019) explains the successful results. Several other cities—Boston, Los Angeles, Seattle, and Washington, D.C.—also vary prices according to time of day and location to balance supply and demand for curb parking across time and space.

Pickrell (2018) argued that the only truly nonrenewable resource is time. Demand-priced curb parking that eliminates cruising will transform the nonrenewable resource of time formerly spent cruising into public revenue and public services. And if on-street spaces are always available everywhere, cities will no longer have to require off-street parking spaces everywhere. All things considered, market-priced parking will be much cheaper than free parking.

10. What happens at the curb doesn't stay at the curb

Market-priced curb parking will allow drivers to choose the best parking space for each trip. In contrast, free curb parking forces drivers to compete for scarce curb spaces by spending time cruising. The lack of an open curb space may seem trivial, but the long chain of emergent consequences exemplifies the butterfly effect, a term coined by meteorologist Edward Lorenz to explain how a small event (a butterfly flapping its wings) can have big effects (a tornado). As UCLA's legendary basketball coach John Wooden put it, "Little things make big things happen."

Underpriced curb spaces lead to curb parking shortages, which lead to demands for off-street parking requirements, which spread the city apart to make room for parked cars, and cars become necessary because the city is spread apart. The more parking cities require for cars, the greater the need for cars, and hence the need to require still more parking. Traffic makes walking and biking less pleasant, congestion slows public transit, and most parking is free, so cars become the default way to travel. More driving pollutes the air and accelerates global warming. Few people will connect any of this accumulating disaster to mismanaged curb parking, but failing to charge market prices for curb parking can produce catastrophic consequences downstream.

By the same reasoning, charging market prices for curb parking will produce a cascade of benefits throughout the city, the economy, and the environment. Open curb spaces will eliminate cruising, increase the reliability of travel times, and reduce the demand for off-street parking requirements. Removing parking requirements will reduce the cost of everything except parking. Infill development on parking lots will make housing more affordable and the city more walkable. All these changes will reduce vehicle travel, fuel consumption, and air pollution. Open curb parking spaces are not merely a convenience for drivers.

The benefits of market-priced curb parking will extend well beyond transportation and the environment. As transportation improves, the city's total productivity will increase because businesses will become more efficient (Sickles and Zelenyuk 2019). Businesses will be less hampered by parking shortages and traffic congestion that delay deliveries and all other business travel (Dalla Chiara and Goodchild 2020). These productivity gains will be hard to measure, and few people will connect them to a few open curb spaces, but the connections are inevitable.

11. Conclusion: let prices do the planning

Curb parking will not be well used until it is well priced. Where curb parking is underpriced, cruising is individually rational but collectively insane. Cruising for parking is one of those cases where, as Philip Goodwin (1997, 2) put it, "Adam Smith's individuals pursuing their own best interests do not add up to Jeremy Bentham's greatest good for the greatest number." Market-priced curb parking will give Adam Smith's invisible hand a green thumb, rational individual choices will add up to sane collective results, and 30% of traffic won't be cruising for parking.

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Appendix. Driving, parking, and walking

The model presented above ignores two factors. First, drivers travel to spend time at the destination, not to spend time parking. Therefore, t can be re-defined as the time spent at the destination, not the time spent at the meter. The parking duration is longer than t because the driver pays at the meter during the time walking to and from the destination. Therefore, the total payment at the meter is the sum of the meter payment for the time spent at the destination plus the meter payment during the time spent walking to and from the destination. Second, drivers should consider the time cost and vehicle operating cost as they drive toward the destination. In congested traffic, the high time cost of driving will lead drivers to park earlier and walk farther.

To incorporate these two factors into the calculation, consider the following variables (and their dimensions).

a	vehicle operating cost ($ per mile)
s	vehicle speed (miles per hour)
D	distance from the origin to the destination of a trip (miles)
d	distance from a parking space to the destination (miles)
$p(d)$	price of parking at distance d from the destination ($ per hour)
t	time spent at the destination (hours)
n	number of people in the car (persons per car)
w	walking speed (miles per hour)
v	value of time spent driving and walking ($ per hour per person).

The total cost of an automobile trip is the cost of driving, parking, and walking. At distance *d* from the final destination the money cost of driving and parking, and the (monetized) time cost of driving and walking are:

$2a(D-d)$ money cost of driving from the trip origin to the parking space (1)

$2nv(D-d)/s$ monetized time cost from the trip origin to the parking space (2)

$tp(d)$ money cost at the meter for time spent at the destination (3)

$[2d/w]p(d)$ money cost at the meter for time spent walking (4)

$2nvd/w$ monetized time cost of walking to and from the destination (5)

The total cost for the trip is thus:

$$2a(D-d)+2nv(D-d)/s+tp(d)+[2d/w]p(d)+2nvd/w \tag{6}$$

Differentiating Equation (6) with respect to *d* and setting the result equal to zero gives the distance between the parking space and the final destination that minimizes the total cost:

$$-2a-\frac{2nv}{s}+t\frac{\partial p}{\partial d}+\left[\frac{2d}{w}\right]\frac{\partial p}{\partial d}+[2/w]p(d)+2nv/w=0 \tag{7}$$

$$\left[t+\frac{2d}{w}\right]\frac{\partial p}{\partial d}+[2/w]p(d)=-2nv/w+2a+2nv/s \tag{8}$$

If drivers pay at the meter for the time they spend walking, and consider the vehicle cost and speed of driving toward their destination, the optimal parking spot depends on both the price of parking and the price gradient at the parking space. A high price at the spot suggests parking closer to the destination to save money while walking. A steep price gradient at the spot, however, suggests parking farther away where parking is substantially cheaper. Depending on the price and the price gradient at the spot, the result can be either a shorter or longer walk than when drivers ignore paying at the meter while walking. A lower vehicle speed and a higher vehicle operating cost suggest parking farther away.

If the walking speed, *w,* is high, the walking distance, *d,* is short, the price of parking at the spot, *p*(*d*), is low, the vehicle operating cost, *a,* is low, and the vehicle speed, *s*, is high, the solution for d^* approaches:

$$\frac{\partial p}{\partial d}=-2nv/tw \tag{9}$$

This result was found above in the model that ignored time and money cost of driving and the money cost of parking while walking to the destination.

Further complications can be considered. The value of saving time may differ between driving and walking. The value of saving time may increase with the distance walked. And the independent variables in the model are not exogenous. For example, parking prices will affect the parking duration and the number of persons in a car. A more complete but hopelessly complicated model would include these and many other interactions. The law of diminishing returns for mathematizing the parking decision, however, suggests leaving these refinements for another day when artificial intelligence can choose the best parking spot.

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