Too expensive to meter: The influence of transaction costs in transportation and communication

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Preliminary version, February 28, 2007

Abstract. Technology appears to be making fine-scale charging (as in tolls on roads that depend on time of day or even on current and anticipated levels of congestion) increasingly feasible. And such charging appears to be increasingly desirable, as traffic on roads continues to grow, and costs and public opposition limit new construction. Similar incentives towards fine-scale charging also appear to be operating in communications and other areas, such as electricity usage. Standard economic theory supports such measures, and technology is being developed and deployed to implement them. But their spread is not very rapid, and prospects for the future are uncertain.

This paper presents a collection of sketches, some from ancient history, some from current developments, that illustrate the costs that charging imposes. Some of those costs are explicit (in terms of the monetary costs to users, and the costs of implementing the charging mechanisms). Others are implicit, such as the time or the mental processing costs of users. These argue that the case for fine-scale charging is not unambiguous, and that in many cases may be inappropriate.

1 Introduction

Lewis L. Strauss, the Chairman of the U.S. Atomic Energy Commission, is often remembered for a famous 1954 claim [63], made in the optimistic days of nuclear power:

> Our children will enjoy in their homes electrical energy too cheap to meter, ... It is not too much to expect that our children will know of great periodic regional famines in the world only as matters of history, will travel effortlessly over the seas and under them and through the air with a minimum of danger and at great speeds, and will experience a lifespan far longer than ours, as disease yields and man comes to understand what causes him to age.

Strauss' expression "too cheap to meter" has entered the lexicon as a catch-phrase for technological promises that have gone unfulfilled. Electricity continues to be paid for roughly in proportion to usage. The cost of electricity is not so low, nor the cost of metering it so high, that the purveyors of electric power have chosen to forgo charging by use. The alternative, either "free" service, or a fixed price for unlimited (unmetered) use has not come to pass in the electricity sector. Just the opposite appears to be happening. There are increasing attempts to deploy "smart meters" that will charge different prices, depending either on time of day, or, in even more sophisticated versions, depending on the level of electricity consumption in the system. In spite of continuing substantial progress in electric power generation technology, overall costs are, if anything, increasing, as fuel prices rise, and there is intense public opposition to building more power plants and transmission systems, as well as concern about pollution and fuel depletion, etc. Hence attention is paid to methods that either reduce electricity consumption, or at least shift it away from periods of high loads (as running clothes dryers at night does). Improved sensor, computing, and communication technologies make it possible to implement sophisticated schemes that were unthinkable until recently, and which promise to optimize various criteria, as determined by economic models.

Similar attempts to implement fine-scale charging are apparent in other areas. This paper explores the history of the cost of charging for use for several different transportation and communication services, and its consequences. It is not a comprehensive survey, but it does provide information that is not easily accessible in any single source. The emphasis is on the explicit costs of the charging mechanism (which are often surprisingly high, even in modern electronic toll collection system) as well as on the implicit costs imposed on users (such as their time, or their mental processing costs). This often leads to counterintuitive incentives im charging.

There is a trade-off between the benefits of metering (charging per use) and its costs. The benefits depend upon the cost structure of the underlying transportation and communication technology, while the costs depend on the cost structure of the revenue collection technology and on the burden it imposes on users.

Individual transportation and communication technologies differ. Transportation, especially the road sector, is wrought with substantial negative externalities, most notably congestion, and it is politically difficult, monetarily expensive, and time-consuming to add capacity. Communication tends to be at the other end of the spectrum, with costs of increasing capacity often low, and not objectionable to the public. Furthermore, in many cases service providers have strong incentives to increase usage.

This paper begins with an overview of relevant economic theory. Then several vignettes are presented that describe the experience with pricing of different technologies (turnpikes and toll roads, the London Underground, lighthouses, Internet).

A discussion and conclusion ties these together, suggesting a broader and non-ideological consideration of financing network infrastructure that depends upon the underlying technology.

2 Economic Theory

2.1 Type of good

Economics defines four types of good based on whether a good is excludable and whether it is rivalrous. Goods that are both excludable (the provider can charge the user for it directly) and rivalrous (one user prevents another) are called *private*, while goods that are neither excludable nor rivalrous are *public*, the classic example of which is national defense.[1] The difficulty in drawing analogies is that many technologies fall into all four boxes, the example of different types of roads having different attributes is shown in Table 1.

TABLE 1:

	Excludable	*Not Excludable*
Rivalrous	Private (e.g. congesting limited access highway)	Congesting (e.g. congested city street)
Not Rivalrous	Club (e.g. roads within a gated subdivision)	Public (e.g. uncongested city street)

To illustrate the concept, road financing differs by category. In much of the world, intercity limited access highways (freeways, motorways) are paid for with tolls charged to users. These roads are excludable, in that it is easy limit entry at on-ramps (e.g. to those who pay a toll), and they are rivalrous, at least part of the time, in that too many users result in congestion. They are thus *private goods*, though of course, many similarly structured roads are not charged for at all, and are financed as if they were public goods through general revenue, or club goods, through a gas tax assessed on club members (drivers).

Second, in many places, local streets are built by developers, and in some cases are maintained by local homeowners associations, who tax themselves for the privilege. This follows the case of *club goods* quite closely. Congestion on neighborhood streets is not common, so they are not rivalrous, but there are only a few entry points (what might be termed *hard exclusion*), and the speeds are rather slow, discouraging through traffic (what might be termed *soft exclusion*).

In the US, city streets are paid for with a combination of local property taxes and state gas taxes. In general it is difficult to exclude users from many streets because of the large number of entry and exit points. Yet many city streets face congestion, and so are rivalrous *congesting goods*, while others are not, making them classic *public goods*. The example of the London Congestion Charge to be discussed later is an exception that proves the rule.

State roads and *free* interstate highways are paid for by state and federal gas taxes. Homeowners are often responsible for the cost of sidewalks, and are certainly responsible for their maintenance (snow removal in winter) despite their being public property. This harkens back to the way many roads were *financed*; the road was simply a right of passage across private property, and was the obligation of the property owner to maintain [36].

2.2 Fixed and variable cost

In part the issues of the type of good, and perhaps the natural way of financing that good lies with the structure of the cost function associated with producing it.

The total cost of production generally includes a fixed cost and variable costs. The fixed cost of a road to serve one car is the same as that to serve one-hundred cars. The variable cost differs, particularly if congestion sets in. Combining the declining average (or per user) fixed cost component and the rising variable cost component gives a *U-shaped* curve as shown in Figure 1.

We graph these two processes in Figure 1. The construction costs per user drop with additional users, but congestion costs per user rises. In this example, construction costs are $1,000,000 per year (the cost is annualized), while congestion costs follow the classic Bureau of Public Roads (1964) equation which is widely used in traffic assignment procedures to non-dynamically approximate queueing on links.

$$T = 0.15\,(V/C)^4$$

where T is travel time, V is vehicles per hour, and C is capacity, assumed to be 2000 vehicles per hour. [2]

The cost of collecting revenue to pay for the road has a similarly U-shaped function. A revenue collection infrastructure has both fixed and variable costs. Each technology of revenue collection will vary in the relative share of fixed and variable components. Some technologies will have a high fixed cost and lower variable costs, others the reverse. Further, some will be able to be spatially and temporally specific, others only suitable for relatively crude identification of use in space or time.

2.3 Price discrimination

The standard conclusion of conventional economics when applied to physical goods has been that the maximal benefit is obtained with price equals marginal cost. But that does not work well when marginal costs decrease with volume (the left side of the U-shaped cost curve). This happens frequently with information goods, and also with many communication technologies and uncongested transportation facilities. In those situation marginal cost pricing does not recover costs, and sellers have increased incentives to price discriminate, namely to charge prices that differ across different customers, depending on those customers' willingness and ability to pay. The theory of differential pricing and its benefits to the economy have been understood since the middle of the 19th century. At that time railroads were the revolutionary new technology, and their very high fixed costs and relatively low marginal costs drove them to pricing schemes that led the theorists to explore and explain what was happening [16]. However, differential pricing is much older than railroads. The paper [51] presents many examples from postal services, canals, lighthouses, and other industries, where price discrimination played an important role. It was common for tolls on canals or river navigation projects to vary dramatically depending on the nature of the cargo. For example, in the middle of the 18th century, iron and lead tolls on the Beverley Beck navigation were six times higher than those for sand, even though the wear

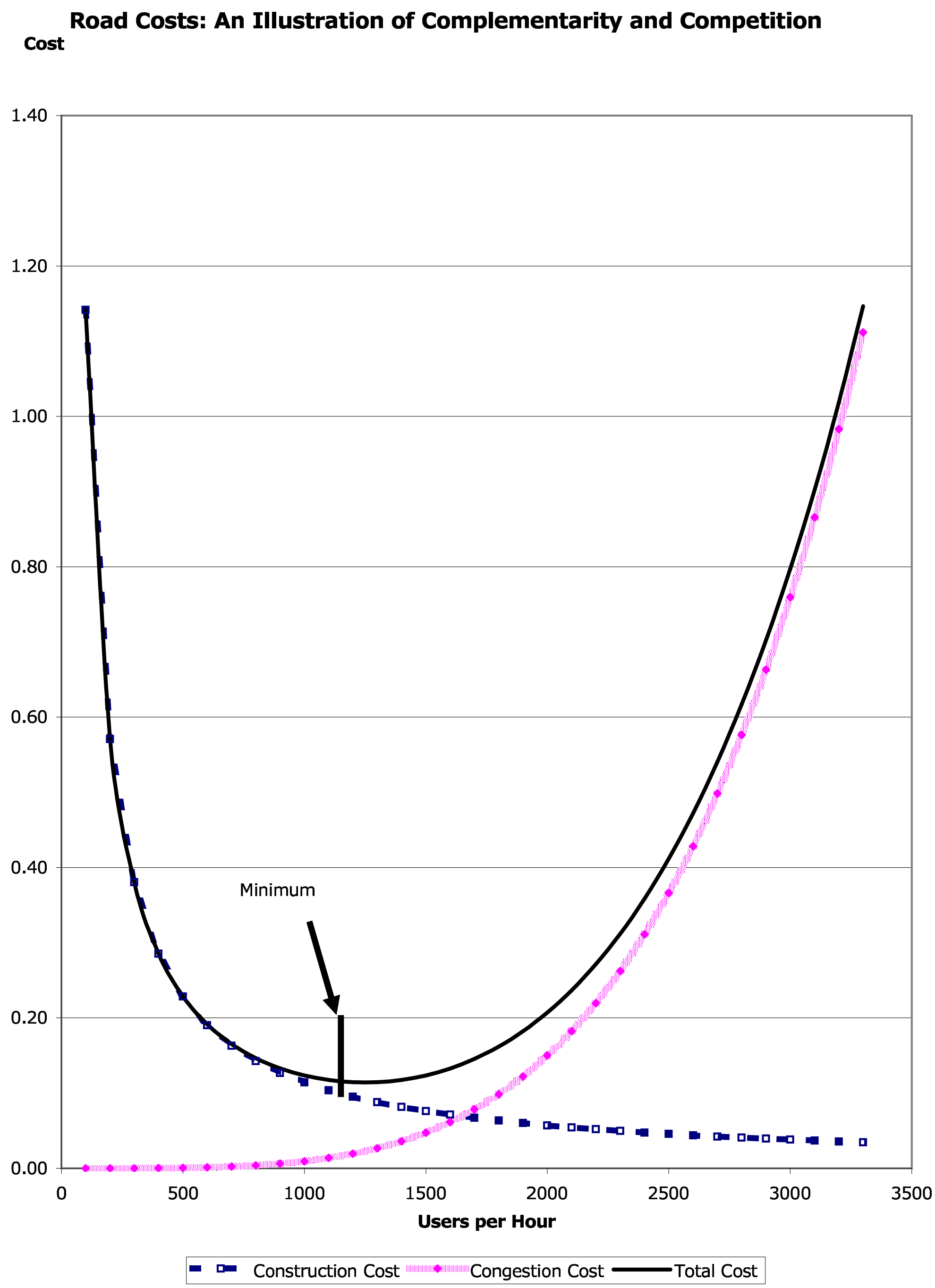

Fig. 1. Fixed and variable costs of a network.

and tear they caused were the same [51]. Also, the strikingly high distance-based differentials in early postal charges were not reflections of costs (as was first demonstrated by Rowland Hill in the 1830s in making the case for the Penny Post reform of 1840 [46]), but were a reflection of the higher value of long distance communication. In some cases tolls varied not only according to the nature of the cargo, but even according to the intended usage of that cargo (so that coal for export might pay less than coal for domestic use). Many further examples of discriminatory pricing are presented in [46, 47, 51]. Thus from the historical standpoint, the attempt to avoid *net neutrality* is not unprecedented.

A major reason for this discussion of price discrimination is that it is often the main reason behind pricing and architectural decisions taken by service providers. However, this is often carefully concealed and denied even when fairly obvious. While price discrimination is in many ways the Holy Grail of commerce, as it leads to maximal profit, it is a practice that arouses strong opposition [50]. It was price discrimination by railroads that brought the first serious federal regulation of commerce in the U.S. And historically, differential pricing has almost always been controlled in transportation and communication. Such control is at the root of common carriage. Even the canal and railroad charters that authorized differential charges almost always had very strong restrictions on price discrimination. It was common to require that all users be charged the same, that charges be based on distance alone, and, especially in early years of canals and railroads, structural separation was enforced in that canals and railroads were commonly forbidden to be carriers. This historical tradition of resistance to differential pricing likely explains why it is seldom acknowledged.

2.4 Flat rate preferences and stimulation of usage

Popular resistance to price discrimination has often been reflected in legislative and regulatory constraints on the practice. But consumer resistance to such practices, as well as to fine-scale charging in general, also arises in more market-oriented ways. One of them is through a marked preference for flat rates. It turns out that people are often willing to pay more for simple pricing. Although there have been numerous cases of this phenomena over the ages, they tended to be regarded as irrational aberrations.

A collection of historical examples of the preference for flat rates is presented in [46, 47]. The first systematic studies that explored the reasons for such consumer behavior appear to have been carried out at AT&T in the 1970s, when that company tried introducing metered rates for local telephone calling in the U.S. (where most residential users had had flat rates plans). What AT&T found is that the vast majority of even the very light users, who would unquestionably have benefited from metered rates, preferred to stick with flat rates. The careful studies that were done at Bell Labs in response are summarized in [67] and in some further papers referenced in [43]. Three main reasons for this flat rate preference were identified. One was the insurance effect (even if usage is low now, it might spike up as a result of some unforeseen circumstance), another was a systematic overestimate of usage (which made flat rates appear more economical than they were), and the third was a harder to characterize hassle factor. Nick Szabo [64] coined the nice term “mental transaction costs” for this third factor, people’s unwillingness to be bothered with fine-grained pricing. (Szabo's work was not related to telecom, and was in the context of evaluating the prospects of micropayment schemes. He correctly concluded, in parallel with [42], see [49] for more recent evaluations, that these technologies were not likely to succeed.)

Over the last few years, researchers in behavioral economics and marketing have also produced a series of studies of consumers' willingness to pay extra for flat rate. A recent survey is available in [32]. (However, those researchers appear not to be aware of the earlier AT&T studies described in [43, 67].)

It should be noted that flat rates can be shown to be advantageous to sellers under some conditions even in the conventional economic model, where preferences for flat rates among customers don't exist. They are a form of bundling, and so provide a way to take advantage of uneven preferences for various pieces or transactions among users [42, 43].

While there is a growing literature on the preference for flat rates, there is yet another factor that is very important, but has not been studied systematically. That is the strong impetus that flat rates tend to give to usage. A collection of vignettes is presented in [46, 47] which show that it is very common for people, when their pricing plan changes from a metered to a flat rate one, to increase their usage by between 50 and 200 percent. In many situations this is of course undesirable. But in many others service providers do have incentives to increase usage. This is very common in communications, but even in transportation, as we will see later.

Even some of the industries that today have strong incentives to decrease usage have sometimes been in a different regime. For example, the electric power industry at the end of the 19th and beginning of the 20th century had high economies of scale and decreasing marginal costs. And even though electric utilities were local monopolies, they were surprisingly enterprising and inventive in stimulating usage. In particular, they sought and succeeded in creating heterogeneous demands (for residential, office, factory, street car, and other uses) that had peaks at different times of the day, so as to result in more complete utilization of the expensive fixed generation and distribution system. For details, see [28]. (They did charge for usage, but in the early days often on a flat-rate basis, for each light outlet, for example.)

3 Turnpikes and Toll Roads

3.1 Traditional turnpikes

The word "turnpike" comes from the technology used to enforce "excludability", a pike laid across the road which would not be lifted until the traveler paid his toll. In England, turnpikes were deployed in the 18th and early 19th century. They helped make the British inland transport system among the best in Europe, whereas before it had been regarded as extremely backwards. For a historical perspective, see [31, 54], and for recent studies showing with modern quantitative methods that turnpikes advanced the British economy, see [4–6].

English turnpikes were a response to the conflict between the growing needs for better transport of a developing although still pre-industrial economy and the inadequacy of the traditional system that forced local inhabitants to devote several days per year to uncompensated labor on roads. Turnpikes were an improvement, but not a very satisfactory one. There were a variety of concerns (such as about making the *King's Highway* no longer be open to all, and barring the poor) which led to concessions such as the use of ostensibly non-profit trusts to operate the turnpikes, and allowing pedestrians and certain users free passage. Still, there were repeated riots (including the famous *Rebecca* riots in Wales in the early 1840s), and constant complaints about inefficiency and fraud. As just one example, Adam Smith in *The Wealth of Nations,* Book V, Chapter I, complained that

> At many turnpikes, it has been said, the money levied is more than double of what is necessary for executing, in the completest manner, the work, which is often executed in a very slovenly manner, and sometimes not executed at all.

Smith's main concern appeared to be about inefficiency. The book [31] discusses that, and the frequent abuses, such as inflated payrolls and outright evasion or theft of tolls. Statute books of the period were full of sanctions and prescriptions. For example, toll collection was often let for a fixed annual fee (through prescribed auction processes, which, however, were often subverted through collusion). This was supposed to avoid the fraud practiced by toll collectors, but of course only moved the enforcement issue into the private sector, where the winning bidder had the same issue of making sure proper payment was delivered. In the end, turnpikes were phased out in the second half of the 19th century, and replaced by open public roads. For us, it is worth noting that many of the complaints about turnpikes were about the non-monetary costs to travellers (such as the delays and inconvenience of toll collection). And it was quite common for travellers to negotiate flat rate annual contracts [31].

It is also worth noting that while turnpikes were being abolished, there were even proposals for making railroads free, as in [13]. These were not taken seriously, but a variety of season passes were introduced and are still in use. (In 2005/06, 26 percent of National Rail receipts in Great Britain came from season tickets [**?**].)

It is understandable that the old turnpikes were expensive to operate. Even disregarding fraud and inefficiency, the need to staff many toll-collection stations was bound to produce high collection costs. What is amusing is that many of the modern electronic toll collection systems that benefit from modern technologies are also very expensive.

3.2 Toll collection technology

Electronic toll collection (ETC) systems are now common on many toll roads, made possible by a variety of automatic vehicle identification (AVI) technologies. On toll roads, ETC increases toll lane capacity, thereby reducing toll processing time and queue lengths at toll plazas. Thus both delays and the number of toll-takers are reduced. The most advanced open-road ETC can identify vehicles at full speed, reducing vehicle delay due to toll collection to zero, from a time of 10-15 seconds associated with paying at a toll-booth, and eliminating the concomitant queueing when demand exceeded the available capacity of manual toll-booths.[3]. Further by reducing delays, ETC increases throughput per lane, from

350-400 vehicles per lane through a toll lane with manual collection up to 2200 vehicles per lane.

Prior to the advent of ETC turnpikes in New York and Pennsylvania lost between 14 percent and 19 percent of revenue collected to collection costs using then-current (labor-intensive) technology [23]. This compares with 9.31 percent found on California's bridges, with the highest efficiency on the most heavily traveled San Francisco to Oakland Bay Bridge. When tolls doubled on California bridges in 1998, the cost of collection relative to revenues collected was halved (aside from additional delays due to the need to give change) so there is no reason to expect these percentages to remain stable as tolls vary.

Even with the adoption of ETC on conventional toll roads, when those roads remain embedded in a network of untolled "free" roads, many users will not adopt ETC. Finkelstein [21] notes an equilibrium market saturation of about 60 percent. As a consequence, manual toll collection still has environmental consequences associated with deceleration and acceleration, and remains economically less efficient than other means of collecting revenue. [55], [56]

Philip and Schramm [57] have shown that ETC can reduce the cost of staffing toll booths by 43.1 percent, money handling by 9.6 percent, and roadway maintenance by 14.4 percent. Mitretek Systems [33] for the Oklahoma Turnpike System reports that the annual cost to operate an automated lane in the Oklahoma Turnpike System is only $15,800 while the annual cost to operate an attended lane is $176,000.

ETC has led to a modest resurgence in the use of tolling as a finance mechanism, increasing from 5.1 percent of total revenue in 1995 to 5.7 percent in 2005. [20], [19] The number of tollroads currently being planned in the US comprises 656 km costing an estimated $6.7 billion. [18] This is a significant number, but pales in contrast with the 40,000 km of largely gas tax-financed interstate highway already built. While some suggest a tipping point in the construction of new toll roads [53], it is important to note a number of roads were disturnpiked over this period, for instance tolls were removed from the Kentucky Turnpike system. Further, as pointed out by Amy Finkelstein (2007) [21], the reduction in the salience of the electronically collected toll allows agencies to increase tolls beyond what they may have been able to do were the out-of-pocket charge felt directly.

One of the advantages of electronic tolling is the ability to impose dynamic or variable tolls, which change by time of day or level of congestion, but as of 2006, only 29 facilities worldwide had done so [9], suggesting the prime motivator to moving toward electronic tolls is the reduction of transaction costs for the producer, and perhaps the ability to raise tolls with fewer complaints rather than improved system management.

A few places have seen congestion charging imposed primarily for traffic (or environmental) management, rather than as a way to pay for the bonds floated for the construction or to enrich investors. Notably, congestion charges have been imposed in Singapore [39], London and Stockholm [1], which after a six month trial in 2006 was then approved by voters in the city (though rejected by those in the suburbs) and implemented by the government. One of the key criticisms of the London scheme has been its high collection costs. The London Congestion Charge, which now charges the vehicle owner £8 per day to travel in the center of London, before the recent toll increase (from £5) had enforcement and collection costs of about 67 percent of operating revenue [27], which compares with a less than 1 percent collection cost loss associated with gas taxes [66]. Prodhomme and Bocarejo [59] conduct a thorough, though controversial, analysis arguing that while the scheme may be a political and technical success it is an economic failure because of its high toll collection costs. The authors estimate the revenue collected from tolls as 2.5 times as large as the benefits. Mackie [38], critiquing their study, notes their findings as ironic, since the main fear about implementing congestion pricing was that it would be an economic success but political failure. Transport for London admits “Scheme operating and other costs” at £5 million for TfL administration, £85 million for TfL contractors, and £20 million for extra buses, totaling £110 million. [37] The agency however claims benefits of £230 million, of which £30 million are lost to compliance costs on the part of the travelers. It might further be noted that since the introduction of the congestion charge, parking revenue in central London dropped (due to the reduced demand) [2]. The same revenue could have been raised much less expensively (and much of the same effect achieved) through the relatively efficient means of taxing parking revenue and charging for parking spaces, though that would not capture through traffic.

Another use of ETC has been the conversion of carpool (high occupancy vehicle) lanes to high occupancy/toll (or HOT) lanes, allowing non-carpool traffic to buy into the excess capacity on the carpool lanes. In the US this has occurred at five locations, one of them in Minneapolis on I-394. While again generally heralded as a success, the MnPass HOT Lanes in the Twin Cities does not recover system operating costs after more than a year operation [40], though this is promised shortly, and may never recover capital costs of investing in the additional infrastructure required to implement the system. Whether the congestion reduction benefits, or the gains from sorting drivers who have different values of time or values of reliability outweigh those capital costs is not yet known.

The question arises as to why tolls would be preferred to taxes to pay for the construction and maintenance of roads, given their high collection costs, especially when congestion pricing of some sort is not the prime motivator. A number of reasons have been given, though Levinson (2002) [36] poses this as a question of the ability to tax-export. Without excludability, roads may be used by both local and through traffic. If the through traffic comprises a significant portion of the total traffic, the economic free riding problem is quite severe. This has several consequences. The incentives for locals to pay for the road are diminished, and there is a welfare loss associated with underprovision of infrastructure. There is also overconsumption of local roads by non-residents who are not charged for their use. Underprovision and overconsumption naturally lead to poor quality. This poor quality of roads was seen prior to the imposition of turnpikes in the late 17th and 18th centuries in England. Bogart shows that turnpike trusts did increase investment, and did not simply replace expenditures of local (parish) government in England [4].

In contrast, with tolls placed at borders, locals can offload a disproportionate share of road costs on non-residents, tax-exporting in a sense, and meeting the Monty Python test for an ideal tax: “taxing foreigners living abroad” [10] . Levinson shows that states in the USA with more non-resident travel (typically smaller states in the northeast part of the

United States) are more reliant on tolls than larger states with a higher proportion of local traffic [35].

4 Public Transport in London

Shillibeer's Omnibus, starting in 1829 the first regular bus transportation in central London, marketed fares of one shilling, quite expensive for the day. [4] Bus is distinguished from coaches, which were then common, by their ability to pick up and put down passengers anywhere along the route, in contrast to delivering passengers from a fixed origin(s) to a fixed destination(s) on a scheduled service.

Omnibuses competed with Hansom cabs for business, especially after the "stones", the paved area of London, was opened up for bus traffic. Some cab operators increased the size of their vehicles. One example from 1849 is Harvey's Curricle Tribus, which could seat three passengers in a cab design, and also had a conductor to collect fares in addition to a driver, clearly increasing transaction costs for the provider, though perhaps speeding the journey for passengers if this transaction could take place while the vehicle was in motion. [60] Whether the conductor was their for efficiency of the passengers, or because of lack of trust on part of the vehicle owner is unclear.

The Central Line, opening in 1900 advertised itself as "The Twopenny Tube" in recognition of its flat fare (in contrast with the convoluted fare structures present on other rail lines, and still present on surface rail systems in England today).[5]

Paying fares for transit was historically quite common, in large part because these public transport systems were private, for-profit enterprises. The costs of collection were not insignificant, the job of the conductor was to collect and enforce fares, though their presence may have had other positive effects on passenger behavior and aided in the maintenance of capital. On a vehicle like a bus or electric tram, the presence of a conductor, who in 1900 was paid 4 shillings and sixpence daily[6], almost as much as a driver's 5 shillings per day [26], could nearly double labour costs. Labour was a considerable cost associated with service provision, more so on buses than trams, which had higher capital costs, but could in principle carry more passengers per driver.

On the Underground, costs associated with ticket-taking were significant. For instance, the 1926 report of London's Hammersmith and City Line has "Ticket Collectors, Policeman, and Porters, &c" as costing £12,045 [7] out of £29,333 of traffic expenses and compared with £85,637 of passenger receipts [24]. "Printing, Advertising, Stationery, Stamps, and Tickets" was another £868, all this for a system under 3 miles in length.

As noted previously, if we believe that there are increasing marginal costs associated with use, charging fares will appropriately match demand with supply, this is the case e.g. with congested buses in the peak period. However, if we are on the left side of the U-shaped cost curve, charging fares still discourages demand, but as there are no added marginal costs with the extra passenger, this reduces total welfare. Many transit systems in the early 21st century are in this situation, at least some of the time. In response, many agencies sell "season passes" under various guises (e.g. university 'U-passes', allowing students and faculty unlimited access to a transit system for a reduced free) to encourage use. Since the pass has a one-time cost, the marginal cost for travel from the perspective of the traveler who has purchased one is zero, making the traveler more inclined to use the system. From the point of view of the operator, this increases certainty in the revenue stream, provides access to capital in advance, and increases utilization, while reducing the number of required transactions and thus transaction costs. From a societal point-of-view, this may reduce car ownership. [3] Season tickets in Zurich increased bus passenger trips by 4.5 percent, while in other Swiss cities, the increase was as large as 16 percent [22].

Season tickets in London for unlimited use of bus cost users £560 per year, and for unlimited use of tube for zones 1 and 2 (central London) cost £928. A single bus fare using an Oyster card is £1, and for tube from zone 2 to zone 1 in peak is £2. Thus for a season ticket to be worthwhile, someone needs to make 560 one-way bus trips per year (or about 1.5 per day, including weekends), and for the tube pass to be worthwhile the user needs to make 1.8 peak period trips per weekday. Whether this is economical depends on the user.

Possessing such a pass increases usage, as the marginal cost of use once in possession of a pass drops from £1 or 2 each way to ”free”. London has seen a major increase in public transport utilization overall, with season ticket usage growing faster than ordinary payment, as shown in Figure 2. Between 1995 and 2005, bus ridership in London increased 40 percent. [41] The Travelcard, allowing integrated daily (or weekly) use of all public transport in London was introduced in 1981. London Transport claimed the introduction of the Travelcard resulted in an increase of underground passenger-miles of 33 percent over the course of the decade between 1982 and 1991 [58], though there were other conflating factors.

Many newer light rail systems (and a number of older Tram systems, such as in Zurich) don't aim to check every passenger boarding to ensure payment, and instead couple an honour system with random enforcement. The risk with such a system is increased fare evasion, especially if the probability of being caught multiplied by the expected fine is below the cost of fare, and thus lowered revenue; the advantage is lowered costs. It is an empirical and site-specific question as to whether that trade-off is worthwhile. A system with fare machines at the entrance and exit, such as the London Underground, with fewer than 300 inspectors for 2.5 million daily passengers, attains fare evasion rates on the order of 2 percent.[8][11] . In contrast, light rail systems without enforcement estimate evasion rates that range from 1.7 percent in Salt Lake City, Utah to 4.7 percent in Denver, Colorado (which has 10 inspectors and 60,000 daily trips). [34] [9].

Other cities, including Seattle and Portland, have adopted fare free zones for transit in their city centers, and some cities have made transit free city-wide, eliminating transaction and enforcement costs entirely, and paying for the system as a public service out of parking fees or general revenue.

5 Lighthouses

Lighthouses, unlike the other technologies that are link and node based, can be thought of as points (or the light they spread as areas). They are interesting to consider, in that unlike roads or rails, say, they have literally zero marginal cost to service additional shipping. Also

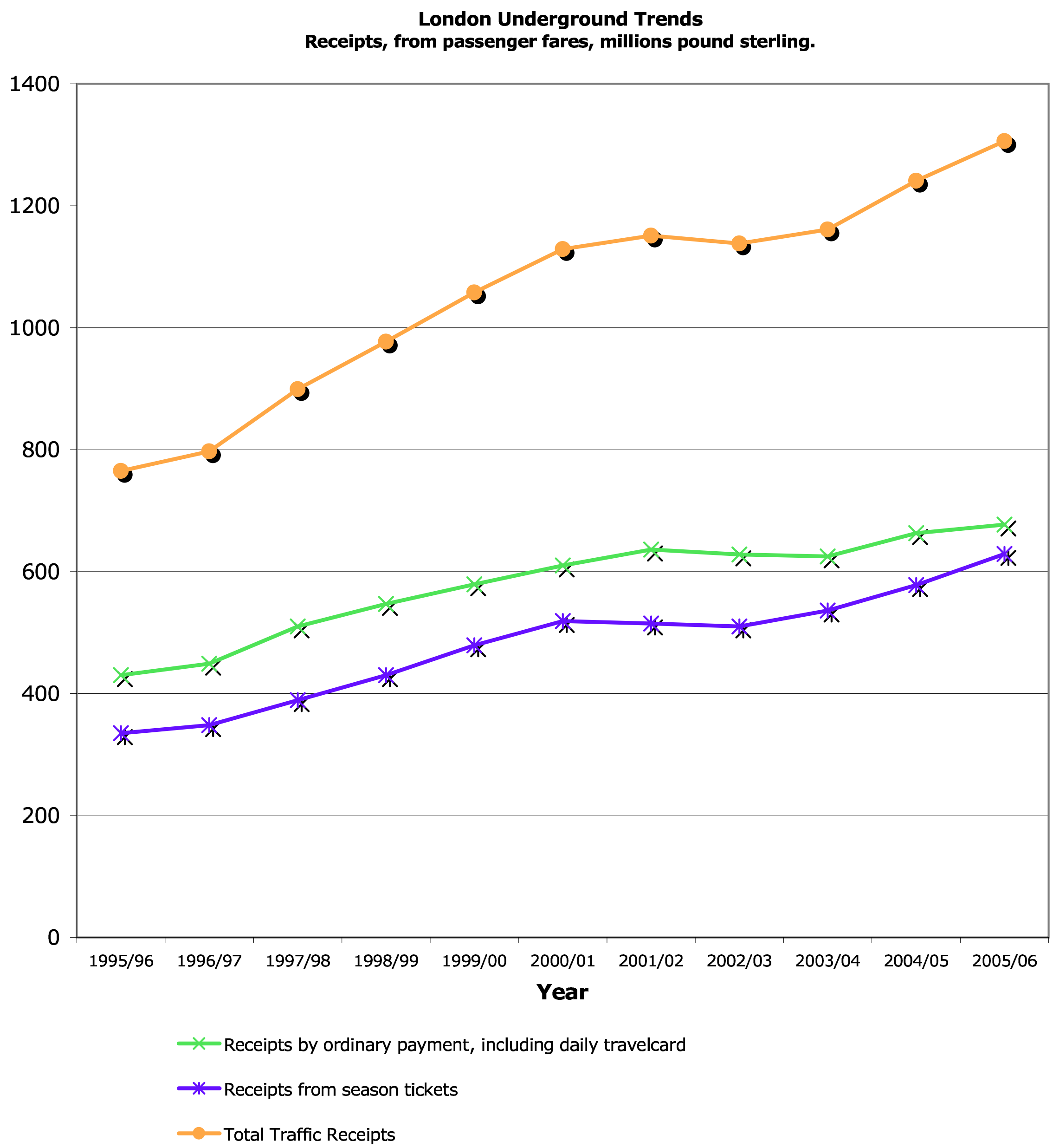

Fig. 2. London Underground revenue from season and ordinary tickets.

unlike roads or rails, there is no easy way to exclude users of light. Similarly, my use of the light does not prevent others from using the light, leading us to conclude they are non-rivalrous. These two points have led some observers to consider them public goods. Economist Ronald Coase [12] noted that they were excludable in that the nearest port could impose a fee on ships that could help subsidize the lighthouse, and thus classified them as club goods. Unfortunately, the Coase paper was poorly written, and gave rise to the myth that many British lighthouses were provided as results of private agreements between shipowners and lighthouse operators. While there were indeed privately owned lighthouses, in the vast majority of cases they relied on the coercive power of the state to enforce payment of their fees (which were set by their charter). Shipowners did not even have the option of saying that they were going to sail only in daylight, and did not have to contribute to the lighthouse dues. This was the key point that Coase's paper did not explain, and so the myth of private lighthouses arose and continued propogating for an amazing two decades, until the first serious refutation by David van Zandt [65][10]. Even those light houses that had been privately owned were acquired (with appropriate financial compensation, as some were extremely profitable to their owners) and turned over to the public charity, Trinity House, in the 1830s. We will not dwell on most of the details of the financial operations of lighthouses, the van Zandt paper [65] is an excellent source of references. We will only point out that the provision of lighthouses was a topic of serious study and debate in Britain in the first half of the 19th century, and there were many complaints about both the privately owned lighthouses, as well as those run by Trinity House.

An important message of this paper is that it is not only how much you charge, but how you charge, that matters. This comes through very clearly in the discussion of lighthouse dues. In the words of the 1822 report [7] (the other two most important reports of Parliamentary committees on lighthouses were those of 1834 that led to the phasing out of private ownership of lighthouses, and that of 1845), "grounds of complaint" were furnished about lighthouse dues "as well on account of the amount to which they were levied, as the manner in which the levy of them was made." There were complaints about Trinity House using profits from lighthouse dues for other (mostly charitable) purposes. The expenses of collection, which ran up to 20 per cent of the gross amount, were regarded as exorbitant, as witnesses claimed that 2.5 to 5 percent should suffice. (Compare to the costs of electronic toll collections systems mentioned above!) There were complaints about lack of transparency, since a wide variety of unpublished rules appeared to be in place, with one witness claiming (p. 109 of [7])

> The mode of collecting the lights is certainly exceedingly inconvenient and arbitrary, and the amount is very heavy. ... We have no means of knowing the rate, as there are no Acts of Parliament for many of the lights.

There was some ambiguity about liability of foreign vessels to the dues, with the result that a ship that had been sailing near British shores without ever entering a British harbor, when driven to one for refuge from a storm, might be assessed dues for previous trips, as well as the return trip. This led to extreme exertions on the part of foreign skippers to stay out of British harbors, leading to incidents such as that related on p. 104 of [7] where a Dutch ship sank with the loss of 380 out of 392 passengers and crew. (In particular, Coase's contention on p. 374 of [12] that light dues were light enough not to affect shipping decisions, while possibly correct for the 2nd half of the 20th century, the period for which he cited some figures, was definitely not applicable in the early parts of the 19th century.) Furthermore, foreign vessels, which had to pay twice as much as British ones, had difficulty in obtaining money for payment of the dues if they were driven into a British harbor. This was perceived to be a detriment to British commerce (even in those days of strong protectionism, when the Navigation Acts were in force), and helped lead to reforms.

6 Telecommunications and the Internet

Many of the telecommunications technologies undergoing development and deployment, such as IP Multimedia Subsystem (IMS) and Next Generation Network (NGN), appear to be motivated by the desire for fine-scaled charging. On the other hand, overall flat rate plans appear to be spreading (see the comments about voice services in the papers and presentations at [29], for example). There appears to be a continuing conflict between policy makers' conviction that metered rates are needed or desirable, and users preferences for flat rates.

The history of telecommunications, starting with the postal system, presents a variety of examples of the importance of pricing. It also shows how conventional approaches often lead decision makers astray, and often continue to do so century after century. The famous British Penny Post reform of 1840 is a very instructive example. It removed the distance sensitivity in pricing (which was motivated by price discrimination considerations and was not based on costs) and instead introduced a simple one-penny price anywhere in the U.K.. This led not only to a dramatic increase in usage, but also initiated a trend of a steady and relatively rapid growth in postal communication, in place of stagnant demand that had been experienced before. This is described in [46][11].

A frequently cited example for the need for metered rates on the Internet comes from the claim that QoS (Quality of Service, technologies that are meant to provide special treatment for certain types of traffic) is necessary. However, there have long been arguments, e.g., [44, 45], and now there are serious studies based on actual experience with large networks, e.g., [30], that at least in the wireline Internet, it is less expensive to add more capacity than to build in QoS. Complicated prioritization mechnisms and the associated charging features not only cost a lot to install, but also increase operating costs dramatically. Even if one accepts the validity of those studies, though, it could still be true that QoS is appropriate to use because of the price discrimination argument.

A very instructive example in considering pricing of telecommunications services is the transition in the 1880-1920 period from flat rate to metered rates for local telephone calls. This change occurred essentially everywhere around the world, with the singular exception of the U.S. The motivation for such a move came from general perception of decision makers in the phone industry, and from a variety of careful studies, which unanimously concluded that flat rates were bound to be ruinous for phone companies and unjust to users, with low volume users subsidizing the heavy users. And indeed, with the technology of that time, where an operator was involved in setting up all calls, the marginal costs were high, so the conventional economic argument for metered rates seemed irrefutable, and was not refuted. However, in the U.S. this argument did not prevail, apparently because of the competition between AT&T and the independent phone companies [46]. Instead, consumer preference for flat rates led to residential pricing remaining flat rate in most of the country. And, contrary to the conventional economic argument, the revenues of the U.S. phone industry as a fraction of GDP tended to be higher than in other countries (see the statistics in [46]), and usage, as measured in minutes per day per line, was far larger.

The Internet, which is subsuming the rest of the telecom industry, started out as a research network with no mechanism for charging individual users built in. When individual users started getting connected to it in large numbers in the early to mid-1990s, they mostly did so through commercial dial-up online services such as AOL or CompuServe, which had metered rates. Of these, AOL was the largest and most prominent, and it was a watershed for the Internet when, in the fall of 1996, AOL moved to flat rates. Since local calls in the U.S. were mostly flat rate, this meant that Internet access as a whole became flat rate in the U.S. The AOL move was precipitated by the introduction of flat rate Internet access by AT&T's WorldNet division[12]. AOL managers feared what flat rates would do to their network, and indeed it did get clogged, as the per-subscriber time online tripled over the following year, see the graphs in [46, 47]. But with time, those same managers came to appreciate the advantages of having closer contacts with customers, and started to boast in their quarterly financial reports of how much usage had increased[13]. Interestingly enough, AT&T WorldNet managers were not aware of the studies on the effect of flat rates, and were basically looking for features attractive to their customers.

The growth of the Internet was accelerated by the switch of first AT&T and then AOL and then the rest of the industry to flat rates. This was actually a very visible and widely discussed move. Another change, also very important, took place soon afterwards, but has received practically no attention at all. It concerned wireless voice usage.

Voice telephony is unjustly neglected in policy considerations, as decision makers worldwide are preoccupied with wireline data and especially the Internet. Yet there are over twice as many wireless voice users as there are Internet users in the world today, and their spending is far more than twice as large as the spending on Internet access. (For general information on role of both wireless and wireline voice, which still provides around 80 percent of telecom revenues, see the papers at the 2007 ITU workshop on "The Future of Voice," [29].) Much of the recent rapid economic growth that is credited to the Internet may instead be due to spread of wireless voice.

In wireless communication, the United States is widely regarded as a laggard, with several incompatible systems and handsets several years behind world leaders. But that misses a very important point. The U.S. is the unchallenged world champion in cell phone usage. This has been one of the most remarkable, and almost totally unknown, phenomena in communications over the last decade.

Unfortunately, unlike with wireline voice, where the ITU has traditionally collected detailed usage statistics, we do not have a comprehensive database of how much time people in different countries spend on their wireless voice phones. Still, around most of the world, it appears that usage is on the order of 3 to 5 minutes per day per subscriber. The

Table 2. U.S. cell phone usage, minutes per day per subscriber around June of each year.

year	usage min/day
1993	4.0
1994	4.2
1995	3.8
1996	3.9
1997	3.6
1998	3.9
1999	5.2
2000	7.3
2001	10.4
2002	13.2
2003	15.5
2004	18.1
2005	20.7
2006	23.0

big exception is the U.S., where current (early 2007) usage seems to be around 25 minutes per day. Table 2 shows the history of wireless voice usage in the U.S., based on data kindly supplied by the CTIA (and available in cruder form from the graphs in [14])[14]. The U.S. attained its leadership position in wireless voice usage not because of any conscious policy decision by government bodies, or by the industry, but by accident. As is discussed in [48], the remarkable growth in usage seen in Table 2 is the result of the introduction of the AT&T Digital One-Rate™ plan in the spring of 1998, which offered a block of time for a flat monthly rate, with no long distance or roaming charges. It was introduced by AT&T Wireless with very modest expectations, created in ignorance of the history of flat rates within AT&T and elsewhere in the telecom industry. But it turned out to be so popular that the rest of the industry had to follow, with the dramatic effects visible in Table 2. (As of this writing, in early 2007, there are several service providers that offer truly flat rate wireless voice service, instead of the block pricing plans that are dominant.)

Unfortunately voice is regarded as irrelevant, and hardly anyone pays attention to it. Yet it is still the dominant revenue source for the telecommunications industry, and plays a key role in human interactions. One can of course ask whether encouraging more voice usage is good. But then we should also ask whether encouraging more data usage is good! And a simple response is that the increased usage visible in Table 2 represents people doing what comes naturally to them when they are not encumbered by worries about per-minute billing, an evolution of phone service away from charging for each connection and towards providing a connectivity service.

From the standpoint of service providers, increased voice usage in the U.S. has not resulted in any disaster. The widely watched ARPU (average revenues per subscriber) have held up at least as well, if not better, than in Europe (see U.S. data in [14]), and the industry is very healthy[15]. This mirrors what happened with wireline voice, where the statistics in [46] show that unlimited local calling in the U.S. was associated with a generally higher fraction of GDP devoted to telephony than in other countries.

In addition to the conventional economic arguments, sophisticated charging schemes give managers of service providers the comforting feeling that they can use them. (The technical term for this phenomenon is "real options," and they are a nontrivial concern in planning, especially in high-tech areas subject to network effects, lock-in, and related issues.) This happened with the various voice prioritization options in PBXs, or the many fancy features in ATM switches, which were essentially never used, but were required in procurement documents. Thus we may very well see a proliferation of complicated control and charging mechanisms in the systems that are installed, even if they are not used in practice.

7 Discussion and Conclusions

The cost of misclassifying a good with a high fixed cost and funding it on a per-use basis are several. First there is under-consumption; by charging more than the marginal cost, society is losing welfare that could be obtained by allowing users who impose little or no burden on others from using the system. Managing this process is not easy, as under-charging may lead to over-consumption, and requires dynamic monitoring of the situation and the utilization of the network technology. Second, there is under-production, the signal to build a more comprehensive network is suppressed by over-charging. This may be especially troublesome if there exist positive network externalities.

The vignettes presented in this paper suggest that the relatively neglected transaction costs (experience both by operators and by users) may be the tail wagging the dog. Reducing these costs for consumers through bundled services (season passes, etc.) greatly increases use. Reducing the mental transaction costs through electronic toll collection (which makes the thinking about payment a bundle, even if every use is still charged for) reduces the salience of the charge, and gives operators significant pricing power. Trying to recover costs in networked industries can be quite expensive, even with modern technologies.

There is no single answer that applies at all times, charging per use vs. bundling depends very much on the context, the cost structure of the technology, its demand, and the costs of collection for users and suppliers.

It is often not that the technology is so inexpensive that we can just give it away, that it is "too cheap to meter" in the words of Strauss, rather it is the cost of collecting charges on each transaction, both in real terms for the operator and user and in dissuading total demand by increasing marginal costs, makes it "too expensive to meter."

8 Acknowledgments

This research has been supported by the UK Economic and Social Review Council, and this material is based in part upon work supported by the National Science Foundation under Grant No. 0236396. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

Notes

[1]The economic ownership of public, club, and private goods may or may not actually fall into the public, club/non-profit, or private sectors as suggested by their names

[2]This curve implies that travelers are both complementors and competitors to each other. That they are competitors comes from the rising variable cost. However, the availability of road space in the first place depends on there being enough other customers or travelers to warrant building it. If there were only one commuter, no one would build a local road, much less an interstate highway system. Furthermore, that traveler could not afford it with the limited gas tax revenue the traveler alone generated. Users are complementing each other in the construction of facilities in the first place. (So next time you are stuck in congestion and thinking of cursing all of the other drivers, thank them instead, for without them, you would not have the opportunity to use the road in the first place.)

[3]Not all deployed ETC systems use the most advanced collection systems, so some require vehicles to pass through tollbooths at reduced speeds

[4]There were 12 pence (d) to a shilling (s), and 20 shilling to a pound (£) prior to decimalization of British currency in 1971. The conversion of currency over time requires many assumptions which we will not attempt to reconstruct here, however Officer [**?**] gives five values for the modern (2005) equivalent of 1 shilling in 1830: £3.39 using the retail price index, £4.33 using the GDP deflator, £37.11 using average earnings, £50.13 using per capita GDP, £126.75 using the GDP, all of which are significantly more the £1.00 bus fare an Oyster card patron would pay in 2007.

[5]Officer [**?**] gives five values for the modern (2005) equivalent of 2 pence in 1900: £0.60 using the retail price index, £0.75 using the GDP deflator, £3.24 using average earnings, £3.70 using per capita GDP, £5.41 using GDP, which are comparable with the £2.00 peak hour zone 1 to zone 2 fare an Oyster card patron would pay in 2007.

[6]£0 4 s 6d in 1900 would be equivalent in 2005 to £16.22 using the retail price index, £20.17 using the GDP deflator, £87.59 using average earnings, £99.91 using per capita GDP, or £146.16 using the GDP [**?**]

[7]£12,045 from 1926 in 2005 was worth: £465,740 using the retail price index, £542,128 using the GDP deflator, £2,072,277 using average earnings, £2,548,451 using per capita GDP, £3,392,186 using the GDP [**?**]

[8]The London Underground currently (c. 2007) advertises that 98 percent of Londoners pay the correct fare in their campaign encouraging patrons to use Oyster smart cards to touch in and touch out.

[9]Lowered collection costs is one reason to rely on the honour system with enforcement, a second reason might be faster boarding times. If as is typical with a bus, each passenger paid on boarding a light rail vehicle, the boarding time with payment is much higher. Alternative

station arrangements could resolve this to some degree, that would then require more space at the station to establish a pre-pay and post-pay zone

[10]In [51] the first refutation was attributed to Daniel Davies in 2002, which would have made it an even more amazing three decades for this simple and easy to establish point to be made in public. But van Zandt had anticipated Davies.

[11]It is worth pointing out that, as is shown in that document, this reform, although widely popular and widely imitated around the world, was a fiscal disaster for the British government. Postal services were extremely profitable before the reform, and became only moderately profitable afterwards, although with time, profits grew back to their former levels.

[12]Some smaller ISPs had offered flat rates earlier, but they were not a serious factor in the market, and so it was only the AT&T move that forced AOL to respond.

[13]Interestingly, AT&T WorldNet customers did not increase their usage much when moving to flat rates, as they interested in other activities than AOL subscribers [17], and simply ended up paying extra money for the freedom from mental transaction costs that metered rates inflicted.

[14]This table extends Table 5 in [48], which only went up to mid-2002, and corrects slightly some of the early entries there.

[15]Increased cell phone usage may have resulted in more traffic crashes. Eby and Vivoda review the literature, and cell phones are blamed for 1.5 to 5 percent of distraction-related crashes [15].

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