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The Deadweight Costs of Operating and Capital Subsidies

by **Kofi Obeng**

This paper determines the deadweight loss of operating and capital subsidies by extending Tullock's *(1998) work. It finds that when both subsidies are received deadweight loss is 6.83% of total cost or $0.861 million on the average, $0.780 million when operating subsidy is received and $0.0503 million when capital subsidy is received. Decomposing the deadweight loss using regression shows that the incentive tier of the federal operating subsidy, federal labor protection, fleet size, and the number of maintenance facilities owned are positively associated with it while leasing maintenance facilities and absence of dedicated funding sources are negatively associated with it.*

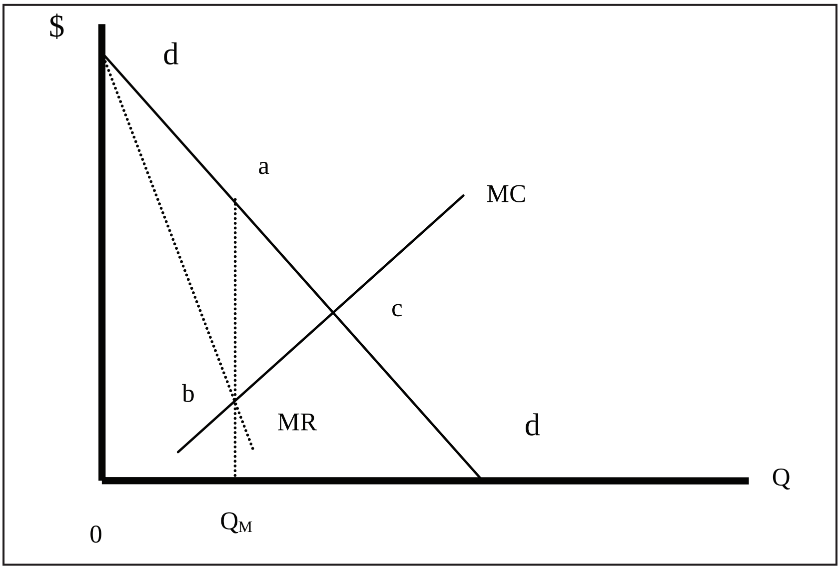
INTRODUCTION

Subsidies can lead to resource misallocation by shortening asset life (Taubman and Rasche 1971), and making transit systems buy more vehicles than they actually need. If they extend asset life, as these authors also note, a misallocation of resources could occur because unproductive capital must be kept for a long time and assets too costly to maintain would continue to be used. In U.S. public transit systems, such a misallocation takes the form of the Federal Transit Administration (FTA) requiring that vehicles purchased with federal capital subsidies must be used for at least 12 years. In addition, there have been reports of inadequate internal controls leading to waste of transit subsidies. In 1992, New Jersey Transit dismissed its auditor responsible for bus subsidy programs because he failed to detect misuse of the pass-through operating subsidies it gave to Middlesex Metro Inc. of New Brunswick and Monmouth Bus Lines of Asbury Park. It was found that approximately $1 million of the subsidies these two companies received were spent on gambling trips, alimony and home furnishings (New York Times 1992).

Another type of inefficiency reported is the effect of subsidies on wages. Winston (2000) notes the works of Pickrell (1985) and Lee (1987) that show that as much as 75% of transit subsidies go to increase labor wages and increase the profits of transit equipment suppliers. To illustrate his point, Winston (2000) wrote at that time that a typical Washington, D.C., Metrobus driver was paid twice as much as a typical driver of one of the private bus companies in that area. Also, the subsidies create a "quiet life" by making transit systems expand their services and pursue other objectives besides cost minimization. Others are, they could make managers show expense preference for some inputs such as staff or visible inputs; they release unobligated non-federal funds for rent-seeking activities[1] and they could reduce motivations to be efficient and create X-inefficiency (Leibenstein 1966). Or, in the context of Tullock's (1967) utility maximizing manager, they could increase cost rapidly to justify even larger subsidies if the manager's rewards are a percentage of cost. The feeling that the subsidies provide "easy money" also may lead to persistent "managerial incompetence ….without willful shirking of work force" (Berger and Hannan 1988: 455).

In the past, several researchers have calculated inefficiency costs especially from monopoly price distortions and market power. Harberger (1954) initiated this calculation by showing that the inefficiency cost of monopoly price distortion is the sum of the lost producer and consumer surpluses denoted in Figure 1 by the triangle bounded by the vertical line through the monopolist's output (Q_M), demand (*dd*) and marginal cost (*MC*), which later became Harberger's triangle. Using this triangle, he calculated the inefficiency cost of imperfect competition in the U.S. to be 0.1% of GNP. van Dijks and van Bergeijk (1997) estimated a weighted average welfare cost of 15% for the Dutch economy, and Solis and Maudos (2008) estimated the social cost of market power in the Mexican banking system as 0.15% of GDP.

Figure 1: Harberger's Triangle



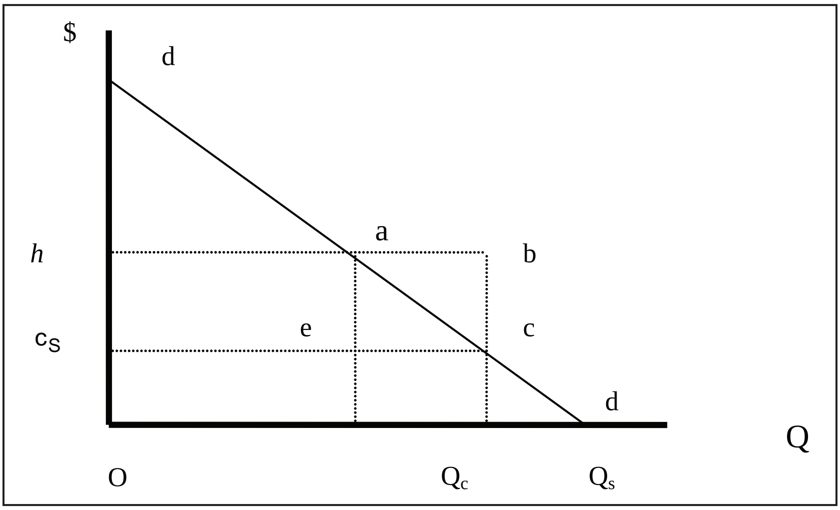
Tullock (1967) added to this calculation when he introduced his loss triangle (Figure 2). Using a constant cost assumption, he showed that with a unit cost of *h* a budget maximizing manager would produce (Q_s) instead of (Q_c) yielding a deadweight loss equivalent to the triangle bounded on the left by demand (*dd*), on the right by the vertical line going through output produced (Q_s), and on top by a horizontal marginal cost line (*h*). This deadweight loss is triangle *abc* in Figure 2. In his model costs increase because the manager must employ more resources to produce the extra output $Q_s - Q_c$ to increase his compensation. According to Tullock (1967) "The true bureaucratic (*budget*) maximizer would exercise close control over costs in order to waste his resources where they would do him the most good" (p. 94). As long as this loss is less than the consumer surplus, Tullock argues that the manager would expand output. Tullock (1998) extended his analysis to show that when subsidies are provided a similar loss triangle as *abc* in Figure 2 can be derived whose area is the deadweight cost of the subsidies.

In this paper, we extend Tullock's triangle to calculate the deadweight loss of operating and capital subsidies offered to U.S. public transit systems. The approach followed, however, is different, in that we focus on input distortions when input subsidies are offered, calculate the deadweight loss for each input, and add them to obtain the deadweight loss of the subsidies. We estimate that the deadweight loss of operating and capital subsidies is 6.83% of the total cost of a typical single mode bus transit system or $0.861 million on the average. The deadweight loss from the subsidies going to labor is $0.440 million compared to $0.085 million and $0.336 million from the subsidies going to capital and the other inputs respectively. The decomposition of the deadweight loss among its sources using regression shows that federal labor protection, the number of maintenance facilities owned, fleet size and the federal formula for allocating the incentive tier of Section 5307 operating funds to transit systems are positively associated with the loss. The deadweight loss is smaller in transit systems that do not have dedicated local funding or own their maintenance facilities.

BACKGROUND

In the U.S., operating and capital subsidies are input specific and are offered to AMTRAK (the national intercity rail company), merchant marine companies in the forms of construction differential[2] and

Figure 2: Tullock's Triangle



operating differential subsidies and transit systems.[3] In transit systems operating subsidies cover the costs of labor, fuel and materials, while capital subsidies are for buying and rehabilitating equipment, right-of-way protection and acquisition, and corridor development to support new fixed guideways. Lately, federal legislation has changed how capital subsidies are used and who can receive federal operating subsidies. Both the Transportation Equity Act for the Twenty-First Century (TEA-21) and the Consolidated Appropriations Act of 2005 discontinued federal operating subsidies to transit systems operating in cities with more than 200,000 populations and broadened the definition of what can be done with federal capital subsidies to include maintenance and other activities. Because federal capital subsidies pay 80% of cost and operating subsidies pay 50% of operating losses on the margin, large transit systems welcomed this change because it requires less local matching funds when used for non-capital purposes, such as short run costs. Besides the federal government, state and local governments also offer capital and operating subsidies.

Table 1 shows real capital and operating subsidies received by U.S. public transit systems from 1995 to 2006. In column 2 operating subsidies from dedicated sources increased from $1.013 billion in 1995 to $1.387 billion in 2008 or by 36.89% (3.35% per year) while column 3 shows that local subsidies increased from $2.612 to $3.524 billion or by 34.92% (3.17% per year). Adding these two columns together and comparing the results in column 4 to the state and federal operating subsidies in columns 5 and 6 respectively, real local operating subsidies are very large and almost equal the sum of the same subsidies from the state and federal governments. For example, real local subsidies were $4.912 billion in 2006 compared to $1.286 and $3.807 billion in federal and state operating subsidies respectively. Column 7 shows that real operating subsidies from all sources increased steadily from $6.674 billion in 1995 to $10.004 billion in 2006, an increase of 49.89% or 4.54% per year. At the same time, in column 8, real capital subsidies increased by 39.46% from $4.745 to $6.617 billion or at a rate of 3.59% per year.

Comparatively, Table 2 shows real operating revenues and operating costs. As can be seen, real transit operating revenues grew by 39.72% or 3.61% per year while real operating expenditures grew by 35.69% (or 3.24% per year). Subtracting the real passenger revenues in column 2 from the real operating costs in column 5, column 6 shows operating losses before subsidies are considered. From this column, passenger revenue is not enough to cover operating costs. However, subtracting the total operating cost in column 5 from the operating funds (inclusive of operating subsidies but excluding capital subsidies) in column 4, column 7 shows that transit systems in total made real after-subsidy operating profits, a result consistent with what Obeng (2000) reported. These after-

Table 1: Operating and Capital Funds ($ millions)

	Operating Subsidies ($ millions)						Capital Subsidies ($ millions)
Year	Real Dedicated Funds	Real Local Funds	Total Local Funds	Real State Funds	Real Federal Funds	Real Operating Subsidies	Real Capital Subsidy
1995	1013.25	2612.14	3625.39	2512.86	536.09	6674.34	4744.95
1996	1080.56	2631.29	3711.85	2601.53	380.11	6693.50	4514.90
1997	1161.12	2551.46	3712.58	2441.56	403.12	6557.26	4890.66
1998	1198.40	2685.21	3883.61	2625.40	460.86	6969.88	4842.21
1999	1371.25	2724.97	4096.22	2928.33	523.29	7547.84	5386.98
2000	1137.57	3088.73	4226.30	2884.49	577.35	7688.15	5567.36
2001	1098.08	3329.53	4427.61	3219.03	638.00	8284.64	6447.60
2002	1229.18	2970.48	4199.66	3734.63	733.41	8667.70	7141.47
2003	1382.99	3020.43	4403.42	3604.78	878.37	8886.58	7195.98
2004	1369.77	3273.85	4643.62	3553.84	1104.24	9301.69	7012.18
2005	1328.01	3409.01	4737.02	3837.43	1179.42	9753.87	6340.71
2006	1387.20	3524.40	4911.60	3806.65	1285.66	10003.92	6617.26

Real profit is in 1982-84 constant dollars. Data for operating expenditure and total operating funds obtained from American Public Transit Association (2008). 2008 Public Transportation Fact Book, 59th Edition. APTA, Washington, D.C.

Table 2: Passenger Fare Revenue and Fares per Unlinked Trip

Year	Real Passenger Revenues ($ million)	Real Fare per Unlinked Passenger Trip ($)	Real Total Operating Funds (TOF) ($)	Real Total Operating Cost (TOC) ($)	Operating Losses before Subsidies ($)	Real after-subsidy profit RP=TOF-TOC ($)
1995	4462.533	0.58	11968.90	11711.75	7249.217	257.15
1996	4726.769	0.59	12205.99	11689.42	6962.660	516.57
1997	4701.371	0.56	12158.82	11798.19	7096.819	360.62
1998	4889.325	0.56	12921.35	12109.51	7220.185	811.84
1999	4971.429	0.54	13337.45	12312.18	7340.751	1025.27
2000	5078.862	0.54	14078.16	13150.70	8071.838	927.47
2001	5020.384	0.52	14278.94	13278.71	8258.326	1000.23
2002	4807.615	0.50	14804.00	13804.34	8996.725	999.67
2003	4972.446	0.53	15228.91	14484.57	9512.124	744.35
2004	5174.484	0.54	15732.19	15090.42	9915.936	641.77
2005	5258.116	0.54	16235.43	15511.98	10253.864	723.45
2006	5553.026	0.56	16723.12	15891.47	10338.444	831.65

These are in 1982-84 constant millions of dollars. Except real after-subsidy profit the data are from: American Public Transit Association (2008). 2008 Public Transportation Fact Book, 59th Edition. APTA, Washington, D.C.

subsidy profits increased almost four-fold (398.65%) from \$257.12 million in 1995 to \$1.025 billion in 1999, fell in 1998 to \$927.47 million before rising again to \$1 billion in 2001. Between 2001 and 2006, real after-subsidy profits declined by 16.85% to \$831.65 million. These aggregate national trends may, however, not hold for some individual transit systems where deficits persist even after subsidies are received. For such transit systems their sources of subsidies may not generate enough revenues for them to realize after-subsidy profits. The same data source (American Public Transit Association 2008) shows that between 1995 and 2006 total unlinked passenger trips increased by 29.04%, while in Table 2 real passenger revenue increased less slowly by 24.44% (2.22% per year) and real fares per unlinked passenger trip declined by 3.45% (-0.31% per year).

Therefore, the reasons for the real after-subsidy profit are increased transit ridership, and the strong growth in real operating subsidy of 4.54% per year outpacing the growth in real operating cost of 3.24% per year. From a public policy perspective, the amount of subsidy provides indications of the value the government places on public transit services; a higher amount showing a very high value and a lower amount indicating otherwise. Thus, if public transit subsidy is increasing, as we have found, it suggests that the government sees the service as essential in accomplishing some social objectives. Furthermore, the sizes of the subsidies reflect the varying objectives which transit systems are called upon to achieve such as making public transit services easily available as a competitive mode of urban transport, improving air quality, mobility and accessibility, and saving energy. As well, they reflect economic activity especially as regards those subsidies that are tied to sales, property and gasoline taxes; these subsidies rise with economy growth and fall during economic downturns.

THEORETICAL MODEL

Given the discussion above it is assumed that transit systems pursue after-subsidy cost minimization in producing outputs which satisfy their mandates. For, with real fares declining, this objective ensures that they can earn after subsidy profits. Of course, the dual of this objective could also lead to after-subsidy profits since it implies cost minimization (Nash1978). Additionally, maximizing operating subsidies from all sources and maximizing fare revenues could increase after-subsidy profits, but the former could create so much wasteful expenditures such as on lobbying for subsidies that we do not consider it viable. Therefore, assume a rational transit system whose input-output decision is to minimize after-subsidy total cost given its demand and operating environment. This decision is constrained by U.S. federal and state government regulations and policies about subsidies and service. Likewise, local governments and transit boards may restrict transit systems' budgets and outputs (as happens in those contracted services where the amount of output to be provided is fixed) or they may set service goals. The transit manager accepts these restrictions and makes decisions about input use to minimize total cost. Thus, for the manager, output is exogenous and his task is to minimize the cost of producing it. Further, because U.S. federal and state governments have formulae for operating and capital subsidies based on output, cost and other variables, the rational manager can affect the amount of subsidies he receives by changing the variables in the formula under his control. For such a manager, these variables are those which affect output and cost. Hence, he considers operating and capital subsidies endogenous and it is assumed that he chooses inputs to minimize total cost net these subsidies. Implicitly, this involves maximizing revenues from subsidies.

For example, in buying buses, the amount of capital subsidies a transit system receives from federal sources depends upon the number bought. At the margin this subsidy is $0.8(rK)$ where, r is the price of a vehicle, K the vehicles bought and 0.8 the federal share in capital cost. Similarly, because the federal share in operating losses is 50% at the margin, the total federal operating subsidies a transit system receives is $0.5(FR - wL - pF)$ where, FR is fare revenue, w and p are the respective prices of labor (L) and other inputs (F). In both cases the amounts of the subsidies clearly depend upon input levels and the manager would want to maximize these subsidies[4] within the limits imposed by the federal government.

Further support for endogeneity is from the federal formula for allocating operating subsidies, which is now being used to allocate capital subsidies to transit systems under the American Recovery and Reinvestment Act. This formula shows that the amount of subsidies received directly depends upon vehicle miles (Q), population (POP) and population multiplied by population density (D) and passenger miles (PM) squared over operating cost (C_o), i.e.,$(PM)^2 / C_o$. Considering that passenger miles depend upon vehicle miles of service provided, that is $PM = g(Q[L,K,F])$, and that operating cost is $C_o = wL + pF$ the federal operating subsidy each transit firm receives can be written in functional form as $A_o = A_o\left\{POP, D, Q(L,K,F), \{g(Q[L,K,F])\}^2 / (wL + pF)\right\}$, or alternatively as $A_o = A_o\,(POP, D,L,K,F)$. Thus, the amount of subsidy a transit system receives under the current federal formula depends on the amount and types of input used. Therefore, an after-subsidy cost minimizing transit system would use more of the inputs for which the federal government provides more subsidy and less of the other inputs given their marginal costs and marginal products. For U.S. public transit systems this could imply overuse of capital relative to other inputs such as labor and fuel. It could also imply higher levels of use of all inputs under economies of scale because output increases more than does cost and this, in turn, increases the federal operating subsidy a transit system receives based upon output and the incentive tier.

With subsidy as endogenous consider a transit system that receives operating and capital subsidies from sources including federal, state and local governments and that minimizes its after-subsidy cost $wL + rK + pF - A_o(L,K,F) - A_K(L,K,F)$ subject to a production function constraint, $Q = Q(L,F,K)$. Here, output (Q) is in terms of vehicle miles,[5] A_o and A_K are operating and capital subsidies respectively and the prices of labor (L), capital (K) and all other inputs (F) are w, r, p in that order as noted earlier. For a transit system that minimizes its after-subsidy cost the Lagrangian of its optimization problem is,

$$(1) \quad \underset{(L,\,K,\,F)}{Min} \; \ell = wL + rK + pF - A_0\left(L,K,F,POP,D\right) - A_K(L,K,F) + \lambda\left(Q - Q[L,K,F]\right)$$

From the first order conditions of this minimization and for an input pair such as labor and capital, the ratio of their respective marginal products f_L and f_K is,

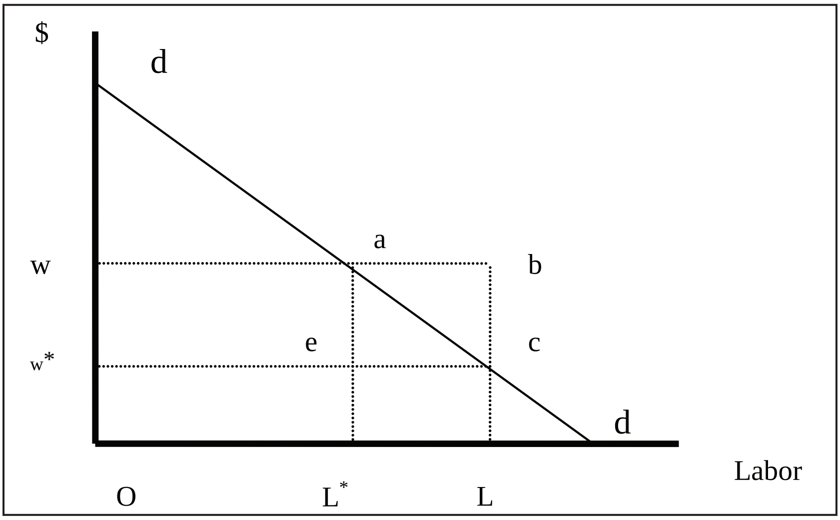
$$(2) \quad \frac{f_L}{f_K} = \frac{w\left(1 - \mu_{oL}H_{oL} - \mu_{KL}H_{KL}\right)}{r\left(1 - \mu_{oK}H_{oK} - \mu_{KK}H_{KK}\right)} = \frac{w^*}{r^*} = \frac{w}{r}\,\xi_{LK}$$

Where $H_{oL} = A_o / w_L L,\ H_{KL} = A_K / w_L L$ and $H_{oK} = A_o / w_K K,\ H_{KK} = A_K / w_K K$ are the shares of the subsidies in input costs, and to fully account for deadweight loss we assume full allocation of each subsidy among all inputs so there is no unspent subsidy. This implies that $\Sigma_i \mu_{oi} = \Sigma_i \mu_{Ki} = 1$ *where* $i = K, L, F$. The parameters μ_{oi} and μ_{Ki} are the respective elasticities of operating and capital subsidy with respect to an input. For each input, the term in parentheses after its price in Eq. (2) is the proportion that a transit system pays from passenger revenue. Additionally, w^* and r^* are the respective misperceived unit prices of labor and capital.[6] Because these misperceived input prices are lower than actual input prices they alter the optimal rates of input substitution and create allocative distortions. That is, if we assume that given input market prices and each transit system hires the efficient combination of inputs, then the optimal rate of input substitution should be w/r in Eq. (2) and ξ_{LK} is the amount by which subsidies make transit systems deviate from this optimal input rate of substitution. For example, if we consider federal operating and capital subsidies and assume they target only labor and capital respectively then $\mu_{KK}H_{KK}$ and $\mu_{oL}H_{oL}$ are respectively 0.8 and 0.5 since in this case μ_{oL} and μ_{KK} take values of one and the other terms in Eq.

(2) disappear. Consequently, $f_L / f_K = (1- 0.5)w/(1- 0.8)r = 2.5\ w/r$ and suggests 2.5 times overuse of capital relative to labor. Comparatively, and by the same assumption, using the percentages of the local match for capital and operating subsidies in this equation for $\mu_{KK}H_{KK}$ and $\mu_{oL}H_{oL}$ respectively gives the ratio of the marginal products as $f_L / f_K = 0.5w / 0.8r = 0.625\ w / r$ showing overuse of labor relative to capital. Thus, both local and federal subsidies distort the optimal rates of input substitution differently or create allocative distortion. This allocative distortion is ξ_{LK} in Eq. (2) and a part of its cost is deadweight loss, which can be calculated by combining the information in Eq. (2) with Tullock's (1997) work whose description follows.

Tullock (1998) considered a service that received government subsidies and showed as in Figure 2 that a part of the subsidies would be wasted in providing this service. Following his approach and consistent with the discussion earlier the demand for the service is *dd,* the average cost is *h* and it is the same as marginal cost, the subsidized average cost is c_s and the quantity demanded is Q_s. The government's cost of the subsidy is the rectangle $hbcc_s$, and the trapezoid $hacc_s$ is the benefit consumers enjoy by using the subsidized service, while according to Tullock (1998), triangle *abc* is the deadweight cost (loss) if the subsidies are not a result of rent seeking activities.

Figure 3: Labor Demand



Analogous to Tullock's exposition, Figure 3 from Obeng and Sakano (2000, 2008) shows input demand when a transit system receives operating and capital subsidies. The transit system's demand for an input such as labor is *dd*,[7] its market wage rate is *w* and, before the subsidies, it employed L^* units of labor and enjoyed a consumer surplus of *dwa*. Because it receives operating and capital subsidies, L^* is not the quantity of labor it demands. From Eq. (2), that quantity is based upon the misperceived wage or implied price w^* at which the transit system employs *L* units of labor, enjoys a consumer surplus of dcw^* and incurs a total resource cost of *wL* and an implied resource cost of w^*L. These costs are respectively waL^*O and w^*cL^*O, and total subsidy is $wbcw^*$. The subsidies result in an increase in benefits to the firm of $wacw^*$ from which after subtracting the total amount of the subsidy $wbcw^*$ going to labor, gives a deadweight loss triangle *abc* which is similar to Tullock's. This triangle is the portion of the subsidy going to labor wasted or misspent perhaps because of over-employment, lax management or inability to negotiate well with labor and it is also equal to the area *aec* in Figure 3. For each input, Eq. (A.5) in Appendix A shows that the deadweight loss (DWL_L) can be calculated as,

$$(3)\quad DWL_i = \frac{CS_i\left(\mu_{oi}H_{oi} + \mu_{Ki}H_{Ki}\right)^2}{2\left(\eta_i^{\ 1} + \mu_{oi}H_{oi} + \mu_{Ki}H_{Ki}\right)} \quad for \ \ i = L, F, K$$

Where, n_i is input demand elasticity, C is the observed total cost, S_i the observed share of an input in total cost, and all other terms are defined already.

Obviously in Eq. (3), the size of the deadweight loss depends upon the own price elasticity of input demand. If input demand is price elastic this loss would be large, the reverse being true if it is price inelastic. For example, if input demand is perfectly price elastic, the first term in the denominator is zero and deadweight loss is $0.5CS_i(\mu_{oi}H_{oi} + \mu_{Ki}H_{Ki})$. On the other hand, if it is perfectly price inelastic, the first term in the denominator becomes very large and the deadweight loss approaches zero. Similarly, the size of the loss depends upon the amount of operating or capital subsidy received. As operating subsidy becomes very large the deadweight loss becomes $0.5CS_i\mu_{oi}H_{oi}$ and as it approaches zero the deadweight loss disappears. Taking the sum of this equation over all inputs and dividing both sides of the result by actual total cost gives the share of the deadweight loss in cost.

Either Eq. (3) or this share of deadweight loss in cost can be used to compare transit systems in terms of inefficiency. However, when this equation is used a quasi optimal amount of each subsidy can be determined under some restrictive assumptions. By observation, most of the deadweight loss occurs in the targeted input which has the largest share in cost. Operating subsidy covers short run cost and labor's share in it is approximately 66.1% (American Public Transit Association 2008). Capital subsidy too is largely for vehicle, facility and right-of way acquisition. Therefore, most of the deadweight losses in operating and capital subsidies would be in labor and capital demand respectively. Hence, assume *DWL* is fixed for all inputs except the most important input in terms of cost share targeted by the subsidy. Then, write similar equations as Eq. (3) for labor and capital and differentiate that for labor with respect to A_o and that for capital with respect to A_K as done in Appendix A. Setting the results of the differentiation to zero and solving gives the quasi optimal levels of the subsidies. For operating subsidy, this yields,

$$\hat{A}_o = \frac{w_o L}{\eta_L \mu_{oL}} \tag{4}$$

Where, $\hat{A}_o$ is the quasi optimal operating subsidy.

Eq. (4) suggests large operating subsidy if the targeted input has price inelastic demand and small operating subsidy if it has price elastic demand. It also suggests large operating subsidies if the elasticity of subsidy with respect to the targeted input is very small. No operating subsidy should be given if the targeted input has perfectly elastic demand according to this equation. By a similar approach the quasi optimal capital subsidy can be obtained. As shown in Appendix A these optimal subsidies are the maximum that should be offered. Their values vary by transit system because input cost and own-price elasticity of input demand also vary by transit system. Dividing the operating or capital subsidy received by its corresponding optimal amount shows which transit system has excess subsidies.

EMPIRICAL MODELS

The determination of excess subsidy and the calculation of deadweight loss both require specifying and estimating an equation to obtain the values of the coefficients in Eq. (3). In this study these coefficients are from a cost function that does not assume cost minimization and that extends the information in Eq. (2). Recall from this equation that the implied prices of labor, capital and all other inputs are respectively w^*, r^*, p^* and are what transit systems misperceive as their input prices. Using these prices, total implied cost is $C^* = w^*L + r^*K + p^*F$ as compared to actual total cost $C = wl + rK + pF$ and its functional form is $C^*\left(w^*, r^*, p^*, Q\right)$. From Shephard's lemma, Appendix B shows that actual total cost is related to total implied cost because the partial derivative of implied cost with respect to implied input price is input demand and it is the same as the partial derivative of actual total cost with respect to actual input price. Eq. (B.2) in Appendix B shows that the logarithm of actual total cost is,

$$(5) \qquad \ln C = \ln C^* + \ln \upsilon$$

Where υ is the factor by which total implied cost must be multiplied to obtain actual total cost. Alternatively, $\upsilon - 1$ is the proportion by which actual total cost exceeds total implied cost.[8] Thus, $(\upsilon - 1)C^*$ is the amount of the subsidy or *wbcw** in Figure 3 and it is far larger than the deadweight loss, *abc.*

Clearly, Eq. (5) is deterministic and assumes that the exact values of C^* and υ are known and free of errors. However, they are not because some of their terms are estimated. Therefore, we add a random error term ε_1 to it to obtain $\ln C = \ln C^* + \ln \upsilon + \varepsilon_1$. Expanding the minimum implied cost function $C^*(w^*, r^*, p^*, Q)$ by Taylor's series up to the second order and substituting the result into $\ln C = \ln C^* + \ln \upsilon + \varepsilon_1$ gives Eq. (B.3) in Appendix B to be estimated jointly with the actual cost share equations derived in the same appendix as Eq. (B.6). This estimation is done after imposing linear homogeneity constraints on the coefficients of input prices, and the requirement for full allocation of all subsidies among the inputs, i.e., $\sum_i \mu_{oi} = \sum_i \mu_{Ki} = 1$ *where* $i =$ K, L, F. Furthermore, for estimation, all the variables are mean centered, except the shares of inputs in actual total cost and the ratios of the subsidies to actual input costs, the latter of which are allowed to take their actual values to ensure the mean firm has allocative distortion from the subsidies.

Decomposition Variables

Estimating the cost and share equations as described, however, does not identify the sources of deadweight loss, but provides the coefficients μ_{oi} and μ_{Ki} needed to calculate this loss. Those sources can be identified through a second stage regression by estimating the hypothesized linear decomposition equation below:

$$(6) \quad \sum_i DWL_i = \omega_0 + \sum_i \omega_m X_m + \varepsilon_2$$

Where, the dependent variable is the sum of the deadweight losses from the subsidies going to labor, capital and the other inputs.[9] In Eq. (6) also, ω and ε_2 are the set of parameters to be estimated and the error term respectively, and X_m the set of variables described below. More specifically, ω gives the marginal dollar values of the variables in the decomposition equation. If it is negative (positive), an increase in the variable with that coefficient is associated with a decrease (increase) in deadweight loss. The variables with negative coefficients, therefore, provide some bases for policies to reduce deadweight losses.

Federal Labor Protection. A source of waste from subsidies comes from the provisions of the Federal Transit Act. Section 5333 (b) of Title 49 of the United States Code (formerly Section 13(c) of the Federal Transit Act), states that Federal funds received by transit systems as subsidies cannot be used to worsen labor conditions. Transit systems receiving these subsidies must have in place plans to protect employees who may be affected by capital acquisition or service improvements from layoffs. It requires paid training and retraining of employees whose jobs are affected by Federal assistance. For those who lose their jobs, Section 5333(b) requires transit systems to pay them a dismissal allowance not to exceed six years of their salaries and benefits. Where the job of an employee of a transit system receiving the subsidies is downgraded she must be paid a displacement allowance equal to the difference in wages in her current and previous positions. This labor protection clause limits transit systems in terms of their abilities to substitute other inputs for labor and leads to inefficiencies in the form of overuse of labor relative to capital or fuel. For example, a transit system that replaces its fleet of small buses with large ones bought with federal subsidies must protect the interests of its affected drivers by making equitable arrangements for them through negotiations with the unions representing them and having such arrangements certified by the Secretary of Labor.

Evidence of labor-capital distortion can be obtained from ξ_{LK}. If ξ_{LK} is less (more) than one it shows that the subsidies make the implied price of labor more (less) than the implied price of capital leading to the substitution of capital (labor) for labor (capital). ξ_{LK} can be used in Eq. (6) to capture the effect of federal labor protection in causing allocative distortions. But, it is not because its terms are in the formula for calculating deadweight loss. Therefore, we use the ratio of total employment to fleet size (L / K) to capture labor-capital distortion.

Federal Incentive Tier Subsidy. The federal matching formulae and the formula for disbursing federal capital and operating subsidies to transit systems also have been noted as sources of allocative inefficiency. From the theoretical section transit capital subsidies from federal sources require 20% local match and operating subsidies 50% match. Pickrell (1992) argues that the very small local match for capital subsidies skews investments in favor of capital-intensive programs and provides little incentive for local officials to consider less costly alternatives. Additionally, 9.2% of the Section 5307 formula grants that bus transit systems receive is incentive tier allocated based upon passenger miles squared over operating cost and it is a source of inefficiency. By penalizing transit systems with high operating costs, the formula distorts the optimal rate of substitution between labor, capital and the other inputs. Obeng and Azam (1995) studied the U.S. federal formula for disbursing operating subsidies to public transit systems and derived the following equation from it:

$$(7)\quad f_L \big/ f_K = \left(\frac{w}{r}\right)(1+\varphi R).$$

Where, R is the ratio of federal operating subsidy to total operating cost and φ is the elasticity of operating subsidy with respect to the incentive tier component (i.e., passenger miles squared divided by operating cost). Since R and φ are positive, the value of $(1 + \varphi R)$ is greater than one showing that by itself the formula distorts the optimal rate of input substitution in favor of capital and leads to inefficiency in terms of overuse of capital relative to labor thereby increasing cost. We account for the incentive tier's effect by including passenger miles (PM) as a variable in the decomposition equation.[10]

Extensiveness of Vehicle Maintenance. Almost three decades ago, Bonnell (1981) summarized a Comptroller General (1981) report on federal transit operating subsidies and their uses to identify the causes of the soaring financial crisis in public transit systems.[11] He reported that due to peaking and restrictive union contracts that prevented the use of part-time labor, transit systems were not using labor efficiently; that transit systems were not properly recruiting, training and promoting mechanics resulting in bus repairs that were improperly done; that transit systems did not have preventive maintenance programs and had rules that prevented the efficient use of maintenance labor. Bonnell (1981) also found that in one large transit system, promotions of bus maintenance personnel were based upon seniority rather than merit, acquired skill or aptitude, and he listed several instances of waste and cost increases. Since that report changes by the Federal Transit Administration (FTA) and its predecessor, the Urban Mass Transportation Administration, have addressed many of these concerns. For example, the FTA now requires transit systems to have maintenance plans for vehicles purchased with federal subsidies and to operate such vehicles for at least 12 years. Despite these changes, subsidies have been linked to early retirement of buses and investments in capital intensive inefficient transit systems (Pickrell 1992). Cromwell (1989) alludes to the less money that recipients of federal capital subsidies spend on vehicle maintenance. He found that private providers of transit services spent 45% more on maintenance per mile and devoted 29% more labor hours to maintenance than did public providers. He further found that a 10% increase in transit capital subsidies reduced vehicle maintenance by 1.6% and that this reduction was statistically significant. Hilton (1974) and Kemp et al. (1983) argue that capital grants do not encourage vehicle and facility maintenance. We account for the importance of maintenance in the decomposition by including three variables. The first is a binary variable (*AGE*) which takes a value of one if average fleet age is greater than 12 years and a value of a zero otherwise to account for the FTA's 12 years of vehicle use regulation. This variable also accounts for the Taubman and Rasche (1971) effects mentioned in the introduction. The second is the number of maintenance facilities owned (M_F) and the third is leasing versus owning maintenance facilities (M_o). These variables are expected to account for the extensiveness and effectiveness of vehicle maintenance programs and their possible effects on coordination of maintenance activities, duplication and over-employment all of which lead to inefficiencies.

"**Easy Money.**" As the discussion in the background section shows, the federal role in providing transit subsidies has been declining. In response local areas have established dedicated funding sources for their transit systems. These sources include property taxes, tolls, utility taxes and vehicle rental taxes. Some states such as North Carolina allow counties to increase their sales taxes by between 0.25 and 0.5 cents and impose special fees on rented vehicles to fund public transit systems. The availability of dedicated funding creates a continuous stream of money to be used for capital acquisition, operations and service expansion. For some transit systems, the funds from these sources make them earn after-subsidy profits as noted earlier. To the extent that some transit systems advocate for the establishment of dedicated local funding sources that may inadvertently lead to after-subsidy profits, they may be rent seeking and this could lead to inefficiency. We account for "easy money" by including a binary variable for availability of local dedicated sources of funding (*LOCDED*).

Federal Regulations and Other Variables. Since the 1980s the federal government has required transit systems to contract out portions of their operations to private sector companies. The premise is that there are cost efficiencies from private sector provision of public transit services or contracting out services to the private sector. To account for contracting the decomposition includes a binary variable (*PUR*) showing if or not a transit system purchases transportation from the private sector. The FTA also requires transit systems to maintain a spare ratio of 20% of the vehicles they operate in maximum service. The rationale is to avoid resource misallocation by using the subsidies to acquire and maintain excessive fleet. This requirement is accounted for in the decomposition by a binary variable (*SPRATIO*) that takes a value of one if the spare ratio is equal to or greater than 20% and a zero otherwise. Finally, fleet size is included in the decomposition to account for heterogeneity.

DATA

The data for estimating the cost, share and the decomposition equations are from the 2006 U.S. National Transportation Statistics (NTS) database.[12] The sample consists of 227 single-mode bus transit systems each of which received both operating and capital subsidies and had no missing data on output and inputs. Labor is measured as hours worked, fleet size is a proxy for capital, and gallons of fuel are a proxy for all other inputs (i.e., all non-labor and non-capital inputs). Labor price (w) is annual total labor compensation including benefits divided by annual labor hours; the price of capital (r) is yearly bus user cost[13] and following Nadiri and Schankerman (1981) capital cost rK is added to operating cost to give total cost and the price (p) of other inputs is total operating cost less total labor compensation divided by gallons of fuel. Using these prices total cost is $C = wL + pF + rK$.

The descriptive statistics in Table 3 show that the ratios of operating subsidy to input costs are far larger than the corresponding ratios of capital subsidy to input cost. For both subsidies, this ratio is largest for the other inputs and smallest for labor. The mean transit system received \$11.212 million and \$2.608 million in operating and capital subsidies respectively while paying \$18.21 per hour for labor, a price of \$2.53 per gallon for fuel (\$8.45 per unit of the other inputs), and incurring capital user costs of \$44,423 per vehicle and a total cost of \$18.946 million. This transit system produced

2.959 million vehicle miles of service using 6.202 million hours of labor, 94 vehicles and 0.584 million gallons of fuel. 42.3% of the sampled transit systems purchased transportation services from private sector companies, 79.3% owned their maintenance facilities, 3.5% leased these facilities and 12.08% owned and leased some of them. Finally, 37% had dedicated local funding and on the average each owned 1.74 maintenance facilities.

Table 3: Descriptive Statistics

Variable	N	Mean	Std. Dev.
Total Cost ($ million)	227	18.946	29.553
Vehicle miles (million)	227	2.959	4.349
Labor wage ($)	227	18.21	58.77
Capital user cost per vehicle ($)	227	44,422.73	6,075.01
Fuel price per gallon ($)	227	2.53	2.61
Labor hours (million)	227	6.202	0.844
Fleet size	227	94	119
Gallons of fuel (million)	227	0.584	1.004
Capital subsidy ($ million)	227	2.608	4.157
Operating subsidy ($ million)	227	11.212	17.814
Ratio of operating subsidy to labor cost	227	1.155	0.234
Ratio of operating subsidy to the costs of the other inputs	227	2.667	0.744
Ratio of operating subsidy to capital cost	227	2.448	1.195
Ratio of capital subsidy to labor cost	227	0.325	0.411
Ratio of capital subsidy to capital cost	227	0.645	0.971
Ratio of capital subsidy to the cost of the other inputs	227	0.714	0.819
Ratio vehicles operated in maximum service to fleet size	227	0.723	0.153
Directly operated service	227	0.577	0.495
Availability of local dedicated funding source	227	0.370	0.483
Number of maintenance facilities	227	1.742	1.340
Proportion owning maintenance facilities	227	0.793	0.407
Proportion leasing maintenance facilities	227	0.035	0.186
Proportion leasing and owning maintenance facility	227	0.128	0.335

Fuel is a proxy for all non-labor and non-capital inputs. Therefore, its costs include the costs of materials, tires and all types of liquid fuels, and a portion of the cost of purchased service.

RESULTS

Table 4 shows the results of estimating the cost and share equations for labor and the other inputs jointly using iterative non-linear seemingly unrelated methods. At convergence the model used 164 observations and gave coefficients of determination of 0.7590, 0.3706 and 0.3150 for cost, and the cost share equations for labor and the other inputs respectively. From the estimated coefficients the long run shares of labor, capital and the other inputs in implied cost are respectively 68.63%, 25.83% and 5.54% and the calculated mean value of ln(υ) is 0.5255 (*Std. Dev. = 0.082*). This latter result shows that total actual cost is 52.55% larger than the minimum implied cost. Alternatively, it shows that at the mean the subsidies account for a little more than a half of the total actual cost of transit systems. Using the relevant coefficients in the price elasticity of input demand equation $\vartheta_i = S_i^* + (\beta_{ii} / S_i^*) \quad 1$, Table 5 shows the mean values of price elasticities of input demand and the deadweight losses.[14] Very clearly, all transit inputs have inelastic demand, and in absolute terms the elasticities of input demand are relatively large for capital (0.8676) and the other inputs (0.5756) than they are for labor (0.2416).

Table 4: Estimated Coefficients

Variable	Parameter	Estimate	Std. Error	t value	Probability
Share of operating subsidy in capital cost (H_{oK})	μ_{oK}	0.1941	0.0012	165.2000	<.0001
Share of operating subsidy in labor cost (H_{oL})	μ_{oL}	0.5631	0.0007	816.1300	<.0001
Share of operating subsidy in the cost of the other inputs (H_{oF})	μ_{oF}	0.2428	0.0010	252.9800	<.0001
Share of capital subsidy in capital cost (H_{KK})	μ_{KK}	0.4789	0.0089	54.0800	<.0001
Share of capital subsidy in labor cost (H_{KL})	μ_{KL}	0.4389	0.0073	60.0000	<.0001
Share of capital subsidy in the cost of the other inputs (H_{KF})	μ_{KF}	0.0822	0.0059	13.8700	<.0001
$\log(w^*)$	β_L	0.6863	0.0044	157.3200	<.0001
$\log(p^*)$	β_F	0.2583	0.0036	72.6600	<.0001
$\log(r^*)$	β_K	0.0554	0.0017	33.4000	<.0001
$0.5\log(w^*)\ \log(w^*)$	β_{LL}	0.0555	0.0033	17.0400	<.0001
$\log(w^*)\ \log(p^*)$	β_{LF}	0.0453	0.0026	17.7000	<.0001
$\log(w^*)\ \log(r^*)$	β_{LK}	0.0102	0.0015	7.0500	<.0001
$0.5\log(p^*)\ \log(p^*)$	β_{FF}	0.0391	0.0023	17.1600	<.0001
$\log(p^*)\ \log(r^*)$	β_{FK}	0.0061	0.0011	5.5600	<.0001
$0.5\log(r^*)\ \log(r^*)$	β_{KK}	0.0041	0.0013	3.1100	0.0022
Constant	β_o	0.7768	0.0490	15.8600	<.0001
$\ln Q$	β_Q	0.7805	0.0415	18.8000	<.0001
$0.5\ln(Q)\ln(Q)$	β_{QQ}	0.1593	0.0436	3.6600	0.0004
$\ln(Q)\ln(w^*)$	β_{LQ}	0.0022	0.0042	0.5300	0.5940
$\ln(Q)\ln(p^*)$	β_{FQ}	0.0002	0.0034	0.0500	0.9571
$\ln(Q)\ln(r^*)$	β_{KQ}	0.0021	0.0017	1.2300	0.2202

Using these results, the mean deadweight loss for the 164 transit systems is $0.861 million, most of which comes from the subsidies going to labor ($0.440 million) possibly by not matching employment to skills, followed by those going to other inputs besides capital ($0.336 million), and then capital itself ($0.085 million). These results appear surprising because labor demand being relatively less sensitive to changes in its price than the other inputs should have the lowest deadweight loss. That, it does not, is because labor's share in cost is the largest of the three inputs, and the larger the cost share of an input the larger is the deadweight loss. It follows from these results that the share of an input in cost has a larger impact on deadweight loss than the price elasticity of input demand. When deadweight loss is expressed as a ratio of total cost, its mean value of 6.83% decomposes into 3.74%, 0.56% and 2.53% respectively from the subsidies going to labor, capital and the other inputs.

Also, Table 5 shows the results when either capital subsidy or operating subsidy is zero. When capital subsidy is zero, transit systems receive only operating subsidy and we are able to calculate deadweight losses for 215 of them using the estimated coefficients. Here, total actual cost exceeds the minimum implied cost by 48.57% and the share of deadweight loss in total actual cost is 5.66% or $0.78 million on the average. This deadweight loss decomposes into 3.05%, 0.36% and 2.25% respectively from the subsidies going to labor, capital, and all other inputs. When operating subsidy is zero, transit systems receive only capital subsidy and we are able to calculate deadweight losses for 220 of them. In this case total actual cost exceeds the minimum implied cost by a mere 9.99% and deadweight loss is only $50,287 or 0.44% of total actual cost on the average. This deadweight loss as a share in cost decomposes into 0.23%, 0.17% and 0.04% respectively from the subsidies going

Table 5: Elasticity, Cost Share and Deadweight Loss

Variable	N	Mean	Std
$\ln(\upsilon)$	164	0.5255	0.0817
Wage elasticity of labor demand	164	-0.2416	0.0656
Price elasticity of demand of the other inputs	164	-0.5756	0.0395
Price elasticity of capital demand	164	-0.8676	0.0083
Share of labor cost in actual total cost	164	0.6873	0.0655
Share of capital cost in implied cost	164	0.0531	0.0215
Share of the cost of the other inputs in actual total cost	164	0.2593	0.0516
Share of labor cost in implied cost	164	0.6749	0.0771
Share of capital cost in actual total cost	164	0.0583	0.0140
Share of the cost of the other inputs in implied cost	164	0.2668	0.0637
Share of deadweight loss in actual total cost	164	0.0683	0.0216
Share of deadweight loss from labor in cost	164	0.0374	0.0149
Share of deadweight loss from the other inputs in cost	164	0.0253	0.0085
Share of deadweight loss from capital in cost	164	0.0056	0.0032
Total deadweight loss ($)	164	861,081.77	1,435,368.63
Deadweight loss from labor demand ($)	164	439,838.54	722,008.38
Deadweight loss from the demand of the other inputs ($)	164	336,147.28	566,079.15
Deadweight loss from capital demand ($)	164	85.095.95	169,844.13
Operating Subsidies Only			
$\ln(\upsilon)$	215	0.4857	0.0696
Share of deadweight loss in total cost	215	0.0566	0.0170
Total deadweight Loss ($)	215	780,137.88	1,232,145.46
Share of deadweight loss from labor in cost	215	0.0305	0.0125
Share of deadweight loss from the other inputs in cost	215	0.0225	0.0071
Share of deadweight loss from capital in cost	215	0.0036	0.0024
Deadweight loss from labor demand ($)	215	385,409	605,925.40
Deadweight loss from the demand of the other inputs ($)	215	328,214.03	522,875.22
Deadweight loss from capital demand ($)	215	66,514.33	133,069.33
Capital Subsidies Only			
$\ln(\upsilon)$	220	0.0999	0.0881
Share of deadweight loss in total cost	220	0.0043	0.0071
Total deadweight loss ($)	220	50,287.10	100,896.42
Share of deadweight loss from labor in cost	220	0.0023	0.0045
Share of deadweight loss from fuel in cost	220	0.0004	0.0008
Share of deadweight loss from capital in cost	220	0.0017	0.0023
Deadweight loss from labor demand ($)	220	19,784.44	39,144.20
Deadweight loss from the demand of the other inputs ($)	220	4,047.22	8,251.73
Deadweight loss from capital demand ($)	220	26,455.45	58,124.55

*Excludes three transit systems whose elasticities of input demand were positive.

to labor, capital, and all other inputs. Comparing these results, operating subsidy is responsible for most of the deadweight loss while capital subsidy adds very little to it.

Additionally, we calculated the ratio of actual to optimal subsidies and found that no transit system received more than its optimal amount of each subsidy. For operating subsidies, the mean of this ratio is 0.1599 (*Std. Dev. = 0.0696*) and for capital subsidies it is 0.1389 (*Std. Dev. = 0.1206*). Therefore, the deadweight losses are not because the transit systems received excess subsidies but the presence of waste in using some of the subsidies, particularly operating subsidies.

Finally, Table 6 shows the results of estimating the decomposition equation. This equation explains 86.53% of the variation in deadweight loss, and all the variables have statistically significant coefficients except three. These are purchased transportation, year-of-vehicle-use regulation and spare ratio regulation. Examining the coefficients, those of transit systems which do not directly own their maintenance facilities and the absence of “easy money” are statistically significant and negative. The respective coefficients of these variables show that they are associated with $234,273 and $228,323 reductions in deadweight loss. The other estimated coefficients are positive and their variables are associated with increases in deadweight losses. From these latter coefficients, the marginal effect of the labor-capital ratio, our indicator of Section 13(C) effect, is an increase of $141,493 in deadweight loss and the marginal effect of the number of maintenance facilities is an increase of $229,716 in deadweight loss. Comparatively, the marginal effects of fleet size and passenger miles (i.e., the incentive tier) are increases in deadweight loss of $4,222.90 and $0.0228 respectively.

Table 6: Sources of Deadweight Loss

Variable	**Estimate**	**Std. Error**	**t**	**Probability**
Intercept	-865,534.00	212,446.00	-4.07	<.0001
Extensiveness of maintenance				
$AGE > 12$: Years of use regulation (Yes =1, No = 0)	-115,807.00	325,693.00	-0.36	0.7227
M_O : Does not own of maintenance facility (Yes = 1, No = 0)	-234,273.00	128,223.00	-1.83	0.0697
M_F : Number of maintenance facilities used	229,716.00	47,205.00	4.87	<.0001
Incentive tier				
PM : Passenger miles	0.0228	0.0030	7.55	<.0001
Federal labor protection				
L/K : Section 13(C) effect, i.e., employees per vehicle	141,493.00	46,954.00	3.01	0.0030
“Easy money”				
$LOCDED$: No dedicated local funding (Yes = 1, No = 0)	-228,323.00	93,181.00	-2.45	0.0154
Other variables				
K : Fleet size	4,222.90	718.87	5.87	<.0001
PUR : Purchased transportation (Yes = 1, No = 0)	33,473.00	100,427.00	0.33	0.7394
$SPRATIO$: Spare ratio regulation	181,915.00	115,008.00	1.58	0.1158

CONCLUSION

The purpose of this paper is to calculate the deadweight losses from the operating and capital subsidies received by U.S. public transit systems. The calculation extends the works of Tullock (1997). It uses data for 227 single-mode bus transit systems and estimates a neoclassical cost function that does not assume cost minimization. The results show that when both subsidies are considered the deadweight loss is \$0.861 million on the average largely due to \$0.440 million, \$0.851 million and \$0.336 million from misusing some of the subsidies going to labor, capital and other inputs respectively. Overall, deadweight loss accounts for 6.83% of the total cost of the average public transit system. When operating subsidy alone is considered, the deadweight loss is on the average \$0.78 million, and when capital subsidy alone is considered it is \$0.050 million. Thus, most of the deadweight loss comes from operating subsidies. A decomposition of the deadweight loss when both subsidies are received using regression shows that the factors which are positively associated with it are the extensiveness of maintenance operations, Section 5333(b) labor protection effect (i.e., the effect of Section 13(c)), the effect of the incentive tier of the federal formula grant and fleet size. Two factors negatively associated with deadweight loss are leasing instead of directly owning maintenance facilities and the absence of "easy money" in the form of not having local dedicated funding sources. The latter result suggests that funding agencies should ensure that transit systems with local dedicated funding sources pursue cost minimization objectives. Also, from the results, deadweight loss from operating and capital subsidies can be reduced by changing the formula for the incentive tier of the Section 5307 formula grants possibly by removing operating cost as a denominator thereby ridding it of its inefficiency effect, and revising the federal labor protection clause imposed by Section 5333(b) of the FTA Act by lobbying for congressional action to reduce the years over which compensation should be paid to those whose jobs are adversely affected by federal subsidies. A limitation of this study is its inability to capture rents and wage premiums from subsidies earned by labor unions and equipment suppliers over time. To that extent, the deadweight losses reported herein are approximate.

Endnotes

1. Federal regulations do not allow using subsidies and other monies from federal sources to influence how subsidies are allocated such as hiring lobbyists. But, transit systems can use their employees who work at least 130 days for them for such purposes.

2. These are paid to U.S steamship yards that are constructing subsidized ships to prevent them from losing their businesses to foreign shipyards.

3. These are paid to U.S. flagship owners for the incremental costs of hiring crews who are U.S. citizens.

4. Since these subsidies also require local matching funds, local subsidies too depend upon input levels.

5. The choice of output does not affect the results.

6. Throughout this paper the terms "implied," "misperceived," and "after-subsidy" are used interchangeably.

7. Though we use labor in this discussion other inputs can also be used. The choice of an input does not affect the equations derived.

8. In specifying this equation we do not include such characteristics of operating environment as population and population density and route miles because their coefficients were not statistically significant in an initial specification of the model that included them.

9. The FTA suggests a spare ratio of 20% of the vehicles operated in maximum service.

10. Although we could have used passenger miles squared over operating cost, we opt for this approach because the total actual cost used in calculating deadweight loss includes operating cost.

11. These findings are also contained in: Comptroller General 1981. Report to the Congress of the United States: Soaring Transit Subsidies must be controlled. United States General Accounting Office, Washington D.C.

12. These transit systems operate regular buses, vanpools, express bus services and demand responsive services.

13. Capital cost is calculated as $rK = Kr_K\ (R + d)e^{-d(z)}$ where, K is fleet size, r_K is the weighted average price of a new public transit bus in 2006 and z is the weighted average fleet age. R is the average prime rate for 2006, d is a straight line rate of depreciation assuming a bus useful life of 20 years.

14. To estimate the equations the expression $(1 - \mu_{oL}H_{oL} - \mu_{KL}H_{KL})^{-1}$ in the actual cost and labor share equations was expanded up to first order to obtain $(1 + \mu_{oL}H_{oL} + \mu_{KL}H_{KL})$. The same expansion was done for similar terms in the capital and fuel share equations. Notice that because μ and H take values between zero and one the quadratic and higher order terms in this expansion reduce the cost and input shares by very small amounts.

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APPENDIX A

From Figure 3 the deadweight loss is,

$$(A.1)\quad DWL_L = L\left(w_o \quad w^*\right) \; \int_{w^*}^{w} L(w)\partial w = \left(\tfrac{1}{2}\right)(\Delta L)(\Delta w)$$

To operationalize Eq. (A.1), let η_i be the absolute value of own price elasticity of input demand and rewrite it as,

$$(A.2)\quad \eta_L = \frac{\Delta \ln L}{\Delta \ln w} \quad where \quad \Delta \ln L = \left(L - L^*\right)/L^*$$

Expanding and solving this equation gives $\Delta L = L^*\eta_L \Delta \ln w$, and substituting the implied price of labor into it gives $\Delta L = L^*\eta_L(\mu_{oL}H_{oL} + \mu_{KL}H_{kL})$ where $\Delta \ln(w) = \left(w_0 - w^*\right)/\, w_o = (\mu_{oL}H_{oL} + \mu_{KL}H_{KLi})$. Additionally, substituting these results into Eq. (A.1 gives the deadweight loss from misusing some of the subsidies going to labor as:

$$(A.3)\quad DWL_L = \frac{1}{2}(\Delta w)\,(\Delta L) = \frac{1}{2} w_0 L^* \eta_L \left(\mu_{oi}H_{oL} + \mu_{KL}A_{KL}\right)^2$$

Expressing L^* in observable terms by solving for it in $\Delta L = L \quad L^* = L^*\eta_L\left(\mu_{oL}H_{oL} + \mu_{KL}H_{KL}\right)$ and substituting the result into Eq. (A.3), gives Eq. (A.4) as the deadweight loss from misusing some of the subsidies going to labor.

$$(A.4)\quad DWL_L = \frac{w_0 L \eta_L \left(\mu_{oL}H_{oL} + \mu_{KL}H_{KL}\right)^2}{2\left(1 + \eta_L\left[\mu_{oL}H_{oL} + \mu_{KL}H_{KL}\right]\right)} = \frac{CS_L \eta_L \left(\mu_{oL}H_{oL} + \mu_{KL}H_{KL}\right)^2}{2\left(1 + \eta_L\left[\mu_{oL}H_{oL} + \mu_{KL}H_{KL}\right]\right)}$$

Where, C is the observed total cost, S_L the observed share of an input in total cost, and all other terms are defined already. Rewriting and generalizing this equation gives,

$$(A.5)\quad DWL_i = \frac{CS_i\left(\mu_{oi}H_{oi} + \mu_{Ki}H_{Ki}\right)^2}{2\left(\eta_i^{\;1} + \mu_{oi}H_{oi} + \mu_{Ki}H_{Ki}\right)} \quad for \quad i = L, F, K$$

Taking the sum of this equation over all inputs and dividing both sides of the result by actual total cost gives the share of the deadweight loss in this cost as:

$$(A.6)\quad \frac{\sum_i DWL_i}{C} = \frac{1}{2}\sum_i \left\{ \frac{S_i \eta_i \left(\mu_{oi}H_{oi} + \mu_{Ki}H_{Ki}\right)^2}{\left(1 + \eta_i\left[\mu_{oi}H_{oi} + \mu_{Ki}H_{Ki}\right]\right)} \right\}$$

Further, differentiating Eq. (A.5) with respect to A_o gives:

$$\frac{\partial DWL_L}{\partial A_o} = \frac{\left\{4\eta_L\mu_{oL}\left(w_oL + \eta_L\left[\mu_{oL}A_o + \mu_{KL}A_K\right]\right)\left[\mu_{oL}A_o + \mu_{KL}A_K\right] - 2\eta_L^2\mu_{oL}\left(\mu_{oL}A_o + \mu_{KL}A_K\right)^2\right\}}{4\left(1 + \eta_L\left[\mu_{oL}H_{oL} + \mu_{KL}H_{KL}\right]\right)^2}$$

$(A.7)$

$$= \eta_L\mu_{OL}\left\{\frac{\eta_L\mu_{oL}^2A_o^2 + 2A_o\mu_{oL}B + \mu_{KL}A_K\left(w_oL + B\right)}{2\left(1 + \eta_L\left[\mu_{oL}H_{oL} + \mu_{KL}H_{KL}\right]\right)^2}\right\} \qquad \text{where } B = w_oL + \eta_L\mu_{KL}A_K$$

Setting Eq. (A.7) to zero and solving for the optimal level of operating subsidy $(\hat{A}o)$, we have:

$$(A.8)\quad \hat{A}_o = \left(\frac{1}{\eta_L\mu_{oL}}\right)\left(B^2 - \eta_L\mu_{KL}A_K\left(B + w_oL\right)\right)^{0.5} = \frac{w_oL}{\eta_L\mu_{oL}}$$

Writing a similar equation as A.4 for capital and differentiating it with respect to capital subsidy gives,

$$(A.9)\quad \hat{A}_K = \frac{rK}{\eta_K\mu_{KK}}$$

To determine if these optimal subsidies are minimum or maximum we further differentiate Eq. (A.8) with respect to operating subsidies. That differentiation yields,

$$(A.10)\qquad \frac{\partial^2(DWL)}{\partial A_o^2} = \frac{\eta_L\mu_{oL}\left[\eta_L(1-2h)\frac{\partial h}{\partial A_o} - h(\eta_L h + 2w_oL)\frac{\partial g}{\partial A_o}\right]}{g}$$

$$\text{where } g = 1 + \eta_L\left(\mu_{oL}H_{oL} + \mu_{KL}H_{KL}\right) \quad \text{and} \quad h = \mu_{oL}A_o + \mu_{KL}A_K$$

Since $\partial h/\partial A_o = \mu_{oL}$, $\partial g/\partial A_o = \eta_?\mu_{OL}/w_oL$ substituting them into (A.10) gives,

$$(A.11)\quad \frac{\partial^2(DWL)}{\partial A_o^2} = \frac{\eta_L^2\mu_{oL}^2\left[1 - 4h - h^2\mu_{oL}/w_oL\right]}{g}$$

Substituting the optimal value of operating subsidy into the expression for *h* and the result into A.11 gives a negative value for the second order partial derivative as can be seen by inspection. Therefore, the optimal subsidies calculated are the maximum subsidies.

APPENDIX B

Both the implied cost and actual total cost are related by the relationship $C = w\frac{\partial C^*}{\partial w^*} + r\frac{\partial C^*}{\partial r^*} + p\frac{\partial C^*}{\partial p^*}$,. This is because $\frac{\partial C}{\partial w} = \frac{\partial C^*}{\partial w^*}, \frac{\partial C}{\partial r} = \frac{\partial C^*}{\partial r^*}, \frac{\partial C}{\partial p} = \frac{\partial C^*}{\partial p^*}$. Since the share of labor in total implied cost is $S_L^* = \frac{\partial \ln C^*}{\partial \ln w^*}$ and $w / w^* = 1/(1 - \mu_{oL}H_{ol} - \mu_{KL}H_{KL})$, the first term of the actual total cost equation is $C^* S_L^* (1 - \mu_{oL} H_{ol} - \mu_{KL} H_{KL})^{-1}$. Writing similar expressions for the other terms, substituting them into the actual total cost equation and then factorizing results in Eq. (B.1).

$$(B.1)\ C = C^* \left\{ S_L^* (1 \quad \mu_{oL}H_{oL} \quad \mu_{KL}H_{KL})^{\ 1} + S_K^* (1 \quad \mu_{ok}H_{oK} \quad \mu_{KK}H_{KK})^{\ 1} + S_F^* (1 \quad \mu_{oF}H_{oF} \quad \mu_{KF}H_{KF})^{\ 1} \right\}.$$

Taking the logarithms of this equation gives Eq. (B.2).

$$(B.2)\ \ln C = \ln C^* + \ln \upsilon$$

Where, υ is the term in braces in Eq. (B.1).

Substituting the translog expansion of ln*C** into Eq. (B.2) gives Eq. (B.3) below.

$$(B.3)\ \ln(C) = \left\{ \begin{array}{l} \beta_o + \beta_L \ln(w^*) + \beta_K \ln(r^*) + \beta_F \ln(p^*) + \beta_Q \ln(Q) + 0.5\beta_{LL}[\ln(w^*)]^2 + \beta_{LK} \ln(w^*)\ln(r^*) \\ \quad + \beta_{LF} \ln(w^*)\ln(p^*) + \beta_{LQ} \ln(w^*)\ln(Q) + 0.5\beta_{KK}[\ln(r^*)]^2 + \beta_{FK} \ln(r^*)\ln(p^*) \\ \quad + \beta_{KQ} \ln(r^*)\ln(Q) + 0.5\beta_{FF}[\ln(p^*)]^2 + \beta_{FQ} \ln(p^*)\ln(Q) + 0.5\beta_{QQ}[\ln(Q)]^2 \end{array} \right\} + \ln(\upsilon) + \varepsilon_1$$

Where, the term in braces is the implied cost function and symmetry and homogeneity of degree one in input price restrictions are imposed on it. In the case of symmetry, for example, $\beta_{KL} = \beta_{LK}$ and $\beta_{QL} = \beta_{LQ}$, and for homogeneity of degree one in input prices the restrictions below apply.

$$(B.4)\ \begin{array}{l} \beta_L + \beta_K + \beta_F = 1, \quad \beta_{LL} + \beta_{LF} + \beta_{LK} = 0, \quad \beta_{LK} + \beta_{KF} + \beta_{KK} = 0, \\ \beta_{LF} + \beta_{FF} + \beta_{KF} = 0, \quad \beta_{LQ} + \beta_{FQ} + \beta_{KQ} = 0 \end{array}$$

From the implied cost function Eq. (B.5) is the share of labor in implied cost.

$$(B.5)\ S_L^* = \beta_L + \beta_{LL} \ln(w^*) + \beta_{LK} \ln(r^*) + \beta_{LF} \ln(p^*) + \beta_{LQ} \ln(Q)$$

Similar equations as (B.5) can also be written for both the shares of capital and the other inputs in implied total cost. Examining this equation S_L^* must be expressed in terms of actual cost share since it is unobservable. To do so we multiply $w = w^* / (1 - \mu_{oL}H_{oL} - \mu_{KL}H_{KL})$ and $p = p^* / (1 - \mu_{oF}H_{oF} - \mu_{KF}H_{KF})$ respectively by labor (*L*) and the other inputs (*F*) and divide each result by actual total cost (*C*). The results in Eq. (B.6) express actual cost shares of labor (S_L) and the other inputs (S_F) in terms of their respective implied cost shares.

(*B*.6)

$$S_L = S_L^* (1 \quad \mu_{oL}H_{oL} \quad \mu_{KL}H_{KL})^{-1} / \upsilon = \{\beta_L + \beta_{LL} \ln(w^*) + \beta_{LK} \ln(r^*) + \beta_{LF} \ln(p^*) + \beta_{LQ} \ln(Q)\}(1 \quad \mu_{oL}H_{oL} \quad \mu_{KL}H_{KL})^{-1} / \upsilon$$

$$S_F = S_F^* (1 \quad \mu_{oF}H_{oF} \quad \mu_{KF}H_{KF})^{-1} / \upsilon = \{\beta_F + \beta_{LF} \ln(w^*) + \beta_{FK} \ln(r^*) + \beta_{FF} \ln(p^*) + \beta_{FQ} \ln(Q)\}(1 \quad \mu_{oF}H_{oF} \quad \mu_{FK}H_{FK})^{-1} / \upsilon$$