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Welfare Effects of a Transport Subsidy in a Spatial Price Equilibrium

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Abstract

The paper shows that in a spatial price equilibrium under monopolisitc competition welfare can be increased by subsidising transport. Therefore transport can be said to exert a positive (pecuniary) externality. This is demonstrated by introducing a subsidy into a partial spatial price equilibrium of the HOTELLING-SMITHIES type in one-dimensional space. Two varieties of demand are analysed, linear and negative exponential. The welfare effect of a transport subsidy is shown to be decomposable into three effects, the expansion effect, the competition effect and the market size effect. Numerical results and decompositions are presented.

Keywords: transport, externality, spatial price equilibrium, welfare.

1 Introduction

In all developed market economies, transport is still a highly subsidised sector, either due to direct monetary subsidies or due to indirect subsidising transport by not charging for negative externalities. Taking Germany (West) as an example, passenger transport on roads is estimated to have generated external costs amounting to almost 100 billion DM in 1991 (MAUCH and ROTHENGATTER, 1994 [7]). Subtracting the surplus of car and fuel tax receipts over operating costs of roads (less than 5 billion DM, according to BICKEL and FRIEDRICH, 1995 [3]) and dividing by passenger kilometers results in a subsidy of roughly 0.15 DM per passenger kilometer. This is an implicit subsidy rate of something like 1/3. For rail transport externalities per passenger-kilometer are considerably smaller, but explicit subsidies are large. Adding both (taking again figures from MAUCH and ROTHENGATTER, 1994, and BICKEL and FRIEDRICH, 1995) results in a subsidy of roughly 0.15 DM per passenger kilometer as well. Similar calculations can be made for goods transport resulting in a subsidy rate of more than 40 % for road (1/3 of which is direct subsidy) and more than 30 % for rail.

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To be sure, the cited figures are subject to critical discussion, to say the least. Even accepting wide margins of uncertainty, however, there is no doubt that there is a wide gap between private and social cost in transport.

Two arguments could be put forward for justifying such a high rate of subsidiation. One is that the subsidy corrects for the excess of average over marginal cost. According to this argument, letting firms and households pay the full cost of transport would be inefficient because the whole system operates under increasing returns. This argument might be convincing for a transport system which, due to indivisibilities, has to operate with significant excess capacity. In a congested system in closely populated areas, however, it is unlikely that we are still on the decreasing part of the average cost curve. Even if marginal exceed average costs to some extent, it is not obvious that this is the case to a larger extent in the transport sector than it is anywhere else.

The second argument, forcefully put forward by a few authors in the German language debate (Willeke, 1996 [11]; Baum, 1997 [2]; Aberle and Engel, 1992 [1]) claims that transport does not only exert negative but also positive externalities. Hence, net externalities might even be positive, such that the total volume of transport turns out to be too small rather than too large. Even though the mentioned authors have written many pages and have held many speeches about positive transport externalities, however, their argument is weak. They present long lists of transport benefits, but the proof why these benefits should be external is lacking. As correctly stated by Rothengatter (1994) [8], the reported effects are pecuniary. Therefore, according to Rothengatter, they have no bearing for the issue of allocative efficiency. All the benefits are fully reflected in market prices.

This objection is certainly true in a perfect market. If markets are imperfect for one or the other reason, however, social benefits and social cost might well deviate from prices and from one-another. This does, of course, by no means imply that pecuniary effects have to be counted as positive externalities. The sign is open. It does mean, however, that pecuniary effects may count as externalities from a welfare economic point of view. More care is needed, and an explicit theoretical framework is required for finding whether or not social benefits exceed private benefits.

It is sometimes argued, that imperfect competition models suffer from arbitrariness, because any result could be generated by an appropriate choice of assumptions. Therefore, one should rely on perfect competition results, which are most accepted as giving first approximations and guiding principles for a hopelessly complex world. This explains why in many fields like optimal tax theory, for example, perfect competition models still have a role to play, though the real world is obviously full of imperfections. The paradigm can not be held up however, if the perfect competition assumption is logically inconsistent with the problem under study. Exactly this is the case when we study efficiency issues in transport.

In a perfectly competitive world there is no transport, except for the trivial reason that natural space is non-homogenous. In homogenous space a perfect competition locational choice equilibrium with strictly positive transport cost does not exist. This is so obvious, that it has been called the Folk-theorem of spatial economics. s If the reader wants a rigorous proof, it is in Starret's theorem (Starret, 1978 [10]), stating that if (1) firms are price taking, (2) no technological externalities exist, and (3) space is homogeneous, then the total incentive for firms to move is at least as large as total transport cost. The firms' incentive to move is the profit they could gain by changing location, given the prices. Hence, either there are no transport costs and our whole issue disappears, or there is no perfect competition equilibrium in a non-trivial sense. There is no choice other than working with imperfect competition models of spatial equilibrium.

The main sections of this paper check whether in a standard spatial price equilibrium model, which is based on a long tradition going back to the work of Lösch (1962) [6], positive pecuniary externalities of transport can be observed.

It is assumed that transport does not generate technological externalities of any kind. Under this condition, there is a positive externality, if the social marginal benefit exceeds the social marginal cost of transport. Increasing the level of transport then would generate additional welfare. Putting this differently, it would be worthwhile from a social point of view, to reduce the distortion by withdrawing funds from private agents and expending them for subsidising transport. This is the basic idea of our theoretical approach. We introduce a transport subsidy into the spatial price equilibrium and check, whether and to what extent a positive subsidy would contribute to social welfare. To make the vague notion of a pecuniary externality precise, we say that transport exerts a positive externality if and only if social welfare can be increased by a positive transport subsidy.

2 Linear demand

We introduce a transport subsidy into a standard partial price equilibrium model for an infinite one-dimensional spatial market. The list of publications about these models is immense. A standard reference for a comprehensive and rigorous treatment is Capossa and Van Order (1978) [4]. A modern textbook is Greenhut, Norman and Hung (1987) [5]. For a simplified treatment, the following assumptions are made:

1. Space is an infinite unbounded line.
2. Firms located at points on this line all produce the same homogeneous good with positive fixed and constant marginal costs.
3. Firms can relocate without cost, and market entry is free.
4. Consumers are continuously distributed over space with uniform density. Demand per unit of space is a linear[1] and strictly decreasing function of the local price.
5. Firms maximize profits by setting a mill price, presuming that rivals' mill prices will not react to price changes (so-called Hotelling-Smithies conjectural variation).
6. Transport costs are linear with respect to distance and quantity shipped.

[1] In a mathematically correct language, demand and cost functions are affine, because they don't go through the origin. Using the sloppy language of economics, however, we call the functions linear, as usual.

More specifically, transport cost per unit of distance and unit of quantity is set equal to one, marginal production cost is set equal to zero, and demand per unit of space is

$$d(p) = 1 - p,$$

where p is the local price. Though this choice of parameters seems to be very special, in fact no generality is lost by this choice of parameters within the class of linear models. As shown in the appendix, any model in this class can be transformed to the form given here by an appropriate choice of units for money, length of space and quantity of goods. What we call a price here, then turns out to be the excess of price over marginal production cost. We call the form of the model as given here the canonical form.

A transport subsidy is introduced by assuming consumers to pay only a fixed share $t \in (0, 1]$ of transport cost, while the share $(1-t)$ is paid as a subsidy financed by a lump sum tax. Hence, there are just two parameters left, namely t and the fixed cost F. It will be shown that the fixed cost is in the range $F \in [0, 4/(27t)]$. F is to be interpreted as a measure of monopoly power. If F approaches its upper bound firms tend to act as pure monopolists, while the market turns into a perfectly competitive one for F approaching zero.

If R denotes a firm's market radius (equal to both sides) and m its mill price, then its return is

$$\Pi(m, R, t) = 2m \int_0^R d(m + tx)\mathrm{d}x \tag{1}$$

$$= 2mR\left(1 - m - \frac{1}{2}tR\right). \tag{2}$$

A firm chooses m maximising this return, taking into account its conjecture about the reaction of the market radius on m, which in turn depends on its conjecture about rivals' behaviour. Note that maximising returns is equivalent to maximising profits, because marginal costs are zero. Hence, the optimal mill price solves

$$\Pi_m(m, R, t) + R_m^e \Pi_R(m, R, t) = 0. \tag{3}$$

Π_m and Π_R denote partial derivatives of Π with respect to m and R, respectively, and R_m^e is the expected derivative of R with respect to m.

Different assumptions about conjectural variations in spatial markets have been suggested in the literature, in particular LÖSCH competition ($R_m^e = 0$), HOTELLING-SMITHIES competition ($R_m^e = -1/(2t)$) and GREENHUT-OHTA competition ($R_m^e = -1/t$). HOTELLING-SMITHIES is an extension of BERTRAND competition to the spatial world and seems to be the most plausible one. LÖSCH competition implies coordinated behaviour of rivals and tends to monopolistic pricing in the limiting case $F \to 0$. This is not credible, taking into consideration that the density of firms goes to infinity for vanishing F due to free entry. On the other end, GREENHUT-OHTA sounds like an overreaction of rivals: on a mill price increase they react by *reducing* their price such that the local price at the market boundary remains constant. HOTELLING-SMITHIES is most convincing and also has been shown to come close to what is called rational conjectural variation in the literature (SCHÖLER, 1993) [9].

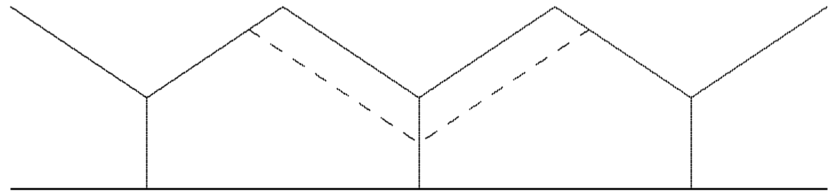

Figure 1: Market areas

HOTELLING-SMITHIES competition is illustrated in figure 1. When firms seek an optimal mill price, they regard their neighbours' mill prices as fixed. Hence, if $\tilde{m}$ denotes the neighbour's mill price and $\tilde{R}$ the distance to the neighbour, then from the equality of local prices of neighbouring firms at their market boundary we have

$$m + tR^e = \tilde{m} + t(\tilde{R} - R^e).$$

Implicitly differentiating R^e with respect to m yields $R^e_m = -1/(2t)$.

Inserting Π_m, Π_R and R^e_m into (3) yield a quadratic equation, having the two solutions

$$m_{1,2} = \frac{1}{2}\left(1 + 3tR \pm \sqrt{13(tR)^2 - 2tR + 1}\right).$$

Both are real, because the minimum of the expression under the square root is $(1-1/13) > 0$. Calculating the second derivative shows that the negative square root delivers the maximum. Obviously, the optimal mill price can be written as a function of tR. This function is called the reaction function, denoted by μ,

$$\mu(tR) = \frac{1}{2}\left(1 + 3tR - \sqrt{13(tR)^2 - 2tR + 1}\right) \tag{4}$$

and plotted in the upper panel of figure 2.

The domain of the reaction function is $[0, 2/3]$. For $tR = 2/3$ we have $m = \mu(2/3) = 1/3$ and $\Pi_m = \Pi_R = 0$, the local price at the market boundary equals 1, and, hence, demand at the market boundary equals zero. A firm with no rivals would choose the mill price $m = 1/3$ and the market radius $R = 2/(3t)$. Therefore, if the distance between firms exceeds $4/(3t)$, they act as independent pure monopolists, and their markets don't touch.

Finally, the radius tR is obtained by the free entry condition

$$\Pi\left(\mu(tR), R, t\right) = F \tag{5}$$

saying that firms enter or leave the market until the maximal attainable return just covers the fixed cost. Using (2) and inserting μ for m leads to a 6th degree polynomial, having no analytical solution. Rewrite (5) as

$$t\Pi\left(\mu(tR), R, t\right) = tF.$$

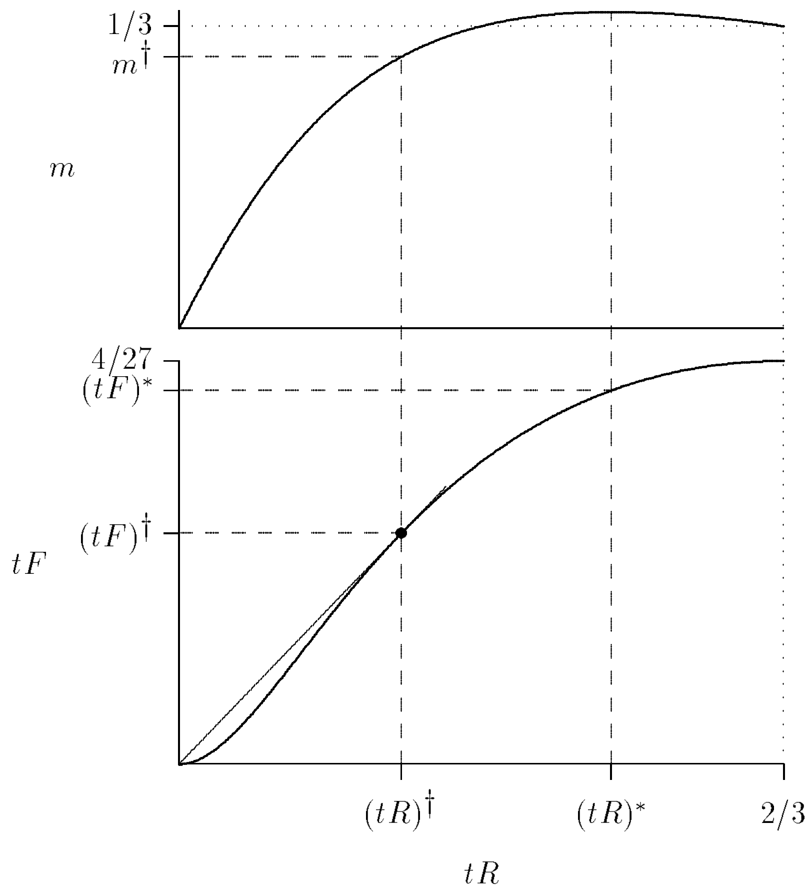

Figure 2: HOTELLING-SMITHIES-equilibrium

It is obvious from (2), that the left-hand side can be written as a function of tR. We call it ρ,

$$\rho(tR) = 2\mu(tR)tR\left(1 - \mu(tR) - \frac{1}{2}tR\right).$$

ρ is strictly monotone increasing in tR, with $\rho(0) = 0$ and $\rho(2/3) = 4/27$ (see the lower panel of figure 2). Therefore there is a unique $tR = \rho^{-1}(tF)$ for $tF \in [0, 4/27]$. For $tF > 4/27$ there is no solution. No firm would enter the market, if fixed costs F exceed $4/(27t)$, because even as pure monopolists they could not cover these costs by the maximal attainable returns.

The determination of an equilibrium is illustrated in figure 2. For example, let $tF = (tF)^\dagger$. Then we obtain $(tR)^\dagger$ from ρ^{-1} (follow the dashed line in the lower panel), and from $(tR)^\dagger$ we obtain $m^\dagger$ from μ (follow the dashed line through the upper panel).

Next we derive the global welfare measure used for assessing the effect of a transport subsidy. Total welfare is the consumers' benefit, measured as the area under the demand curve, minus transport costs and fixed costs, per unit of space. The benefit of a consumer faced with local price p is $(1 - p^2)/2$ (see figure 3). Hence, consumers residing on one

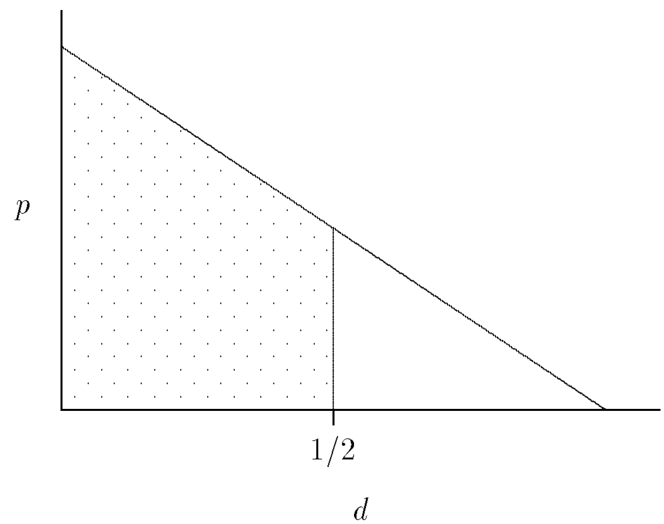

Figure 3: Consumers' benefit, linear demand

side of a firm (i. e. between a firm's location and one of its market boundaries) gain an aggregated benefit

$$B = \frac{1}{2}\int_0^R \left(1 - (m + tx)^2\right) \mathrm{d}x. \tag{6}$$

The total transport cost, including the subsidised share, amounts to

$$T = \int_0^R x(1 - m - tx)\mathrm{d}x \tag{7}$$

for the same interval of space. Hence, the welfare measure is

$$V(t, m, R) = (B - T - F/2)/R. \tag{8}$$

Substituting m and R we obtain the welfare measure as a function of the parameters F and t

$$W(F,t) = V\left(t, \mu\left(\rho^{-1}(tF)\right), \rho^{-1}(tF)/t\right). \tag{9}$$

Figure 4 plots the measure over F and t by showing level curves for the welfare levels

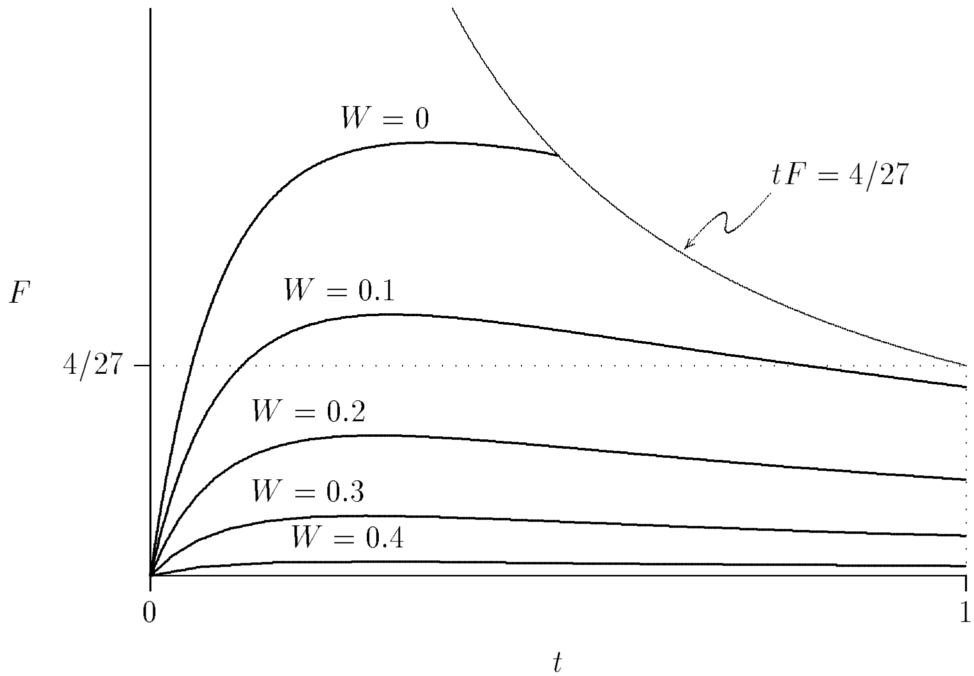

Figure 4: Welfare, linear demand

$0, .1, \ldots, .5$. The level curve for $W(F,t) = .5$ is the abscissa. Obviously, for $F \to 0$, the density of firms tends to infinity, transport costs tend to zero, and the local price tends to zero everywhere as well. Hence, for $F = 0$, a benefit of $1/2$ per unit of space uniformly accrues to consumers.

The figure shows that for $F \in (0, 4/27]$ a transport subsidy is welfare increasing. The maximum welfare is attained for t around .3, that means for a subsidy around 70 %. The exact value of the welfare maximising subsidy slightly varies with F. A further increase of the subsidised share of transport cost then eventually makes welfare sharply decline and brings it to minus infinity, as t approaches zero.

Things are a little bit more complicated for $F > 4/27$. Remember that firms only enter the market if $tF \leq 4/27$. Hence, for $F > 4/27$ a subsidy could open a market, which otherwise would not be served (mobile pizza service, say). We call this the *new market effect*. For sufficiently low subsidies this effect is beneficial, because markets with negative net welfare would still remain closed. For a subsidy rate exceeding 50 % [2], however, firms could start to enter a market, which should not be opened from a social point of view.

[2] At the point where the level curve for the welfare level zero touches the $(tF = 4/27)$-hyperbola, the two equations $W(F,t) = 0$ and $tF = 4/27$ must hold. The solution is $t = 1/2$ and $F = 8/27$.

In the following, we abstract from the new-market effect and try to illustrate, why a subsidy increases welfare in an existing market. Three effects are at work, which we call the expansion effect, the competition effect, and the market size effect. They correspond to the three components in the derivative of $W(t, F)$ with respect to t,

$$W_t = V_t + V_m m_t + V_R R_t.$$

Subscripts denote the derivatives of the respective variables with respect to subscript variables, evaluated at the equilibrium point. We explain these three effects in turn.

Due to the *expansion effect* V_t, local prices decline (except of the points where firms are located), holding the mill price and the market radius constant. The price decline is proportional to the distance of the consumer from the firm. For t not too small, this is welfare increasing, because the local price everywhere exceeds marginal cost, which equals the distance x. Note that there are no marginal costs other than transport cost. Hence, the subsidy brings the local price closer to marginal costs and leads to a production and demand expansion. This generates additional welfare, as long as local prices exceed marginal costs. If t is sufficiently small, however, a subsidy increase reduces welfare, because consumers closer to the market boundary of a firm already pay less than the marginal cost. V_t equals zero, if these losses in a larger distance just make up for the gains in a shorter distance. Figure 5 shows the $(V_t = 0)$-locus[3], right of which V_t is negative (i. e. increasing the subsidy is welfare enhancing), and left of which V_t is positive (i. e. increasing the subsidy is welfare reducing).

The *competition effect* $V_m m_t$ normally reduces the mill price due to the fact, that with decreasing t the market radius reacts more sensitively to the mill price. Hence, demand becomes more elastic and the price mark up declines. For t not too small, this is again welfare increasing, because local prices exceed marginal cost. If t is sufficiently small, however, a further subsidy reduces welfare, because more distant consumers already pay less than marginal costs.

The competition effect is said "normally" to reduce the mill price. To be precise, this occurs only for $tR < (tR)^* = (3\sqrt{3} + 1)/13 \approx .477$, which corresponds to $tF < (tF)^* = \rho((tR)^*) \approx .137$. For $tF > (tF)^*$ the mill price reacts non-normally: bringing firms closer together by reducing t *increases* the mill price. The reason is that for tR close to $2/3$, the local price near the market boundary comes close to one, and the elasticity of demand per unit of space comes close to infinity near the market boundary. Reducing tR has a double effect, it strengthens competition with the neighbouring rival making demand more elastic, but it also reduces the local price near the boundary, making demand less elastic. For $tF > (tF)^*$ the latter effect dominates.

Figure 6 shows the landscape of signs of $V_m m_t$. Right of the $(V_m = 0)$-locus[4] V_m is negative (i. e. an increase of the mill price is welfare decreasing). Left of it V_m is positive, i. e. an increase of the mill price is welfare enhancing, because for small t local prices are already much too low near the market boundary. North-east of the $m_t = 0$-locus m_t

[3]The $(V_t = 0)$-locus is obtained as follows: By (8) $V_t = 0$ is equivalent to $B_t = T_t$. Using the derivatives of B and T according to (6) and (7), this condition can be rearranged as $t = 2tR/(3m + 2tR)$. Using this and $F = \rho(tR)/t$, one can plot t and F in (t, F)-space for $tR = 0, \ldots, 2/3$.

[4]Similarly to the $(V_t = 0)$-locus (see footnote 3), the $(V_m = 0)$-locus is obtained from the condition $B_m = T_m$, rearranged as $t = tR/(2m + tR)$.

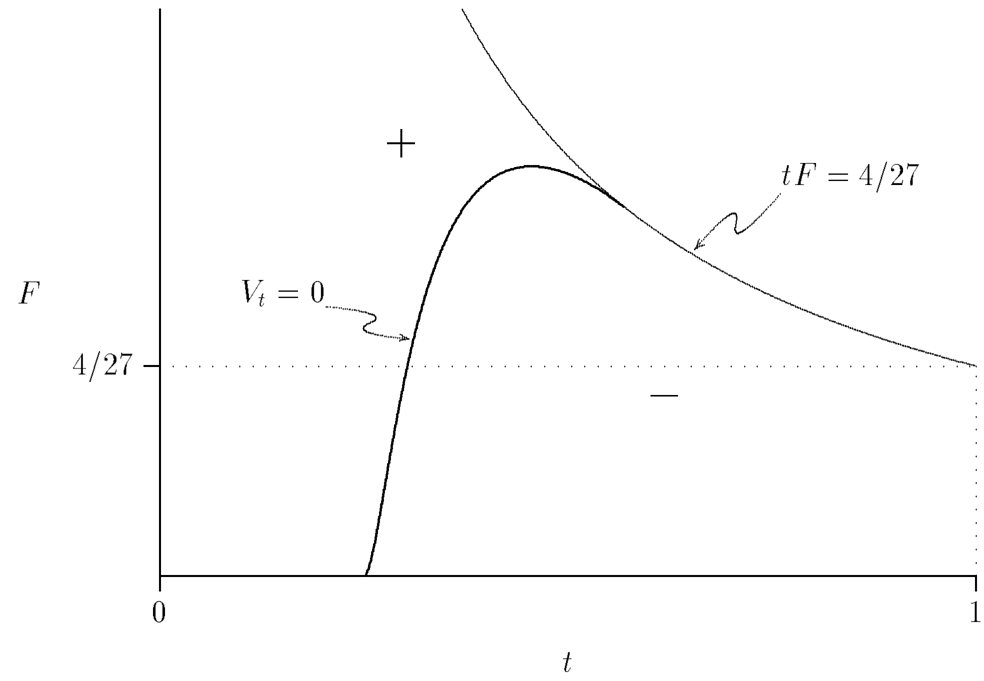

Figure 5: Expansion effect, linear demand

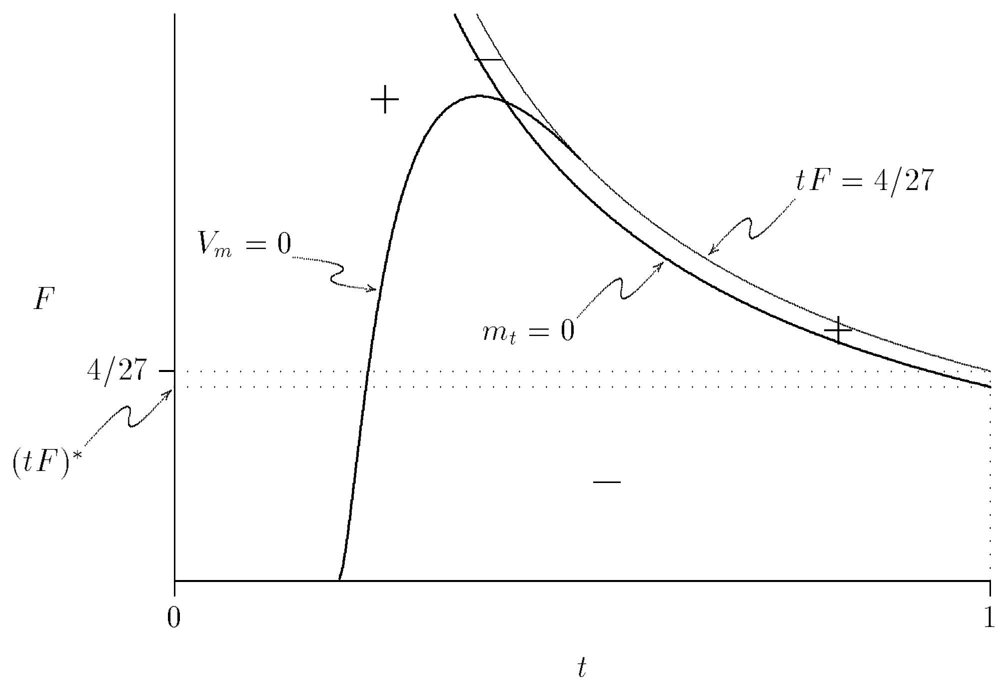

Figure 6: Competition effect, linear demand

is negative, i. e. the mill price reacts non-normally, south-west of it m_t is positive. The $(m_t = 0)$-locus is the hyperbola with $tF = (tF)^*$.

The non-normal section is generated by the assumption, that there is an upper price bound ($p = 1$ in our case), where demand vanishes completely, and where the price elasticity goes to minus infinity. This behaviour looks somewhat artificial, and it would vanish, if demand smoothly tended to zero for the local price tending to infinity. Hence, we consider this case in section 3 by assuming a negative exponential form of demand.

Finally, there is the *market size effect* $V_R R_t$, the welfare implication of which is less obvious. A transport subsidy can shrink or widen the firms' market size, and both, a larger or smaller market size can be beneficial, depending on the specific parameters. The landscape of signs of $V_R R_t$ is drawn in figure 7.

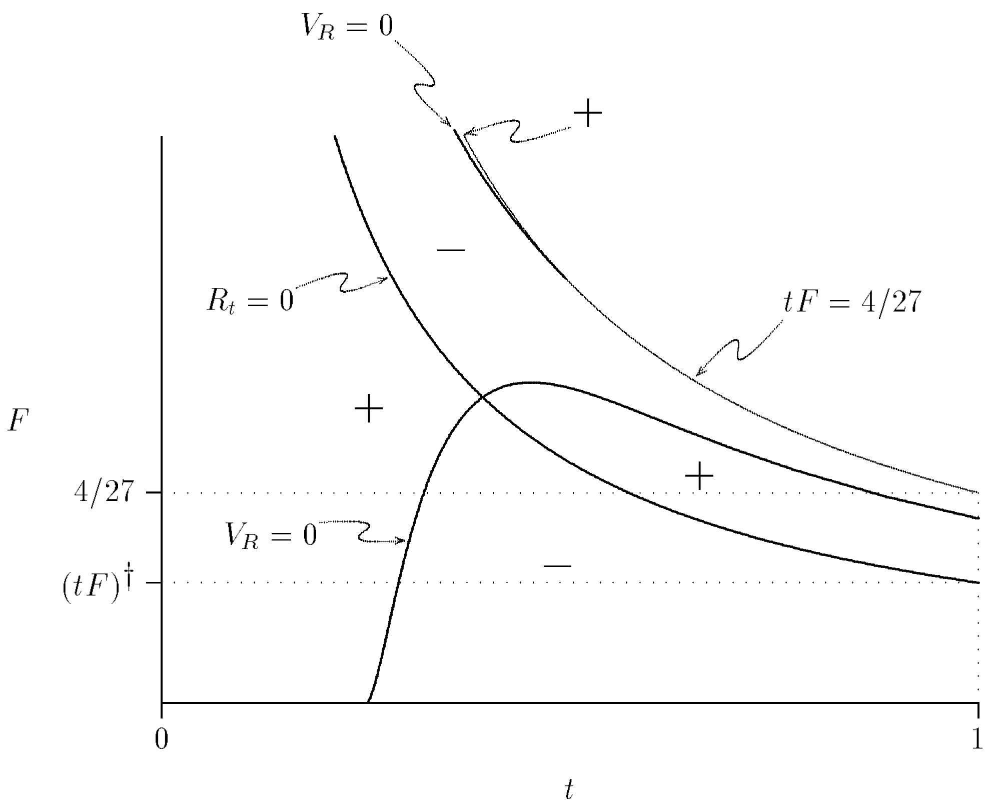

Figure 7: Market size effect, linear demand

The $(R_t = 0)$-locus is the hyperbola with $tF = (tF)^\dagger \approx .085$. $(tF)^\dagger$ is the point where the elasticity of ρ with respect to tR is unity (see figure 2). For $tF < (tF)^\dagger$ ($tF > (tF)^\dagger$) the derivative R_t is negative (positive). The $(V_t = 0)$-locus[5] consists of two

[5]According to (8) the condition $V_R = 0$ is equivalent to $(B - T - F/2)/R = B_R - T_R$. This can be rearranged as

$$t = \frac{(m-1)/2 + 2tR/3}{m/2 + tR/3 - tF/(2(tR)^2)}.$$

Similarly to the $(V_t = 0)$-locus, this is used for plotting the $(V_R = 0)$-locus in (t, F)-space.

curve segments, the humped curve, under (above) which V_R is positive (negative), and a curve segment close to the $(tF = 4/27)$-boundary at the top of the figure. The latter is in the domain of negative welfare and of no practical importance.

Summarising this, we observe an expansion effect of a transport subsidy, which is always welfare enhancing if the subsidy is not too large, a competition effect, which is also welfare enhancing for not too large subsidies, except from a narrow band of non-normal reaction, and a market size effect with mixed consequences. If the subsidy is not too large, however, the welfare enhancing effects have been shown numerically to dominate.

What about the quantitative shares, which these three effects have in the total impact? These shares differ over the parameter space, of course. Hence, we confine the analysis to the base case $t = 1$. Figure 8 plots W_t and its three components over $F \in [0, 4/27)$ for $t = 1$. We observe the welfare effect to stem mainly from the expansion and the competition effect over a wide range of fixed costs. Both effects have a similar magnitude. It's only for F coming close to the upper bound 4/27, that $V_m m_t$ diverges to $+\infty$ and $V_R R_t$ diverges to $-\infty$. These divergences are due to the fact, that R_t tends to ∞ for F tending to 4/27. As noted before, the non-normal reaction μ for $tR > (tR)^*$, making m_t diverge to $-\infty$ for F tending to 4/27, is regarded as artificial and is avoided by the negative exponential demand function introduced in the next section.

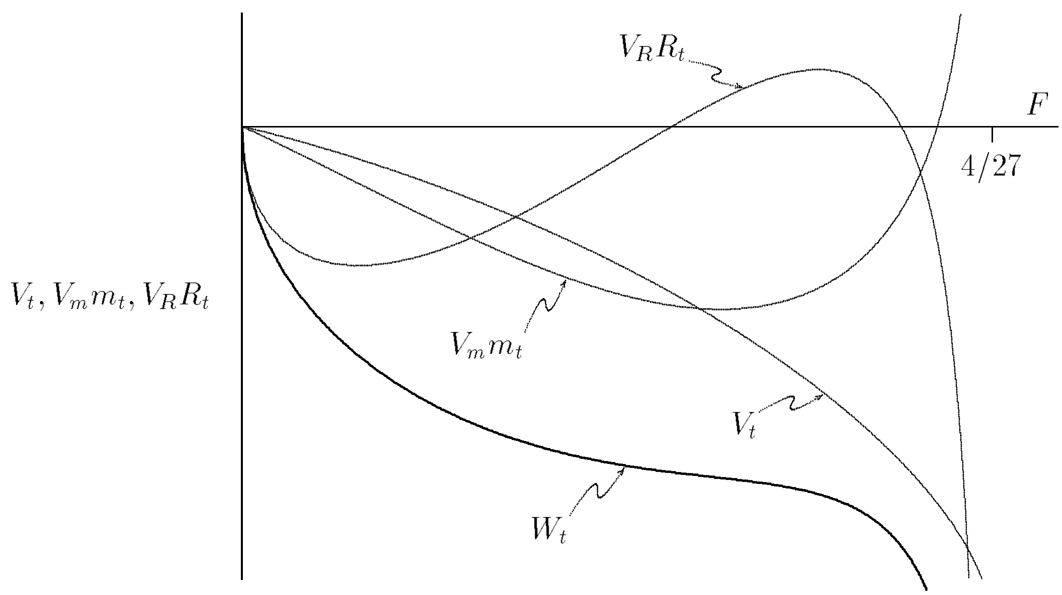

Figure 8: Decomposition of W_t, linear demand

3 Negative-exponential demand

It has been mentioned in the last section, that for $tF > (tF)^*$, the model with linear demand behaves strangely, in that a decrease in tF increases the mill price, while intuitively it should bring about more competition between firms and, hence, a decreasing mill price. The reason for this non-normality is that price elasticity of demand tends to infinity, if the local price tends to unity. Hence, though shrinking the market radius intensifies competition between neighbouring firms, it also reduces price elasticity of demand at the market boundary. For $tF > (tF)^*$ the latter effect dominates.

To avoid this non-normality, let local demand per unit of space have the canonical form

$$d(p) = \exp(-p).$$

Any model with negative exponential demand can be translated into this form by an appropriate choice of units. We omit the proof, which would follow the lines of the linear case. Then a firm's returns Π are

$$\begin{aligned} \Pi(m, R, t) &= 2m \int_0^R d(m + tx)\mathrm{d}x \\ &= 2\frac{m(1 - \exp(-tR))}{t\exp(m)}. \end{aligned} \tag{10}$$

Solving the optimum condition (3) then yields the reaction function

$$\mu(tR) = \frac{\exp(tR) - 1}{\exp(tR) - 1/2}. \tag{11}$$

Obviously, this function strictly increases in tR, with $\mu(0) = 0$ and $\lim_{tR\to\infty} \mu(tR) = 1$. tR is obtained from the free entry condition (5), with ρ obtained from (10) as

$$\rho(tR) = 2\mu(tR)\exp(-\mu(tR))(1 - \exp(-tR)).$$

It's easily seen that this is strictly increasing in tR, taking into consideration the fact that $\mu(tR) < 1$ by (11). The limits are $\rho(0) = 0$ and $\lim_{tR\to\infty} \rho(tR) = 2\exp(-1)$. Hence, there is a unique solution for $tF \in [0, 2\exp(-1))$, while no firm would enter the market for $tF \geq 2\exp(-1)$.

The benefit of a consumer faced with local price p now becomes $(1 + p)\exp(-p)$ (see figure 9). Hence, on one side of a firm consumers gain the benefit

$$B = \int_0^R (1 + m + tx)\exp(-m - tx)\mathrm{d}x.$$

The total transport cost amounts to

$$T = \int_0^R x\exp(-m - tx)\mathrm{d}x,$$

and, as before, the welfare measure is (9), with V defined in (8). Figure 10 plots the measure over F and t by showing the level curves for the welfare levels $0, .2, \ldots, 1$. The level curve for $W(F, t) = 1$ is the abscissa, because, for $F = 0$, the local price uniformly equals zero and a welfare of 1 per unit of space uniformly accrues to consumers.

Figure 10 shows qualitatively the same results as for the linear case. For $F > 2\exp(-1)$, a subsidy has a new-market effect, if t falls short of $2\exp(-1)/F$. It is always beneficial, as long as the rate of subsidy does not exceed 50 %. A larger subsidy

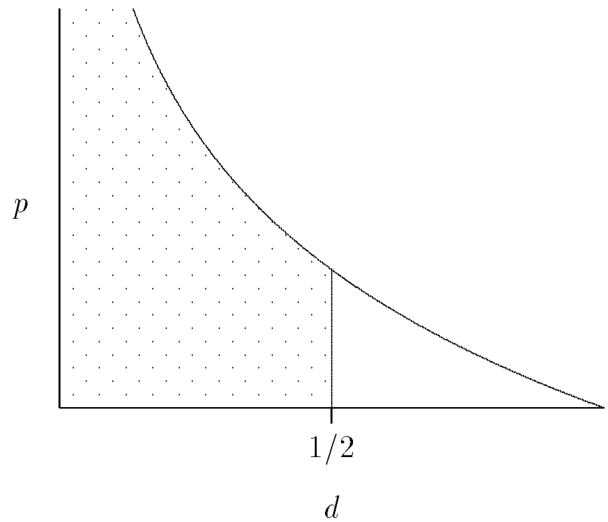

Figure 9: Consumers' benefit, negative exponential demand

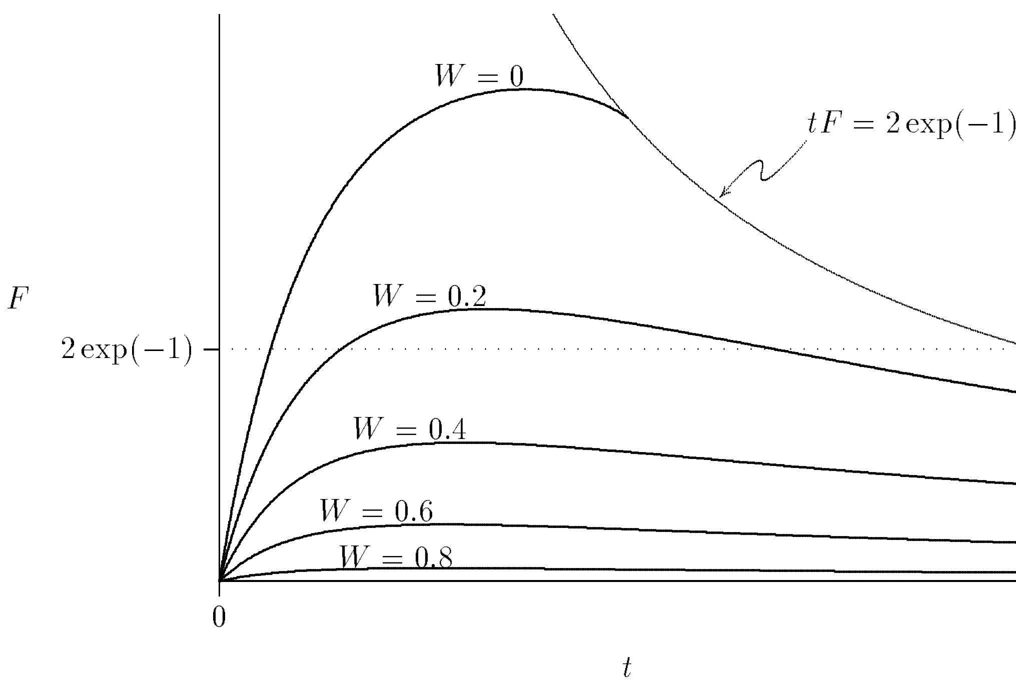

Figure 10: Welfare, negative exponential demand

could bring firms into a market, where a negative net welfare is generated, because fixed costs are too large.[6]

Figures 11, 12 and 13 show the signs of the expansion, competition and market size effect, respectively.

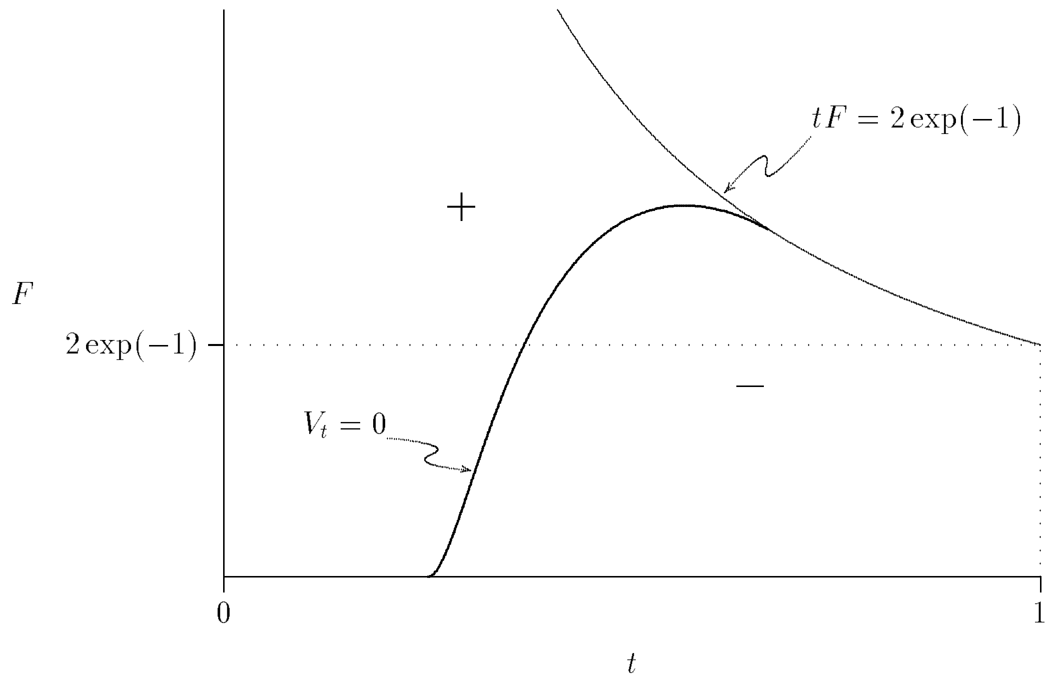

Figure 11: Expansion effect, negative exponential demand

The overall picture closely resembles the picture for the linear model, with one exception: there is no non-normal reaction in the negative-exponential case. The narrow band north-east of the $(R_t = 0)$-line in figure 6 is therefore missing in figure 12. For the same reason, the sign of the competition effect does not turn to positive close to the monopoly point $F = 2\exp(-1)$ in figure 14. Except from this difference, figure 14 resembles figure 8.

4 Conclusion

It has been shown that in a spatial price equilibrium with monopolistic competition there is a positive externality of transport. This has been proved by demonstrating that a subsidy on transport financed in a non-distorting way increases social welfare. The effect has three components, an expansion effect, a competition effect, and a market size effect.

Before drawing the political conclusion that the present level of explicit or implicit subsidies on transport is socially desirable, however, some qualifications have to be expressed. First, more is needed to check the robustness of the result in partial equilibrium

[6] For negative exponential demand the curve for welfare level zero touches the $(tF = 2\exp(-1))$-hyperbola at $t = 1/2$ and $F = 4\exp(-1)$. See also footnote 2.

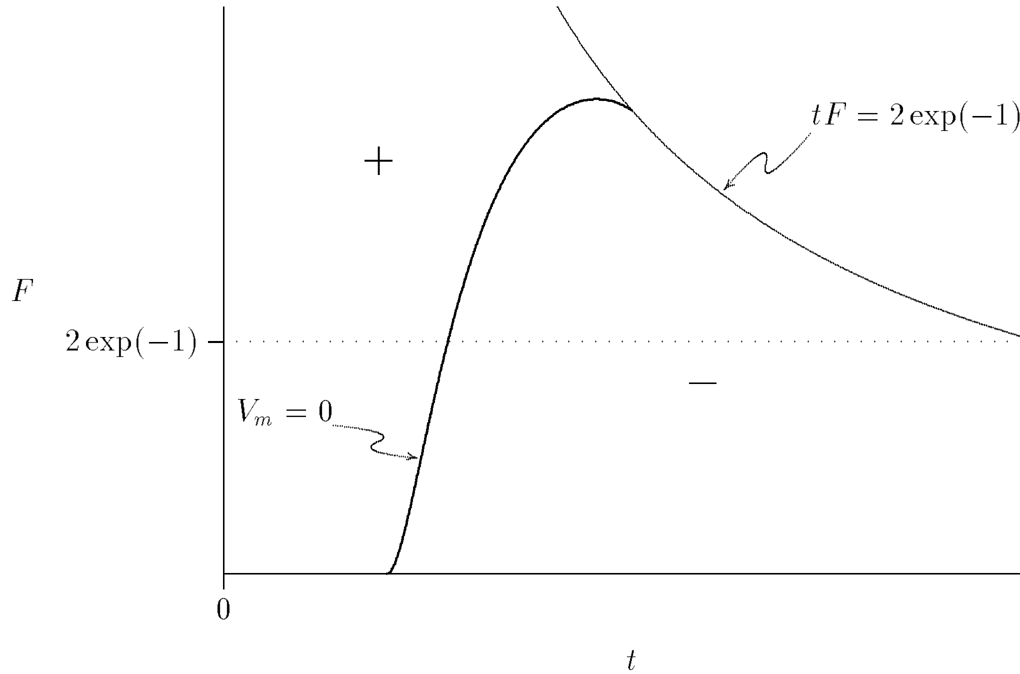

Figure 12: Competition effect, negative exponential demand

analysis. Other plausible assumptions about pricing strategies can be made, such as uniform pricing with BERTRAND behaviour. In such a framework the degree of competition is higher than in the HOTELLING-SMITHIES approach and, as a consequence, the welfare effect of a subsidy may be smaller. Second, though the principal patterns are likely not to depend on the special functional forms chosen here, quantitative conclusions can not be drawn without empirical research. Third, and most importantly, this study suffers from limitations of a partial equilibrium analysis. It is based implicitly on the assumption that competition is perfect in the rest of the economy. Our next step is to check, whether the effect survives a rigorous general equilibrium analysis.

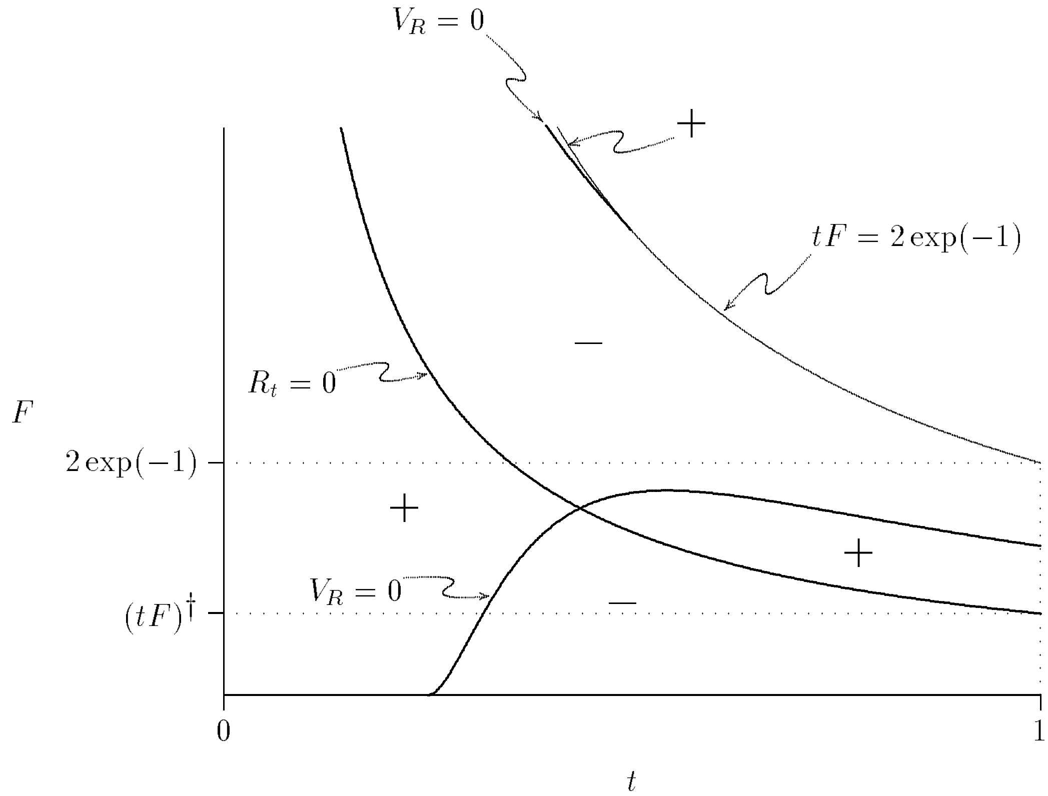

Figure 13: Market size effect, negative exponential demand

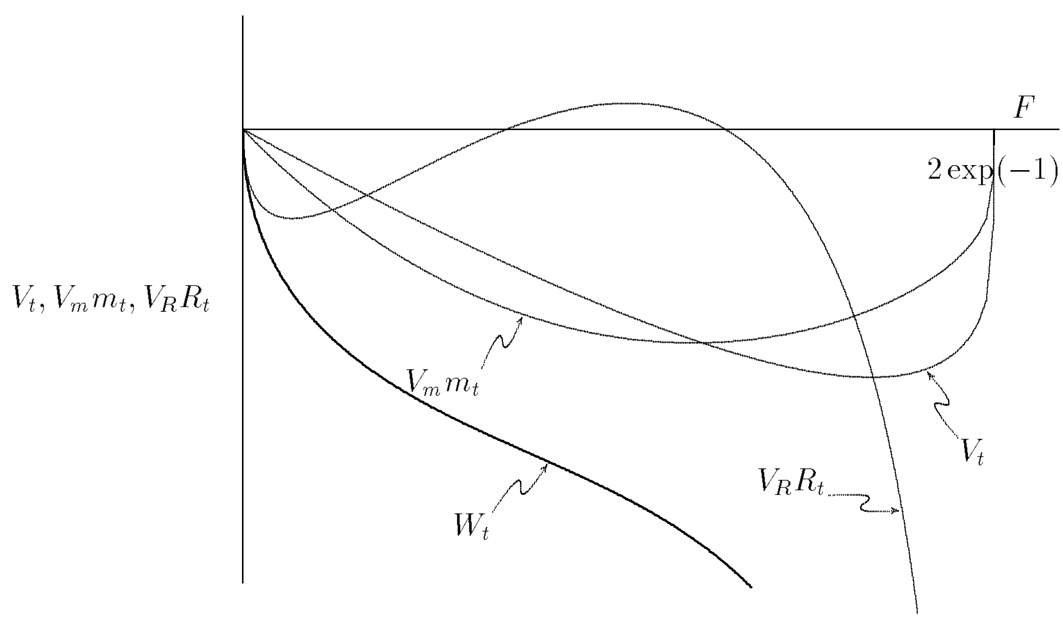

Figure 14: Decomposition of W_t, negative exponential demand

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Appendix

This appendix shows that, within the class of linear models, no generality is lost by choosing the canonical form. The reason is that one can choose units of space, quantity of goods, and money such that the canonical form is obtained. With this choice of units only one parameter is left to be studied (beyond the subsidy rate $(1-t)$), namely the (canonical) fixed cost $F \in [0, 4/27]$.

Let units of space, quantity of goods, and money be given. Call them "m" for space, "kg" for quantity, and "$" for money. Let

$$\tilde{d} = \alpha - \beta \tilde{q}$$

be an arbitrary linear demand function with demand quantity per unit of space $\tilde{d}$ [kg/m], price $\tilde{q}$ [$/kg], and positive parameters α [kg/m] and β [$\mathrm{kg}^2/(\mathrm{m}\ \$)$]. Furthermore, let τ

[\$/(kg m)] be the transport rate, and let $\tilde{c}$ [\$/kg] and F [\$] be the marginal and fixed cost, respectively. Introducing the excess of price over marginal cost $\tilde{p}$ [\$/kg] as a new variable, i.e. $\tilde{p} = \tilde{q} - \tilde{c}$, the demand function reads

$$\tilde{d} = \alpha - \beta\tilde{c} - \beta\tilde{p}.$$

Now we choose new units $\tilde{\mathtt{m}}$, $\tilde{\mathtt{kg}}$, and $\tilde{\$}$, such that the factors e, l, and g, respectively, convert space, quantity, and money from old to new units. Then demand becomes

$$d = \frac{l(\alpha - \beta\tilde{c})}{e} - \frac{\beta l^2}{ge}p.$$

d [$\tilde{\mathtt{kg}}/\tilde{\mathtt{m}}$] is demand per unit of space, and p [$\tilde{\$}/\tilde{\mathtt{kg}}$] is price minus marginal cost, both in terms of new units. Furthermore, $\tau g/(le)$ [$\tilde{\$}/(\tilde{\mathtt{kg}}\ \tilde{\mathtt{m}})$] is the transport rate in new units. Hence, fixing e, l, and g such that

$$\frac{l(\alpha - \beta\tilde{c})}{e} = \frac{\beta l^2}{ge} = \frac{\tau g}{le} = 1$$

leads to the canonical form. With $\phi = \alpha/\beta - \tilde{c}$ this gives $e = \tau/\phi$, $l = \tau/(\beta\phi^2)$, and $g = \tau/(\beta\phi^3)$. $1/e$ [m], $1/l$ [kg], and $1/g$ [\$] are the respective canonical units of space, quantity, and money.