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SPATIALLY-DIFFERENTIATED TRUCKING MARKETS: EQUILIBRIA UNDER PRICE REGULATION WITHOUT ENTRY RESTRICTIONS

By Gordon Mills *

No. 106

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DEPARTMENT OF ECONOMICS

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Abstract

Trucks provide transport between a pair of cities, with the demand for transport from A to B being more intensive than for the reverse (back-haul) direction. The trucking industry comprises individual owner-drivers, and there is no restriction on entry. For the two markets, the regulator sets the prices high enough to ensure that the number of trucks available does not fall short of the number of loads to be shipped. Shippers choose trucks at random. Each truck is based at either A or B, leaves its base iff a load is obtained, and returns to base with or without a load.

The analysis explores the ways in which extra costs are incurred as the regulated prices are raised above the necessary minimum levels. It is shown also that there can be an equilibrium with some trucks based at the back-haul city B, as an alternative to the intuitively more obvious equilibrium having all trucks based at A.

1. Introduction

Where capacity controls do not prevent or hinder entry into trucking, some or all of the line-haul task (ie. long distance haulage of full truckloads) may well be undertaken by a large number of small firms, often owner-drivers each with a single truck. Where this has occurred without rate regulation, such owner-drivers may experience arduous working conditions and modest financial returns (as, for example, in inter-state haulage in Australia cf. pp.38-47 of National Road Freight Industry Inquiry, 1984).

To ameliorate these conditions, rate regulation without capacity licensing is sometimes proposed (as it was to the National Road Freight Industry Inquiry - see p.85 of that report). Although such partial regulation might be expected to be ineffective in increasing financial returns, it might well reduce driving hours. (Also note that such limited regulation - without capacity limitation - has been and is used in other contexts eg. the former CAB regulation of US domestic aviation, and conventional or more formal fee-fixing for professional and quasi-professional services such as the selling of real estate.)

The regulator who sets line-haul freight rates has a problem arising out of the commonly occurring imbalance between the forward-haul and back-haul freight flows. In this study a model is developed that emphasises this imbalance. It is used mainly to consider spatial matters, particularly the common assumption (made, for example, in DeVany and Saving (1977)-see p.586) that trucks are based only at the origin of the larger freight flow. In particular, the model is used to explore whether and under what conditions trucks may be based also at the back-haul city, and hence how the regulator may influence the spatial distribution of such basing.

With its recognition of separate capital and operating costs, the model is also used to explore the different ways in which the industry incurs extra costs, as the regulator raises prices above the minimum levels needed to ensure that trucking demands are met.

The next section of this paper details the assumptions of the model, while section 3 deals with the equilibrium concept that is employed. Sections 4 and 5 provide some general analysis for the regulated equilibria having trucks based (respectively) at the forward-haul city only, and both there and at the back-haul city. The properties of the competitive equilibrium are established in section 6. For the regulated equilibria, sections 7 and 8 present properties and results when the regulator sets the same price for the forward- and back-haul, while sections 9 and 10 extend these results to the case of unequal prices. Section 11 briefly examines a stability question and a related issue in risk neutrality; conclusions are presented in section 12.

2. The elements of the model

The model supposes a simple freight network serving just two cities. For freight haulage from city j to the other city, the demand quantity x_j (measured in full truckloads) is taken to be a monotonically decreasing function of p_j, the (regulated) price per truckload. It is realistic to suppose that this demand quantity does not depend on the price for haulage in the opposite direction.

On the premise that there are constant returns to scale in the line-haul task, it is supposed that these trucking services are supplied by a large number of owner-drivers, each of whom has charge of a single vehicle. The fleet of vehicles is homogeneous. For the given city-pair, each truck can make one round trip in the period, or be left at its base (i.e. no alternative use is considered).

A truck, whether deployed or not, has an ownership (capital) cost of k per period. When the truck travels, it is assumed to be fully loaded or not loaded at all. For each round trip, there would be an operating cost of c, if the truck were to travel unladen in both directions. This excludes the separable costs (viz. loading and unloading costs, and the extra fuel and wear-and-tear costs) that are incurred on a particular leg if and only if the truck travels loaded. The prices p_j are defined net of these separable costs.

Empirical evidence for Australia - see National Road Freight Industry Inquiry (1984) Table 2.5 - suggests that c is not less than k. This relationship is likely to hold also in other high-wage, developed countries; and it is used throughout this analysis.

To complete the specification of the model, the following further assumptions are made:

(i) All parties have full knowledge at all times, except that in regard to load prospects, the owner-driver initially knows only the probabilities of obtaining loads in each of the two directions. Certain knowledge of whether a load from the truck's base location will in fact be obtained in a particular period becomes available only at the beginning of the period. Also, the owner-driver learns whether a return load is obtained only after arrival at the other city. In short, the haulage markets are spot-markets. (Strictly, the model relates only to that sector of the industry comprising itinerants, who have no regular contractual relationship with a shipper; but with these itinerants, there may be grouped those who need to seek casual loads on the back-haul; and it is these groups whose behaviour accommodates the imbalance in freight flows.)

(ii) Service quality is homogeneous. The shippers select trucks at random. Thus, in any one period, the probability of obtaining a load from city j is the same for trucks based at j as it is for those trucks that are based at the other city and do make the trip in the period.

(iii) A truck leaves its base iff a load is obtained. (This is the observed practice. In the comparison with probable revenue, the relevant cost is the short-term cost, c. It is shown in the next section that to leave whenever a load is obtained is consistent with risk neutrality. Furthermore, although not leaving without a load might seem to suggest risk aversion, it is shown in section 11 that in all 'significant' cases, this practice too is consistent with risk neutrality.)

(iv) After reaching the other city, the truck returns to its base within the period, whether or not a return load is found. (This approximates the observed practice.)

(v) In the long-run decision on truck ownership, the owner-driver is risk neutral; ownership is maintained iff expected revenue per period at least covers expected cost per period.

(vi) The per-period number of truckloads hauled in each direction is large. Thus it is a valid approximation to use analytical methods which treat the quantities of the model as being continuously variable.

3. The concept of regulated equilibrium

In the absence of restriction on entry, long-run equilibrium under price regulation requires that at any city at which trucks are based, the expected revenue per truck per period shall equal the expected total (operating and capital) cost per truck per period. Furthermore it is supposed that such regulated equilibrium requires that, at each city, the number of trucks offering service shall not fall short of the number of truck-loads to be shipped. Where the regulator sets relatively high prices, this equilibrium generally has a proportion of the trucks remaining at their base city . (In contrast, a competitive market adjusts so as to reach equilibrium in prices as well as quantities; in the outcome, all trucks make the trip in each period, though some may travel empty on the back-haul. See, for example, Layard and Walters (1978), pp.178-9. Further discussion of this case is reserved for section 6.)

Let q_j denote the number of trucks based at city j, and y_j the number of those that actually make a round-trip in any one period.

These are linked through w_j, the per-period probability of obtaining a load from city j:

$$y_j = w_j q_j \qquad \text{for } j = 1, 2 \tag{1}$$

In each period, the total number of trucks offering service at city 1 comprises q_1 plus y_2. Hence, in equilibrium, the number of loads offered equals the number of loads obtained for haulage:

$$x_1 = w_1 (q_1 + y_2) \tag{2}$$

with a similar relationship, to be denoted (2'), for the equilibrium at city 2.

It is convenient to express the long-run equilibrium condition (for truck-ownership) as an equality between expected revenue per truck <u>per round trip</u> and expected cost per truck per round trip (rather than per period); hence, when there are trucks based at city 1, the equilibrium condition is

$$p_1 + w_2 p_2 = c + k/w_1 \tag{3}$$

When there are trucks based at city 2, there is a similar relationship, to be denoted (3').

From (3), expected revenue is greater than c, and hence the practice of leaving the base whenever a load is obtained is consistent with risk neutrality.

4. Regulated equilibrium with trucks based at one city only

The model has two distinct types of equilibrium, depending on whether there are trucks based at one city only, or trucks based at both cities. It is convenient to begin with the former, to be called a type 1 equilibrium.

Without loss of generality, suppose that the demand functions and the regulator's choice of prices are such that

$$x_1 \geq x_2 \quad \text{and} \quad x_1 > 0 \tag{4}$$

Where $x_1 > x_2$, it is not possible to provide sufficient haulage capacity at city 1 if the trucks are based at city 2 only (because a truck never leaves base without a load). Furthermore, where $x_1 = x_2$, it is again sufficient (for the type 1 equilibrium) to concentrate on the situation having trucks based at city 1 only.

In that case, $q_2 = 0$ and $y_2 = 0$; and hence from (1) and (2)

$$y_1 = w_1 q_1 = x_1 \tag{5}$$

When the y_1 trucks reach city 2, the probability that any one truck obtains a load there is w_2 such that

$$0 \leq w_2 = x_2/y_1 = x_2/x_1 \leq 1 \tag{6}$$

This probability is determined by the demand functions and the regulator's decisions; the level and structure of costs play no role. Of course, costs do influence w_1, given by application of (3):

$$w_1 = k/[p_1 + w_2 p_2 - c] \tag{7}$$

This probability depends only on the costs and the prices chosen by the regulator. However, from (5), $q_1 = x_1/w_1$; the demand quantity x_1 does influence the number of trucks owned, of course. The value for w_1 falls in the desired half-open interval (0,1] iff it is possible to find prices such that

$$p_1 + w_2 p_2 \geq c + k \tag{8}$$

In summary, (4) and (8) comprise a set of sufficient conditions for existence of a type 1 equilibrium with trucks based at city 1.

5. Regulated equilibrium with trucks based at both cities

Again suppose, without loss of generality, that $x_1 \geq x_2$ with $x_1 > 0$ for the price-region under consideration. The type 2 equilibrium, having trucks based at both cities, requires that for each fleet, expected revenue per trip equals expected cost per trip, as given in equations (3) and (3'). Solving these equations for w_1 yields the quadratic equation:

$$f_1 w_1^2 + 2g_1 w_1 = h_1 \tag{9}$$

where $f_1 = (c - p_1)\, p_1$ (10a)

$2g_1 = k(p_1 - p_2) - (c - p_1)(c - p_2)$ (10b)

and $h_1 = k(c - p_2)$ (10c)

Provided p_1 is not equal to c, equation (9) has the solution

$$w_1 = - g_1/f_1 \pm \sqrt{[h_1/f_1 + g_1^2/f_1^2]} \tag{11}$$

and this has one or two real roots whenever the argument [ ] is non-negative. (For w_2, there are similar results, to be denoted (9'), (10') and (11').)

For any pair of values w_j satisfying $0 < w_j \leq 1$ (for j = 1,2), the equilibrium solution is completed by using (1) and (2):

$$q_1 = (x_1 - w_1 x_2)/w_1(1 - w_1 w_2) \tag{12}$$

$$q_2 = (x_2 - w_2 x_1)/w_2(1 - w_1 w_2) \tag{13}$$

Because $x_1 \geq x_2$, $q_1 \geq 0$. Also $q_2 \geq 0$ iff

$$w_2 \leqq x_2/x_1 \qquad (14)$$

with $w_2 < 1$ generally. Some implications are considered later.

In summary: to obtain a type 2 equilibrium having demand functions and prices satisfying (4), the argument [ ] in (11) must be non-negative, while a set of sufficient conditions also requires

$$0 < w_1 \leqq 1 \qquad (15)$$

and $$0 < w_2 \leqq x_2/x_1 \qquad (16)$$

These probabilities depend only on the prices chosen by the regulator; they are not affected by the quantities x_1 and x_2

6. The competitive equilibrium

Before developing further analysis of the regulated equilibria, it is instructive to examine the properties of the competitive case, where there is adjustment in prices as well as quantities. As before, suppose that each truck leaves its base iff a load is obtained, and that shippers select trucks at random.

Competitive forces ensure that the price on the back-haul, taken here to be haulage from city 2, will be lower than the forward price. Consistent with the lowest possible level of costs, those forces also ensure that the forward price is so low that $w_1 = 1$. Hence there are no idle trucks based at city 1 and there is no empty travel from city 1.

The backhaul price p_2 may be low enough relative to p_1, and the demand imbalance small enough, to yield $x_1 = x_2$. In that case, from (1), (2) and (2′), it is seen that $w_2 = 1$; hence at city 2 also, there is no idle capacity and no empty travel. Thus it is immaterial which city is chosen as base for any particular truck, and these circumstances support either type of equilibrium.

On the other hand, for the more interesting case where the competitive prices yield $x_1 > x_2$, the number of trucks offering at city 2 exceeds x_2, and competition ensures that the backhaul price p_2 (net of load-related costs) is driven down to zero. As seen in section 4, it is not possible to serve all the shippers if trucks are based at city 2 only. But the other type 1 equilibrium does exist, with $w_1 = 1$; condition (3) then yields $p_1 = c + k$.

If the type 2 equilibrium were to be feasible, (3') would require $p_1 = c + k/w_2$ while (3) still yields $p_1 = c + k$. Because $w_2 < 1$, these conditions are inconsistent. Hence, in the significant case where the competitive equilibrium has $x_1 > x_2$, a type 2 equilibrium is not feasible.

7. The case where the regulator chooses equal prices

Fully distributed cost (FDC) pricing (cf.Braeutigam 1980) ignores demand differences. Such thinking commonly leads regulators to neglect peak/off-peak distinctions, and hence to prescribe the same price at all times, as was the case (for example) in the former CAB regulation of US air fares (cf. Levine, 1987, p.413). Equally, that FDC approach leads naturally to a neglect of forward-haul/back-haul differentiation, with the regulator setting the same price p for haulage in either direction.

For that approach, consider first the type 1 equilibrium, with trucks based at city 1. The condition (8) reduces to

$$p(1 + w_2) \geq c + k \quad (17)$$

The left hand side is expected revenue <u>per trip</u>, to be denoted r_1. This is influenced by p directly and also through the demand functions which determine the ratio $x_2/x_1 = w_2$. Now $\partial w_2/\partial p$ can have either sign. However, because

$$\partial r_1/\partial p = 1 + (1 + e_1 - e_2)\, x_2/x_1 \quad (18)$$

(where the demand elasticities e_1 and e_2 are defined so as to be positive), then clearly under most circumstances $\partial r_1/\partial p > 0$. (A necessary condition for the opposite case is that p be high enough to make $e_2 > 1$. In practice, demand has to be very elastic indeed before r_1 is inversely related to p; this is unlikely to occur in the transport context.) To ensure that demand is met, the regulator can usually simply set a price high enough to satisfy (17). Further, note from (3) that $\partial w_1/\partial p$ is negative iff $\partial r_1/\partial p > 0$.

It is also of interest to consider how the proportion of empty travel depends on p. There is no empty running on the forward-haul, and the proportion of trips that are empty on the back-haul is $(1 - w_2)$. Hence the empty proportion overall is

$$(1 - w_2)/2 = (1 - x_2/x_1)/2 \quad (19)$$

The way in which this varies with p depends on the demand functions.

Turning now to the (general) type 2 equilibrium, substitute the common price p in conditions (3) and (3'), to yield

$$p(w_1 - w_2) = c(w_1 - w_2) \quad (20)$$

If the regulator's chosen price is not equal to c, then (20) requires equal probabilities, $w_1 = w_2 = w$, to ensure a balance between expected revenue and expected cost at each of the two cities.

Then, in solving the quadratic equation (9) for w, the subscripts may be omitted from (10) yielding $f = (c - p)p$, $2g = (c - p)^2$ and $h = k(c - p)$. Because f and h have the same sign, the argument of the square root function in (11) is positive, and hence the roots are real. Furthermore, the absolute value of the root is greater than that of g/f. Hence only the positive root gives a non-negative value for w, and thus the probability w is unique.

The equilibrium conditions (3) and (3′) may now be written

$$p(1 + w) = c + k/w \tag{21}$$

As p increases, what happens to the value of w? Suppose that $\partial w/\partial p \geq 0$. Then as p is increased, the left hand side (expected revenue per trip) increases while the right hand side (expected cost) decreases, leading to a contradiction. Hence, in (21), $\partial w/\partial p < 0$, and the equilibrium exists provided the regulator can choose a price that is high enough to make $w \leq 1$, while not so high as to drive both demand quantities to zero.

The proportion of empty travel may be derived by application of (2), (2′), (12) and (13), to give the overall proportion as

$$1 - (x_1 + x_2)/2(y_1 + y_2) = (1 - w)/2 \tag{22}$$

As p increases, w falls and this proportion rises, as is to be expected. (See the next section for further discussion.)

If the type 2 equilibrium is also to satisfy (4) i.e. is to have $x_1 \geq x_2$ with $x_1 > 0$, then the quantity expressions (12) and (13), applied with the common probability w, show that $q_1 \geq q_2$; that $q_1 \geq 0$; and that $q_2 \geq 0$ provided $w \leq x_2/x_1$, where these demand quantities are determined at the chosen p. Whenever x_2 is strictly less than x_1, this upper bound is more restrictive than the previous requirement $w \leq 1$. This type of equilibrium exists iff a common price p can be chosen that is low enough to satisfy (4) and also high enough to give $w \leq x_2/x_1$. This existence is affected by the behaviour of x_2/x_1; some cases are examined in the next section.

There remains to be considered the special case in which the regulator choses $p = c$. The quadratic equation (9) for w is not applicable, because $f = 0$. Instead, substitution in (3) yields

$$w_1 w_2 = k/c \leq 1 \qquad (23)$$

The solution for the probabilities is not unique. The economic interpretation is clear: the operating cost c is recovered on the outward leg; then, taking trucks based at city 1 as an example, the expected revenue on the return leg is $w_2 c$, while the probability of the trip being made is w_1, and hence the expected per-period revenue from the return leg is $w_1 w_2 c$. It does not matter how the probabilities are distributed provided their product satisfies (23).

Finally, note that because the industry breaks even financially, the conventional measure of aggregate welfare reduces to that of consumer surplus. Hence welfare decreases as the regulator's price p increases. Further, for given p, aggregate welfare is the same whether trucks are based at both cities or at one city only.

8. Equal prices: numerical examples and some further analysis

The numerical examples employ a linear demand system

$$p_j = a_j - b_j x_j \quad \text{for } j = 1, 2 \tag{24}$$

where $a_j > 0$ and $b_j > 0$. Then each numerical case is defined by the set of demand and cost data, specified as $[a_1, a_2, b_1, b_2, c, k]$.

It is well known that, in the absence of entry restrictions, a regulated price higher than the competitive price induces extra capacity. To focus on this feature, and to show what forms the 'excess' capacity may take, consider the case of symmetrical demand, for which the importance of the spatial element is minimized.

As the common price p is increased above the competitive price, the gross revenue (per load hauled) increases. Because long-run equilibrium implies financial break-even, the extra revenue is dissipated in extra costs, which take the form of extra capacity owned and/or extra empty running. As seen in Table 1, the type 1 equilibrium has no empty running; the excess is solely in capacity owned. Indeed q_1 increases for a while even as p increases beyond a/2 (corresponding to unit demand elasticity).

In contrast, the type 2 equilibrium does involve empty running and hence for given p, it has less excess capacity than the type 1 equilibrium, as is illustrated in the lower part of Table 1 for a numerical case, Example A. (In this example, there is an exception at p = 10, where w = 1 and neither equilibrium has empty running.) From (22), the proportionate incidence of empty running in the type 2 equilibrium increases as w decreases; hence the absolute maximum for 2q (capacity owned) will occur at a price slightly lower than the price (2a + c)/4 which maximises the type 1 capacity

Turning now to focus on the spatial element, the principal issue is whether and under what circumstances a type 2 equilibrium exists, to permit trucks to be based at city 2, even though the demand for haulage from that city is the lower of the two demands. The influence of the demand ratio x_2/x_1 is considered later. First, consider an example in which that ratio is held constant at $s < 1$ as p varies, to see whether there is any other factor at work.

This situation is illustrated by Example B, having data [20, 20, 4, 5, 10, 8] which imples $s = x_2/x_1 = 0.8$. As always, the type 1 equilibrium (with trucks at city 1) has $w_2 = x_2/x_1$, here the constant s. In this numerical case, the minimum price for the type 1 equilibrium is $p = 10$ (which may be compared with the competitive outcome of $p_1 = 10.\dot{2}$, $p_2 = 7.\dot{7}$). As before, w_1 decreases from 1 as p is raised above 10, reaching $w_1 = 0.8$ at $p = 11.12$ approx. The upper bound for the feasible region is $p = 20$, at which demand falls to zero. The minimum price for a type 2 equilibrium is $p = 11.12$, because it is at this price that the type 1 solution gives $w_1 = w_2$. The dependence on price of w_1 (for type 1) and w (for type 2) is summarised in Figure 1.

Also of interest is the number of trucks based at each city. As before, for any given price, the type 2 solution generally has fewer trucks and more empty running than the type 1 solution; the sole exception is at $p = 11.12$, where the two solutions are identical, with $q_2 = 0$. As p is increased, however, the ratio q_2/q_1 in the type 2 solution increases, as shown in Figure 1. For the case where the demand ratio is constant, this is a general result: from

(12) and (13), with equal prices, the capacity ratio is

$$q_2/q_1 = (x_2 - wx_1)/(x_1 - wx_2) = (s - w)/(1 - ws) \qquad (25)$$

for $w \leq s$. Hence as price is increased, w decreases and q_2/q_1 increases, subject to an upper bound of $s < 1$. The required increase in per-unit cost is achieved through reduction in w, which adds to the proportion of capacity not used, and to the proportion of empty running (as seen in (22)). The latter effect requires the increase in the capacity ratio.

In such a case, the regulator who wishes to favour the basing of trucks at city 2 has to note that this is not possible at all unless price is somewhat above the minimum type 1 price; as the price rises above that level, the proportion of the total fleet that is based at city 2 also rises. Of course, the higher price eventually reduces the absolute size of the fleet; in Example B the number of trucks at city 2 peaks at $p = 15$ approximately.

Finally, in order to focus on the influence of the ratio of demand quantities, consider some alternative demand systems with the regulator choosing the same price p throughout (implying constant w). Provided the type 2 equilibrium exists for each case, then from (25), it is seen that $\partial(q_2/q_1)/\partial s > 0$. Thus, as may be expected intuitively, the larger the demand ratio x_2/x_1, the greater is the number of trucks based at city 2 as a proportion of the total number of trucks, other things being equal.. And the smaller the demand quantity at city 2 relative to that at city 1, the less likely is it that a type 2 equilibrium can exist at any price.

9. Some analysis of the regulated equilibria for unequal prices

When the regulator chooses unequal prices, the analysis inevitably becomes more complicated. For the type 1 equilibrium (with trucks based at city 1), some important properties are summarised in Table 2.

As noted in section 4, such an equilibrium exists if (4) and (8) are satisfied. To have the best chance of getting an expected revenue per trip that is large enough to satisfy condition (8), it is clear from Table 2 that the regulator should favour a large value for p_1 (property II), and a value for p_2 that is close to the point of unit elasticity for haulage from city 2 (property IV).

For the type 2 equilibrium, the possible relationships between the unequal prices and the operating cost c are the basis for the classification sketched in Table 3, which analyses the nature of the solution(s) to the quadratic equation (11). Sufficient conditions for the existence of this equilibrium remain as stated at the end of section 5. Although the diversity of results does not permit any simple, general statement about the prices most likely to favour existence, the results in Table 4 give insights into the various cases that can occur. For changes in p_1 (with p_2 held constant), the table deploys regions that are defined by reference to the value of $\partial w_2/\partial p_1$, and the results are obtained by differentiation of (3). Of course, differentiation of (3′) w.r.t p_2 yields parallel results for the effect of changes in p_2, with p_1 held constant.

10. Unequal prices: general results and numerical examples

With two independent price instruments, there is of course a somewhat greater variety of outcomes. Nevertheless one general result for the type 2 equilibrium may be established readily. For a given choice by the regulator of prices p_1 and p_2, consider the influence of the demand quantity ratio $x_2/x_1 = s$, where as before attention is confined to the region $s \leq 1$. From (12) and (13), the generalisation of (25) is

$$q_2/q_1 = (w_1/w_2)(s - w_2)/(1 - w_1 s) \qquad \text{for } w_2 \leq s \qquad (26)$$

and hence $\partial(q_2/q_1)/\partial s > 0$. Even with unequal prices, then, where the type 2 equilibrium exists, the trucks based at city 2 are a larger proportion of the total, the greater is the demand quantity ratio x_2/x_1. And because $q_2 > 0$ only when $w_2 < s$, this type of equilibrium occurs more readily, the larger is s.

To explore the consequences of the variation now permitted in the ratio of the regulated prices, consider cases in which one price is held constant while the other is varied. The first case uses the symmetrical demand system of Example A (used previously in Table 1), with p_1 varying and $p_2 = 40$, giving $x_2 = 5$. The type 1 equilibrium does not exist for $p_1 < 24.4$ (approx.), at which level $w_1 = 1$ and $w_2 = 0.39$. As p_1 increases, the number of trucks q increases (as seen in Figure 2). Because x_2/x_1, is increasing, w_2 increases; and w_1 decreases, of course. At $p_1 = 30$, the type 1 probabilities are $w_1 = w_2 = 0.5$, and $x_2/x_1 = 0.5$. Here the type 2 equilibrium begins, but because c also is 30, it is not unique; the figure is based on the values which are the limits as p_1 tends to 30 from above viz. $w_1 = 1$ and $w_2 = 0.25$. As shown in the figure, q_1 and q_2 each have a turning point, while $q_1 + q_2$ has two. As before, the type 2 equilibrium has less capacity and more empty running than the type 1 equilibrium, other things being equal.

For a final illustration, consider Example D with data [18, 15, 1.6, 0.8 , 6, 3], and suppose constant $p_1 = 6.2$ (and hence $x_1 = 7.375$). As p_2 increases, x_2/x_1 decreases; the minimum value to satisfy $x_1 \geq x_2$ is $p_2 = 9.1$, at which level both equilibrium types exist. In the type 1 equilibrium, w_1 increases and w_2 decreases, reaching $w_1 = 0.92$ and $w_2 = 0.22$ at $p_2 = 13.675$ (of Figure 3). These probabilities match the type 2 probabilities, and in the type 2 equilibrium, the capacity ratio q_2/q_1, which has been falling, is reduced to zero. Hence for higher p_2, the type 2 solution does not exist (because x_2/x_1 is now too small to support it), while the type 1 equilibrium exists for p_2 up to 13.805.

11. Stability and risk neutrality

Although specification of dynamic adjustment processes under regulation is not attempted here, it is of interest to look at one condition that is necessary for stability of the type 1 equilibrium, viz. the condition that at the prevailing prices and probabilities there is no incentive for an owner to enter the industry by basing a truck at the 'other' city (city 2 in the case where the fleet is based at city 1). For the general case of unequal prices, stability thus requires that expected revenue at city 2, $E(R_2)$, should not exceed expected cost, $E(C_2)$:

$$p_2 + w_1 p_1 \leq c + k/w_2 \qquad (27)$$

while the probabilities and prices also satisfy condition (3) for equilibrium at city 1.

This stability condition has a strong connection with the operating practice of not leaving the base without a load. For this practice to be consistent with risk neutrality, expected revenue on the return leg w_2p_2 must be not greater than c. An immediate result is that inconsistency requires $p_2 > c$.

It can also be shown that when the type 1 equilibrium is stable, that operating practice is consistent with risk neutrality. To see this, eliminate p_1 from (27) and (3), to obtain

$$w_2p_2\ (1 - w_1w_2) \leqq w_2c\ (1 - w_1) + k\ (1 - w_2) \qquad (28)$$

Furthermore, since $c \geqq k$, and provided w_1w_2 does not equal unity, this may be written

$$w_2p_2 \leqq c \qquad (29)$$

Thus stability is sufficient for risk neutrality. However, such stability is not necessary: in Example D, at $p_2 = 13$ (for instance), the equilibrium does not satisfy the stability condition, and yet the risk neutrality requirement (29) is met. Further, at $p_2 = 12$ the stability and risk neutrality conditions are both breached.

For the type 2 equilibrium, there is a simpler result on risk neutrality. Now both conditions (3) and (3′) apply, and elimination of p_1 between them yields (28) considered as an equality. Again, because $c \geqq k$, (29) may be derived. Hence, in the type 2 equilibrium, the operating practice of not leaving base without a load is always consistent with risk neutrality.

Thus the short-run operating decision, to leave base iff a load is obtained, is generally consistent with risk neutrality. The sole exception occurs when the type 1 equilibrium does not satisfy the stability condition (29); then, staying at the base when a load is not obtained <u>may</u> imply risk aversion. However this matters little since the type 1 equilibrium is then unstable. Both results follow because the other city is an attractive base.

However such instability does not necessarily result in a type 2 equilibrium being established if the type 1 equilibrium is disturbed; as numerical examples show, the type 2 equilibrium may or may not be feasible when the other equilibrium is unstable. Thus if instability is to be avoided, the regulator's choice of prices may need to be more circumscribed than at first appears to be the case.

Finally, note that for the case of equal prices, simple results may be obtained on the incidence of instability. Elimination of the common price p from (27) and (3) yields the stability condition

$$(w_1 - w_2)\, w_1 w_2 \leq (w_1 - w_2)\, k/c \qquad (30)$$

Now from (3),

$$\text{as } p \gtreqless c, \text{ then } w_1 w_2 \lesseqgtr k/c \qquad (31)$$

and then (30) leads to the results stated in Table 5.

12. Conclusions

Although initial intuition may suggest that in a situation of demand imbalance, the entire truck fleet will be based at the city having the larger demand for haulage (a situation here called a type 1 equilibrium), in the model developed in this paper it is usually possible also to have a so-called type 2 equilibrium, in which there are trucks based at both cities. In this type 2 equilibrium, the probabilities of obtaining loads at the two cities are determined only by the regulator's choice of prices. Further, when the prices are equal, the probabilities are the same.

When the regulator raises prices above the minimum that is required to ensure that all demand is met, the consequent increase in revenue per unit of output is dissipated, of course, by the incurring of extra costs - here costs of extra capacity, and sometimes costs of extra empty running. In the type 1 equilibrium, empty running is confined to the back-haul, and hence is kept to the minimum dictated by the demand imbalance that appears at the prices chosen by the regulator; and the extra expenditure is focussed entirely on the acquisition of more capacity. In the type 2 equilibrium, however, there is generally extra empty running as well, occurring on both the forward- and back-haul. Hence, if the regulator raises prices to reduce average working hours per driver, this is achieved by the reduction in the probabilities, though the type 2 equilibrium is less effective in this respect than the type 1 equilibrium.

Because aggregate industry cost always matches industry revenue, the type 2 equilibrium generally has less capacity than the corresponding type 1 equilibrium. Because the conventional welfare measure reduces to that of consumer surplus, aggregate welfare is the same for the type 2 as for the type 1 equilibrium, given the prices.

The existence of the type 2 equilibrium is favoured by the proportionate demand imbalance not being too great; it also requires prices high enough to support the degree of empty running inherent in the type 2 situation. A regulator, wishing to boost the level of economic activity at the source of the back-haul can often choose prices that favour the establishment of the type 2 equilibrium, and may also choose prices so as to maximise the proportion of the fleet based at the back-haul city. Under some circumstances the type 1 equilibrium is unstable - in the sense that at prevailing prices etc. there is an incentive to enter by basing a truck at the backhaul city; this too can favour the establishment of a type 2 equilibrium.

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TABLE 1 Demand symmetry with equal prices

General case: Suppose $a > c + k$. Because of demand symmetry, $w_2 = 1$. For both types of equilibrium, the lowest feasible price is $p = (c + k)/2$, and this is also the competitive price.

Price, p:	$(c+k)/2$		$a/2$		$(2a+c)/4$		a
e:		inelastic	unity	elastic		elastic	
$\partial q_1/\partial p$: (Type 1)		+		+	zero	−	

Numerical case: Example A, having data set [50, 50, 2, 2, 30, 10]

Price, p:	20	25	30	32.3	32.5	40	49
Type 1 w_1:	1	0.50	0.33	0.29	0.29	0.20	0.15
q_1:	15	25.00	30.00	30.62	30.63	25.00	3.40
y_1:	15	12.50	10.00	8.85	8.75	5.00	0.50
Type 2 w:	1	0.74	0.58	0.52	0.52	0.39	0.30
2q:	15	19.40	19.96	22.282	22.280	18.42	2.59
2y:	15	14.37	12.67	11.63	11.53	7.19	0.77

TABLE 2 Properties of the type 1 equilibrium for unequal prices, with trucks based at city 1

	Property	Sketch of proof
I	$\partial w_2/\partial p_1 > 0$ and $\partial w_2/\partial p_2 < 0$	$w_2 = x_2/x_1$
II	$\partial r_1/\partial p_1 = 1 + p_2 \partial w_2/\partial p_1 > 0$	r_1 is l.h.s. of (3)
III	$\partial w_1/\partial p_1 < 0$	to ensure r.h.s. of (3) matches l.h.s. as p_1 increases
IV	$\partial r_1/\partial p_2 \gtreqless 0$ as $e_2 \lesseqgtr 1$	$\partial r_1/\partial p_2 = (1 - e_2)x_2/x_1$
V	$\partial w_1/\partial p_2 \lesseqgtr 0$ as $e_2 \lesseqgtr 1$	to ensure r.h.s. of (3) matches l.h.s. as p_2 increases.

TABLE 3 Various cases of the type 2 equilibrium, for unequal prices

Case	Prices p_1 and p_2	Result
I	Both greater than c, or both less than c	In (10), f_1 and h_1 have same sign, and hence (11) gives unique w_1. Similarly for w_2.
II	One price greater, and one price less than c	Now f_j and h_j have opposite signs; to obtain valid w_j, need to have opposite signs for g_j and f_j (each j); need to consider positive and negative roots.
III	Price p_1 equal to c	Reduces to case with both prices equal to c (cf. section 6); except for singular case with $w_1 = 1$.

TABLE 4. The influence of p_1 when p_2 is held constant, in the type 2 equilibrium

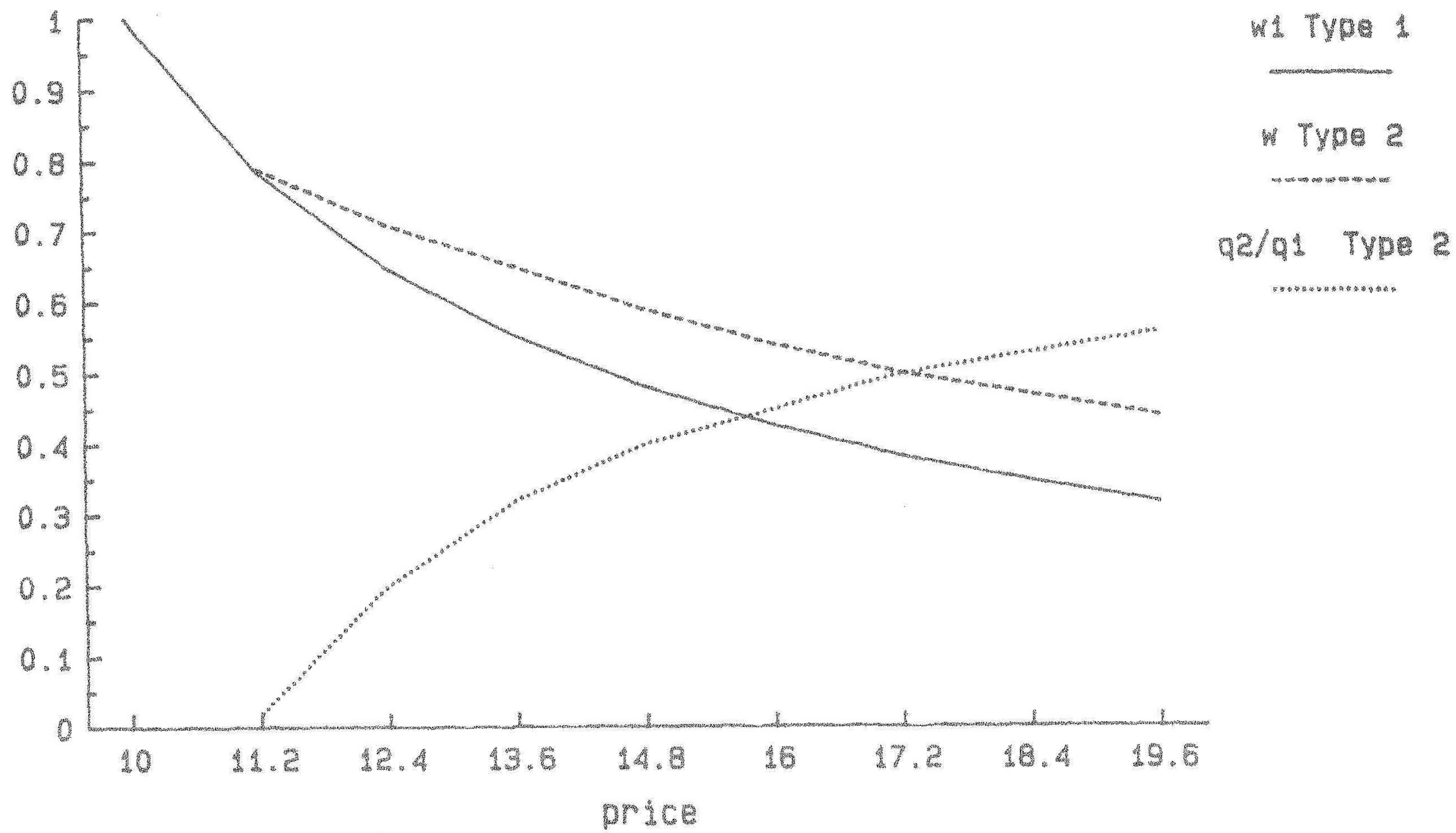
Region label:	A	B	C
Region defined by value of $\partial w_2/\partial p_1$	$< -1/p_2$	$[-1/p_2, 0]$	> 0
Other influences of p_1			
$\partial r_1/\partial p_1$	< 0	$[0, 1]$	> 1
$\partial w_1/\partial p_1$	> 0	$[0, - w_1^2/k]$	$< - w_1^2/k$

TABLE 5. Stability results for the type 1 equilibrium (having trucks based at city 1), for equal prices

$E(R_2) \lesseqqgtr E(C_2)$ according to the following cases:

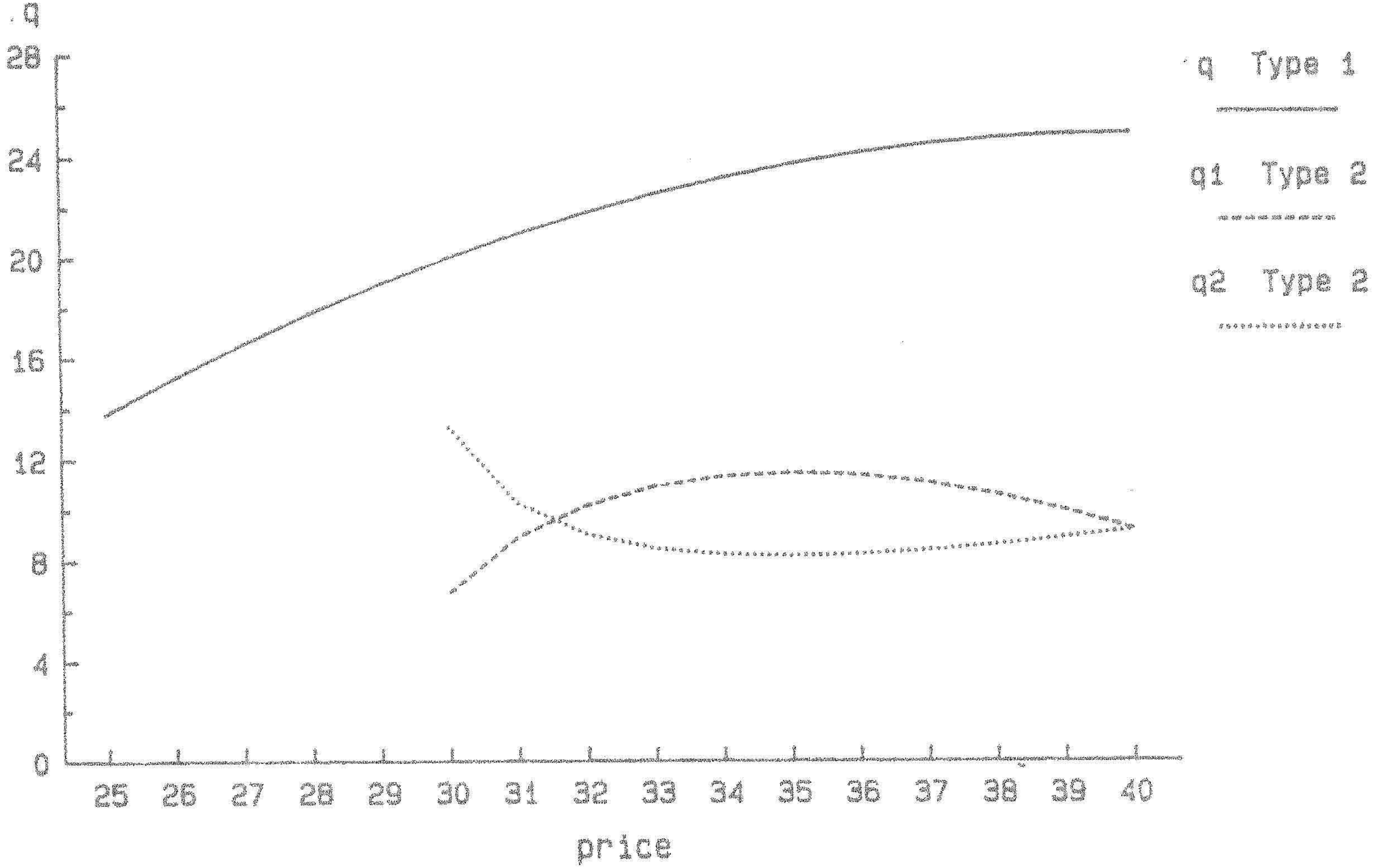
Price condition \ Probability condition:	$w_1 > w_2$	$w_1 = w_2$	$w_1 < w_2$
$p > c$	$<$	$=$	$>$
$p = c$	$=$	$=$	$=$
$p < c$	$>$	$=$	$<$

FIGURE 1



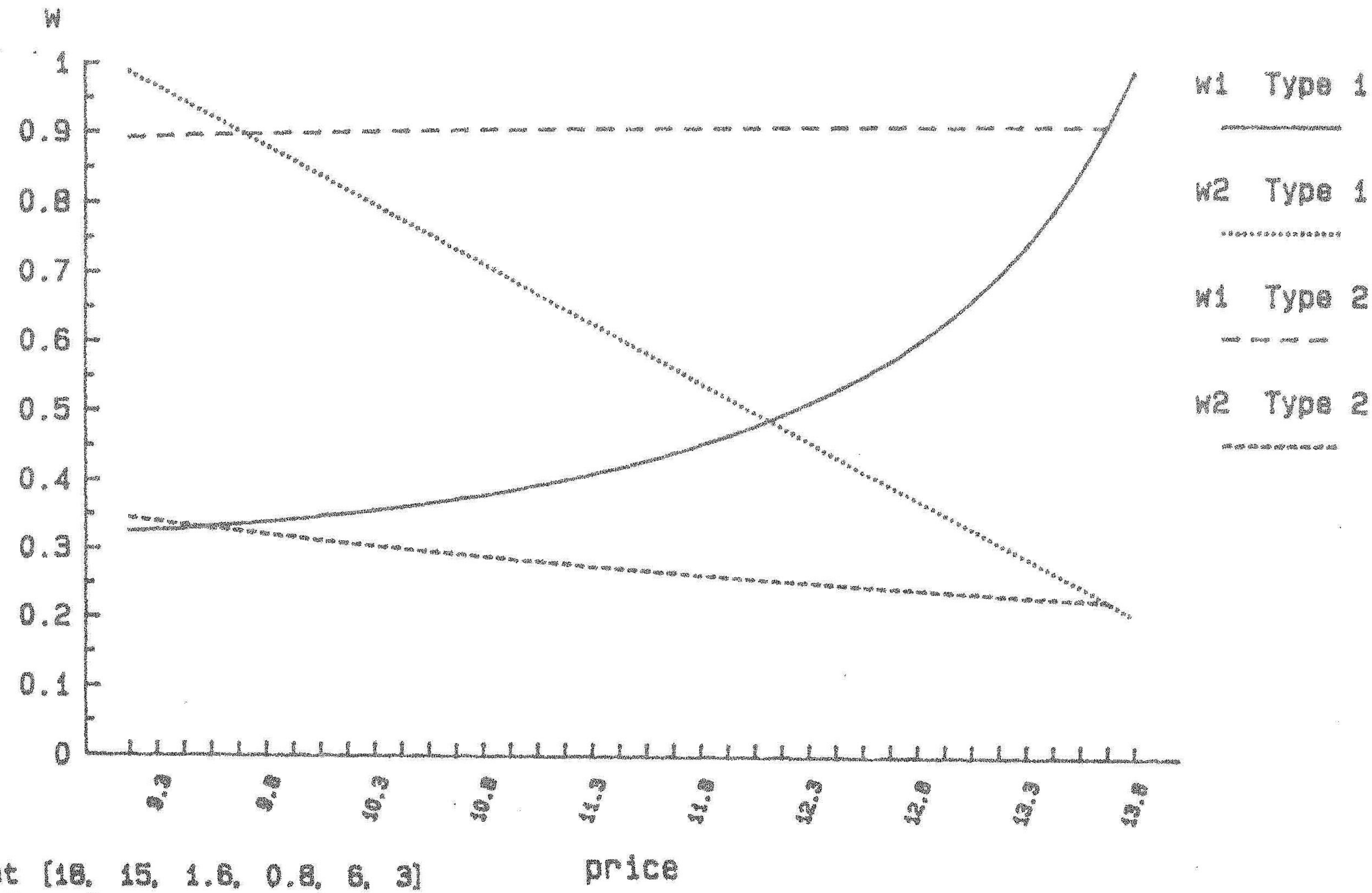
Data set [20, 20, 4, 5, 10, 8]
p1 = p2
deltap1 = deltap2 = 1.2

FIGURE 2



Data set [50, 50, 2, 2, 30, 10]
p1 varying, p2 = 40
deltap1 = 1, deltap2 = 0

FIGURE 3



Data set [18, 15, 1.6, 0.8, 6, 3]
p1 = 6.2 , p2 varying
deltap1 = 0, deltap2 = 0.125

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