WORKING PAPER 398

RE-EXAMINING OLD PROBLEMS WITH NEW METHODS: PORTBURY RE-VISITED

G.P. CLARKE, M. CLARKE AND A.G. WILSON

School of Geography
University of Leeds
LEEDS LS2 9JT

November 1984

Re-examining old problems with new methods: Portbury re-visited

Clarke, G.P., Clarke, M. and Wilson, A.G.

Preface

It is now eighteen years since the Ministry of Transport examined the feasibility of constructing new harbour facilities at Portbury, Bristol. Part of that analysis was based on the use of a gravity model. Since 1966 significant progress has been made in many aspects of urban and regional modelling. There is now a basic competence in many aspects of modelling which could not have been envisaged in the early days.

So far however, there have been few empirical applications of these latest techniques which are vital if progress is to be made. The original Portbury problem and its associated data sets provides an excellent opportunity to examine the new set of models in a real public planning context. The aim here is not to assess critically the original Portbury decision per se - this is done in a number of other studies - but more to use the models in an illustrative way showing how improvements to existing appraisal methods can be made with careful thought and application.

ACKNOWLEDGEMENTS

The authors are grateful for the data sources compiled by Martyn Senior in his recent paper and for the help obtained from Mark Birkin in the digitizing of the British Isles maps for use in the GIMMS computer package. We also acknowlege the financial support of the E.S.R.C.

1. Background

Throughout the late 1950s and early 1960s considerable concern was being expressed about the future viability of many British ports. This was due to the realization that in order to keep apace with the rising volume of international trade and the increasing severity of foreign competition, more investment would be needed in deep water general-cargo berths (see the Rochdale Report produced by the Ministry of Transport, M.O.T., 1962).

The Port of Bristol Authority, appreciating that Bristol's existing deep water facilities were working near or at capacity, proposed the so-called 'Portbury Project', a scheme to introduce nine new deep water berths to the Port of Bristol (two intended for bulk cargoes and seven for general cargoes, M.O.T., 1966, p. 1). It was estimated at the time that the scheme would cost around £27 million.

In July 1965 the National Ports Council included the project in their 'Interim Ports Plan'. The proposal looked favourable given the increasing need for extra facilities and the fact that Liverpool and London were becoming increasingly congested; the favourable location of Bristol in relation to the planned M4 and M5 motorways was also relevant. As the M.O.T. (1966) note:

> "the case for Portbury rested in part on its own merits and in part on the need to create a third major liner terminal as an insurance against the ever present risk of congestion and dislocation in the country's two principal ports of London and Liverpool" (M.O.T., 1966, p. 3).

On the debit side, however, the scheme was very expensive. Since Portbury would be a new site requiring the construction of a large new entrance lock, the overall cost per berth at Portbury was around £3 million as against around £1.6 million for other new developments. Clearly, to justify this amount of investment, the Bristol Port Authority needed to convince all concerned that the scheme would generate sufficient cargo tonnage to make such an investment viable. Unfortunately for the Bristol Authority, their forecast of 2,600,000 tons of foreign exports by 1980 was considerably below the findings of an independent consultancy firm who predicted a tonnage of only 465,000 tons by 1980. Indeed, to reach the forecast of the Bristol Authority, it would have needed a huge increase in export traffic above the 1964 level of 200,000 tons.

Because all investment proposals over £0.5 million had to be approved by the Ministry of Transport, the ultimate decision of whether or not to invest in the scheme lay in their hands. Senior (1983) in a recent re-appraisal of the spatial analysis notes:

> "Clearly the Ministry of Transport and its advisers had serious reservations about the Portbury investment and thus the Ministry of Transport instituted its own independent analysis". (p. 86)

This analysis was made up of two major sections. First a radial analysis was undertaken to calculate the potential hinterlands of each export port. With this data the Ministry could work out the likely or possible area that Portbury might 'capture' given the nature of its expansion. Using this analysis, the Ministry noted (M.O.T., 1966, p. 8) that Portbury could at least in theory "absorb the increase of medium-sea and deep-sea exports forecast for the Midlands region". This was because the radial analysis showed Bristol to be very dependent on exports produced in a ring of between 75 and 100 miles: notably the West Midlands. However, the Ministry also noted that an increase of 500,000 tons of additional exports could only be achieved if Bristol gained the whole of this increase, to the exclusion of other ports. (For a fuller discussion of the radial analysis, see Senior (1983) p. 86-88).

The second analysis was based on a gravity model.

2. The model used in the original study

The gravity model adopted by the M.O.T. took the following form:

$$T_{ij} = A_i B_j O_i X_j^a f(d_{ij}, b) \tag{1}$$

where

$$A_i = \frac{1}{\sum_k B_k X_k^a f(d_{kj}, b)} \tag{2}$$

and

$$B_j = \frac{X_j^{(1-a)}}{\sum_k A_k O_k f(d_{kj}, b)} \tag{3}$$

to ensure that

$$O_i = \sum_j T_{ij} \tag{4}$$

$$X_j = \sum_i T_{ij}. \tag{5}$$

The main variables are:

T_{ij} = flow of exports from zone i through port j

O_i = the total amount of exports originating in zone i

X_j = the total amount of exports handled by the port j

d_{ij} = distance between zone i and port j

a,b = parameters of the model.

The function of distance $f(d_{ij}, b)$ was taken as

$$\frac{1}{d_{ij}^{\ b}} \quad \text{or} \quad d_j^{-b}. \tag{6}$$

This model was used to produce a set of forecasts. For the Port of Bristol the gravity model forecast only 260,000 tons of dry cargo exports by 1980 compared to 470,000 tons forecast by the consultants for the

Bristol Authority and 2,700,000 tons by the Authority themselves. Consequently the Ministry of Transport decided that investment in new facilities at Portbury would not be viable and hence plans for development were shelved indefinitely.

Since 1966 this decision has caused several authors to criticize various aspects of the handling of the enquiry, especially the use of, and results obtained from, the gravity model. Tanner and Williams (1967) criticized the enquiry from the point of view of regional economic development issues. They argued that the re-structuring of several major transport routes, especially the construction of the M4 and M5 motorways, would have made a pronounced difference and was not fully taken into account (amongst other things) by the use of a distance matrix to measure spatial impedance. Indeed they quote Manners (1966) who likened the whole region of Bristol to a potential S. Netherlands, with Portbury as its Rotterdam, and coining the phrase 'Randstad Severn'!

Heggie (1969) aimed his criticisms at the 'unrealistic and simplistic nature' of the gravity model claiming its forecasting power to be very poor. Wilson (1969), in a rejoinder to Heggie, criticized many of Heggie's assertions but agreed that the Portbury model was not the best example of then recent planning applications. Wilson defended its use however, stressing

> "the gravity model and the related analysis appeared to play a valuable and perhaps crucial role in the Portbury decision" (p. 49).

More recently Senior (1983) has again attacked the simplistic use of the gravity model although far more constructively. He argues that with a 'more intelligent and imaginative use',

> "the model forecasts would have suggested that Portbury was a marginally viable, rather than a hopelessly nonviable project" (p. 1).

Even with these improvements, however, Senior supports the original conclusions of the Ministry of Transport. He too attacked Heggie and before his reassessment concluded:

> "Heggie quite misleadingly attributes the oversimplified forecasts to the model itself rather than to the way the model was used. No model, no matter how realistic, is immune to oversimplified useage. Although it would be extravagant to claim that the Portbury model provides a very good representation of reality, it nevertheless, if used intelligently, can provide instructive forecasts" (Senior, 1983, p. 94).

Against this background our aim now is to explore the original data sets, plus those we can add in hindsight, using the new set of equilibrium models built up particularly over the last few years. This should provide a good illustration of their potential for planning purposes. First, the equilibrium models will be set up, followed by the data to be used; the model has then to be extended to provide the basis for a series of numerical experiments.

3. Equilibrium models

The set of equilibrium models to be used combine analysis of spatial interaction with predictions of spatial structure:- in this case the relative sizes of the competing ports. Again it should be emphasised that these methods have been developed in recent years and were certainly not available in 1966. For overviews, see Harris and Wilson (1978), Beaumont et al (1981), Clarke and Wilson (1982, 1983) and Wilson (1981).

The basis for illustrating this work has been the singly-constrained interaction model of the form developed by Huff (1963) and Lakshmanan and

Hansen (1965) modified in various ways to cater for different sectors of the economy, including the ports work mentioned above.

The interaction model in this case takes the following form:

$$S_{ij} = A_i O_i W_j^{\alpha} d_{ij}^{-\beta} \tag{7}$$

where

$$A_i = \frac{1}{\sum_j W_j^{\alpha} d_{ij}^{-\beta}} \tag{8}$$

and

S_{ij} = the flow of exports from zone i to j

O_i = the volume of exports from zone i

W_j = the attractiveness of a specific port j (usually taken as proportional to the size of facilities available at the port)

d_{ij} = the distance between export zone i and port j

α and β are parameters of the model.

The equilibrium model is formed by adding the condition that the predicted export flows $\{S_{ij}\}$ when summed over all ports are consistent with the given zonal export quantities,

$$\sum_j S_{ij} = O_i \tag{9}$$

and this provides enough equations for port sizes, W_j, to be estimated.

4. Data and an extended model

As we have seen above, the criticisms of the original Portbury model were as much aimed at the data used and the way the model was employed as at the form or type of model, especially in the case of Senior (1983) who has re-examined the original gravity model with a variety of new data sources. This provides us with a wide range of data to draw upon.

The first measure or data source required is zonal exports (the O_i's in the models). The Ministry of Transport was fortunate to have the observed 1964 non-fuel exports for England, Scotland and Wales, aggregated into 41 origin zones (see Appendix A). Their subsequent forecasts for 1980 were made by simply updating all the zonal export totals by a uniform 84%, based on the assumption that the growth in the national economy, as measured by the gross domestic product, would be of the order of 3.89% per annum. Whilst this figure in itself is obviously open to criticism, of more worry was the assumption that this growth rate would apply uniformly across the country. With this in mind Senior devised a more reasonable measure of 1980 export totals. He increased national exports by the 84% figure but then divided this national total amongst the regions based on 1978 percentage contributions of each region to the total recorded exports (calculated from D.O.T. and N.P.C. (1980) and M.O.T. (1966)). These regional export values were then divided among constituent zones according to their share of regional exports in 1964 (Senior, p. 105). Since our aim is to model flows for 1980, these figures were taken for the analysis.

The spatial impedance variable (d_{ij}) was kept as distance as in the original 1964 model. The use of distance rather than time has also been criticised, as indicated earlier, but given the difficulties of converting road distances into time, distance was felt to remain an adequate measure for our purposes. Moreover, ease of travel can be changed if necessary via the β parameter, particularly if it is made i-dependent.

With these two data sources defined we can then attempt to model the structural variables - in this case the W_j's, or port sizes (for 25 ports in the UK, as listed in Appendix D). In other words for the given system and set of parameter values (α and β) we wish to determine the values of $\{W_j\}$. This can be achieved using one of a number of hypotheses, which it can be shown turn out to be equivalent. The simplest is the addition of the balancing equation already noted above, (9). Overall, they range from so-called consumer surplus maximization, producer profit maximization to revenue-cost balancing (see Clarke, 1984). Here we continue with the revenue-cost balancing approach first presented, for the retail sales model, in Harris and Wilson (1978), subsequently modified by Wilson and Clarke (1979) and Clarke (1981).

Typically in the conventional retail location model zonal supply (W_j) is measured in square feet of floorspace (or some similar term). The balancing conditions for equilibrium solutions of the retail location model, as suggested by Harris and Wilson, are

$$D_j = KW_j \tag{10}$$

where D_j is the amount of revenue attracted to j and K is the unit cost of supplying floorspace in j. In other words, an equilibrium solution would exist when revenue balanced costs.

Clarke (1981) demonstrated that the solution to the consumer surplus mathematical programming representation of the same model required that,

$$D_j = \frac{\gamma}{\alpha} W_j \tag{11}$$

where γ was the lagrangian multiplier associated with the total stock constraint,

$$\sum_j W_j = W \tag{12}$$

and α was the attractiveness parameter.

Thus to define an equivalence between the two models above we require

$$K = \frac{\gamma}{\alpha}. \tag{13}$$

This has important ramifications for our problem of modelling export flows. We are in effect measuring supply and demand in the same units j that is, demand is measured in tonnage of goods and supply can be measured in tonnage capacity. This implies that,

$$\sum_j S_{ij} = O_i \tag{14}$$

and hence,

$$\sum_{ij} S_{ij} = \sum_i O_i = \sum_j W_j \tag{15}$$

where O_i is the zonal demand or tonnage.

Using an iterative method for solving the equations, we assume that the balancing conditions are given by (10) with $K = 1$, or, equivalently, by (9). This however gets us into difficulties when $\alpha > 1$, because we are assuming that $\alpha = \gamma$ (from (13) above). As soon as $\alpha > 1$ this no longer holds because of (11). When we increase α without appropriate compensation on γ we are in effect reducing the value of γ which has the net effect of reducing the total amount of stock and equation (15) no longer holds. Explicit use of the ratio $\frac{\gamma}{\alpha}$ instead of K, however, means it is possible to make appropriate adjustments in the supply side of the system, some of which will only change the total amount of stock (i.e. γ change) others that will have implications for the actual spatial distribution of facilities (α change)(see Clarke, 1981).

5. Numerical experiments

Given our data and solution procedures the first step is to solve the models for a range of α and β values. A note on the behaviour of these parameters provides a useful starting point.

The α parameter is taken as a measure of the importance of port size or as the Ministry of Transport referred to their 'a' parameter, "an indication of the way in which size measures the attractiveness of a port" (M.O.T., 1966, p. 47). (In the conventional work on the retail model α refers to consumer scale economies, see Clarke and Wilson, 1983.) Thus in effect when $\alpha > 1.0$ we have weighted the importance of larger ports. With a high α value therefore we would expect a solution where supply is concentrated at fewer larger ports.

The β parameter reflects the sensitivity of export flows to spatial separation of origins and ports. The higher the value of β the more difficult travel is assumed to be which penalizes the long distance journey and produces a more widespread or localized configuration of port facilities.

Figures 1 - 3 show these parameters at work. In Figure 1a-c α is assigned the value 1.1 and β is allowed to vary. As Figure 1a shows a relatively high value of α will always produce a concentration of facilities whatever the value of β. For $\beta = 2.0$, however, facilities are fairly well distributed across the country since although the high α value is encouraging concentration, the high β means that travel is relatively difficult and so flows are allocated to the nearest port which satisfies the high α conditions. As β decreases a far more concentrated pattern emerges since both parameters are now encouraging concentration. Figure 1c shows the situation when β reaches 1.00 and we see only Manchester, London, Tees and Glasgow managing to attract facilities. Figure 1d shows this regional effect is lost when β reaches 0.5. Here all facilities are now concentrated at Manchester. This is simply because Manchester is at the geographic heart of the system and is obviously the most attractive port when the ease of travel parameter is so low and there are no restrictions on capacity.

Figure 2 shows a variety of solutions for changing β when $\alpha = 1.00$. Lowering the value of α has in effect encouraged a more dispersed pattern of facilities since the extra advantage of size for each port, has been relaxed. A comparison of Figures 1 and 2 shows this quite clearly. In Figure 2a the lower α value has allowed facilities to become present at Hull, Liverpool and Newcastle. Similarly the ports of South Wales and Bristol have become more attractive.

Figure 3 shows β variation around $\alpha = 0.95$. As work has shown with the conventional retail model (see Clarke and Wilson, 1982, 1983) when $\alpha < 1$ all zones have non-zero W_j vales. Clarke (1984) shows how the mechanism of $\alpha < 1$ produces such behaviour. He concludes that uniform values of $\alpha < 1$ should be avoided when searching for realistic solutions.

So far we have seen the variety of patterns obtained from α and β variation. However these results are obviously not very realistic in terms of real world port facilities. This is because the models are providing optimal solutions given unlimited size restrictions on the size of any one port. Clearly the size of ports is restricted and therefore the natural extension to these models is to introduce some kind of capacity constraints to each port.

In the original gravity model the observed 1964 port exports were chosen as the port-size measure W_j. Since we are modelling flows for 1980 we have used one of the 1980 export capacity senarios for the 25 ports identified in the original Portbury study. As Senior (1983, p. 97) reports,

> "there scenarios were designed with general reference to
> (a) the minimum capacity revised for 1964 non-fuel exports,
> (b) NPC (1965) recommendations on the construction of new berths,
> (c) the projected need to cater for an 84% increase in exports,
> (d) the expected loss of obsolescent capacity at London, Liverpool, and to a lesser extent Glasgow, and more importantly,
> (e) the provision of export capacity at Bristol capable of handling the 2.6 to 2.743 million tons of exports forecasted by the P.B.A.
> These considerations were then translated (crudely) into port capacities" (see Appendix C)

Using observed port exports or predicted throughputs as capacity constraints implies that the ports are being or will be used to full capacity. Clearly this is not the case and so, somewhat arbitrarily in the absence of precise information on port capacities, the predicted throughputs for 1980 have been increased by 20%, and these used as capacity constraints.

Figure 4 shows the pattern of facilities for α = 1.1 and β variation, whilst Figure 5 shows the pattern of facilities for α = 1.0 and β variation. Comparisons with Figures 1 - 3 show that the patterns overall in Figures 4 and 5 are far more dispersed since centres such as Manchester are now constrained and cannot expand beyond a certain level. Since Manchester is constrained we see Liverpool and London (obviously much larger docks in reality) becoming far more dominant for low β values (see Figures 4d and 5d).

By using capacity constraints in this way we are approaching more realistic solutions but are still faced with a major problem. Once the capacity constraints have been introduced supply no longer matches demand, or, in other words, the volume of exports cannot be fully handled by the set of port sizes (unless β is extremely high). In Figures 4 and 5 for example ports such as Liverpool, Manchester, London and Tees continually attract more exports than they can handle. The model is forced, by the capacity constraints, to cut-off export flows to each port at a certain level and the excess cannot be re-distributed. This is a consequence of the parameter values given our particular solution procedures. If β is relatively low, for example, it is simply not feasible or possible for the models to create a situation where a large number of small ports are in operation.

How then can we overcome this problem? First, we can simply increase the size of the constraint values, which would allow the larger ports to absorb more demand. Senior (1983, p. 92) refers to the report by the National Ports Council in 1969 (N.P.C., 1969, p. 64) which suggested that:

> "efficiently operated general-cargo berths using conventional methods could achieve a throughput of over 100,000 tons per year, but that the majority of throughputs were in the range of 30,000 to 50,000 tons, implying at best a 50% utilization of capacity" (Senior, p. 92).

Figures 6 and 7 show the solutions resulting from an increase of forecasted 1980 throughputs by 50%. A comparison of Figures 4 and 5 with Figures 6 and 7 show that the patterns which emerge from the models are identical in spatial terms, although each port has been able to absorb more exports and hence get closer to matching supply and demand. It is interesting to note that so far Bristol (Portbury) has not come out favourably in the model solutions. This is because, as we have seen, the larger ports are far more attractive even when we constrain their maximum capacity.

The reason the overall patterns do not change is simply because the original problem is still with us. That is ports such as London and Liverpool are still attracting too much demand and even though their overall capacities have been increased, they still cannot handle the amount of exports the models are trying to allocate. If we assume that our capacity constraints are now realistic the only way we could fully deal with the flow of exports would be to have massive investment in ports such as London, Liverpool and Teesside.

Having failed to match supply and demand through increasing our capacity constraints it is clear that we have to try and stop the models from allocating exports to the most congested ports, in our case, London, Liverpool and Tees. If we can penalize these ports in some way then we might expect some re-distribution and a pattern which might, more closely, resemble reality. An effective method of achieving this is to embed the spatial interaction model into a mathematical programming framework. This would enable the port capacities to be imposed as formal constraints within the mathematical programme, we would expect a resulting pattern of facilities which was far more widespread.

A suitable mathematical program, derived from our interaction model, turns out to be (Clarke, 1981):

$$\max_{\{W\}} L = -\frac{1}{\beta}\sum_{ij} S_{ij}\log S_{ij} + \gamma\left(\sum_{ij} S_{ij}\log W_j - \beta\right) \tag{16}$$

where

$$S_{ij} = A_i O_i W_j^{\alpha} d_{ij}^{-\beta} \tag{17}$$

and s.t.,

$$\sum_j W_j = W \qquad (18)$$

$$W_j \leq W_j^{max} \quad \forall_j \qquad (19)$$

$$W_j \geq 0$$

where

W_j^{max} is the maximum capacity of each port

W_j is the actual supply.

This can be solved using a reduced-gradient solution procedure (Wilson, 1981) which is carried out in a non-linear programming computer package set up by MacGill et al (1979).

Figure 8 shows the effects on the $\{W_j\}$ pattern of variation around $\alpha = 1.1$ for the non-linear mathematical program. Here the model constraints have been calculated by increasing the predicted throughputs for 1980 by 20% and are hence comparable to the results depicted in Figure 4. A comparison of Figures 4 and 8 shows the latter with a far wider dispersion of facilities given the same parameter values. The differences are not difficult to explain.

In Figure 4 the models are trying to allocate demand to the most favourable ports given the values of the parameters and the solution procedure. When we impose constraints upon the size of these favourable ports it is not possible for the models to re-distribute the excess levels of demand back into the system. In Figure 8 however the constraints have been imposed as formal conditions governing the nature of the solution and the mathematical program will make sure all exports are accounted for and hence total supply matches demand. In order to do this the model must allocate some supply to the smaller ports as the most favourable are quickly filled up. As Figure 8 shows, however, not all ports receive supply and we shall return to this problem shortly.

It is interesting that the patterns change little in Figure 8a-d as β is reduced, although Figure 8d does show a slightly more concentrated pattern than Figure 8a. The variations between patterns are mainly seen at Hull, Swansea, Grangemouth, Newcastle and Southampton.

Figure 9 shows β variation around $\alpha = 1.0$ for the mathematical program. A comparison between Figures 8 and 9 shows that the solutions are very similar although the patterns in Figure 9 are slightly more dispersed as one would expect given a lower α value. Once again the ports which vary the most are Hull, Southampton, Newcastle and Grangemouth.

From Figures 8 and 9 we see that Bristol does relatively well and under the conditions of the mathematical program would, it seems, be able to reach the PBA's estimate of 2,600,000 tons by 1980! The reason for this of course is that all the medium-sized ports do well when the largest ports have been constrained and Bristol does better than most since it is well-sited in relation to the Midlands and South-Western England. Does this mean then that the M.O.T. may have been wrong to reject the Portbury proposal?

In effect there are a number of problems with the assumptions of our models. The outcomes of our models tells us a great deal about our system, under the assumptions we have adopted, and forces us to think more carefully about what actually has happened. (This of course is the reward for undertaking numerical experiments). In this analysis the importance of Bristol has probably been over-emphasised, and the next step is to explore why.

The first problem hinges on the data we have used:- that is the predicted port sizes or capacities for 1980 made in 1964. In reality those predictions have under-estimated the importance of the (then) smaller ports and over-estimated the importance of the larger. In 1964 for example the ferry ports of eastern and southern Britain did cater for relatively low levels of exports. Based on these patterns the 1980 predictions were calculated. Since then however the increase in exports handled by the ferry ports has been immense. Senior (1983) quotes the actual non-fuel exports of 1978, shown here in Appendix C, and it is immediately apparent that there are large differences between the actual 1978 exports and those predicted for 1980. Much of the growth foreseen for the larger and medium-sized ports has gone to these ferry ports.

The growth of these ferry ports has resulted from the increased role of containerization in modern-day freight flows and the increasing importance of EEC trade. The rapid rise of containerization began in the late 1960s (see Van der Burg, 1969) and clearly was not picked up in the M.O.T.'s predictions for 1980 (although discussed in the M.O.T. White Paper, 1966). This shows the dangers of long term forecasting when there is a possibility of significant technological change.

The second factor which tends to over-emphasise Bristol's importance is that the model is allocating supply on the basis of the distances between original zones and the ports:- that is over-land distance. For more conventional urban modelling purposes this is a realistic criterion. However, whilst it is important here, perhaps more crucial is the average distance travelled from each port to overseas destinations. That is whilst Bristol comes out favourably in geographic terms for journeys to ports in Britain, its long-sea-journey times to overseas ports clearly effects that overall attraction. Clearly, the attraction of the ferry ports is that once on the coast of France, Belgium or Holland most of the European interior is easily accessed.

Given the above discussion, the next step is to incorporate the importance of the growth in the ferry ports, and examine the impacts on the remaining ports. This forms the basis of the next section.

6. Towards more realistic models

We have seen in our model runs so far, that under our present assumptions the smaller (in the 1960s) ferry ports have not been able to attract any facilities partly because their real attraction does not necessarily result from overland locational accessibility.

Part of the problem lies in using uniform α and β parameters. Uniform values in effect penalize those ports which are not very accessible, in distance terms, to the British interior. It will be remembered, for example, that the α parameter represents scale economies:- thus when $\alpha > 1$ the most favourable ports are made more so at the expense of others in the system. This problem can be overcome, or at least made less acute, by introducing α and β-specific parameter values (to each port).

The resulting equilibrium model would thus take the form,

$$S_{ij} = A_i O_i W_j^{\alpha_j} d_{ij}^{-\beta_j} \tag{21}$$

where the variables are as listed previously.

In order to give a flavour of the various possibilities open to us we first work with β-specific values for the 1980 predicted data and then α-specific values for the more realistic 1978 known data. How do we determine β or α-specific values?

Conventional calibration of destination specific β values requires a full observed interaction matrix for the time period under investigation $\{S_{ij}\}$. Unfortunately this is not available to us and hence we have devised an approximate calibration procedure, the results of which must be interpreted with some care. The procedure continues as follows:- we use the 1980 export-capacity scenario values of $\{W_j\}$ as some observed set W_j^{obs}. Using the interaction model given by (21) we then wish to find $\{\beta_j\}$ so that,

$$\sum_j S_{ij}^{pred} \leqslant W_j^{obs}. \tag{22}$$

(Thus the model is allocating at least the 1980 $\{W_j\}$ values to each port.)
If

$$\sum_j W_j^{obs} = \sum_i O_i^{obs} \tag{23}$$

then clearly we wish to find $\{\beta_j\}$ where,

$$\sum_j S_{ij}^{pred} = W_j^{obs}. \tag{24}$$

Thus, if

$$\sum_j S_{ij}^{pred} \leqslant W_j^{obs}, \tag{25}$$

(that is the model is under-allocating facilities to a particular port) then,

$$\beta_j = \beta_j - inc \tag{26}$$

where inc is a small constant incremental value of β (though it could be made more complicated).
Conversely, if,

$$\sum_j S_{ij}^{pred} \geqslant W_j^{obs} \tag{27}$$

(that is the model is allocating too much trade to a particular port, in this case the most geographically accessible) then,

$$\beta_j = \beta_j + \text{inc.} \qquad (28)$$

Figure 10a shows the set of β-specific parameter values which emerge from this procedure for the 1980 predicted port sizes. Here Bristol is given the 1978 W_j value of 300,000 tons which is 100,000 tons above the 1964 throughput (i.e. an increase but not on the scale envisaged after investment in the Portbury scheme). Since the model wishes to put facilities into Bristol (because of its overland accessibility, as we have seen) it must make β_j for Bristol relatively high in respect to all other $\{\beta_j$'s$\}$:- 1.62. In Figure 10b Bristol is given a W_j value of 2,600,000 tons (the P.B.A. estimate) and as can be seen, the β_j value for Bristol has to be extremely low to capture such a large share of the market (again relative to all other port sizes and parameter values).

Using these two sets of β-specific parameter values, Figures 11a and 11b show the equilibrium solutions, for a fixed α value of 1. We use the equilibrium model here since we are not concerned with capacity constraints.

It can be seen from Figure 11a and 11b that there is a wider spread of facilities for the equilibrium models (as compared to the patterns shown in Figure 2, for example). However it seems at first strange that all ports still do not have facilities - in other words the equilibrium solutions shown in Figure 11 differ from the observed pattern of facility sizes using the calibrated procedure in Figure 10. A little thought provides a straightforward answer:- the observed facility sizes seen in Figure 10 do not satisfy the basic theoretical assumptions under-pinning the equilibrium model, that is the balancing of revenues and costs. The results shown in Figure 11 however do satisfy this criterion. This is a common feature of results obtained from these and related models:- that optimal or equilibrium solutions do not correspond exactly to real world observations.

Again it should be noted that the 1980 predicted data greatly underestimates the importance of the eastern and southern ferry ports. Using known 1978 data we would thus expect these ferry ports to fare better in our quasi-calibration procedure. Similarly, since we are primarily concerned with the attractiveness of various ports, it might be more realistic to work with α-specific parameter values.

Equations (22)-(28) showed the mechanism for calculating a set of $\{\beta_j\}$ and the same mechanism can now be used to find $\{\alpha_j\}$. Equations (25)-(28) can thus be replaced by

$$\text{if} \quad \sum_j S_{ij}^{pred} \leq W_j^{obs} \tag{29}$$

$$\text{then} \quad \alpha_j = \alpha_j + \text{inc} \tag{30}$$

$$\text{and if} \quad \sum_j S_{ij}^{pred} \geq W_j^{obs} \tag{31}$$

$$\text{then} \quad \alpha_j = \alpha_j - \text{inc.} \tag{32}$$

We have kept Bristol at its real 1978 value in line with the other west Britain ports which have not done so well since the mid 1960s. From Table 1 we can see that all the western ports have low α values as do the larger more favourable ports such as London, Manchester, Glasgow and Tees. That is, in order to account for the $\{W_j\}$ 1978 values, the model must assign for α-values to stop these ports attracting too much trade.

In contrast however all the ferry ports of eastern and southern Britain have relatively high α-values. That is to cope with the large flows passing through these ports the models must allocate them high α-values.

Figure 12 presents equilibrium model solutions using these α-specific parameter values. Now every port is allocated some facilities and the overall pattern closely resembles the real 1978 export situation. Thus α-specific values seem a reasonable method of compensating for important ports which are not favourably located in respect to overland accessibility.

It is worth briefly noting that we could also model the flow of exports in an incremental fashion:- that is incorporating some observed set of $\{W_j\}$ and then allocating extra facilities. In terms of the model the refined version would be of the form:

$$S_{ij} = A_i O_i (W_j^{fix} + W_j^{inc})^{\alpha} d_{ij}^{-\beta} \tag{33}$$

where W_j^{fix} is the observed port size (for some base year)

and W_j^{inc} is the change in facility size within the time period considered,

and the remaining variables are as before.

The additional constraints would be,

$$\sum_j W_j^{inc} = W^{inc} \tag{34}$$

where W^{inc} is the total amount of extra facilities

and $W_j^{inc} \geqslant 0$ (if no ports are to decline). (35)

Note that various alternative constraints can be devised to handle decline in port size but we do not consider them here.

Figure 13 shows the model output for fixed α and β values. Because of the large number of constraints the mathematical program form of the spatial interaction model has been used. In Figure 13a the initial set of $\{W_j\}$ are the observed 1964 export totals passing through each port. In Figure 13b the observed 1978 export totals are used. In both cases the model must allocate at least the observed $\{W_j\}$ for each port. As before the most favourable ports, in terms of overland location, receive the additional facilities.

This type of exercise enables 'inertia' to be modelled in the system: that is given the existing system, which ports would receive extra facilities? However, it does not alter any of our previous arguments: that is the same mechanisms are at work as before.

Clarly a great variety of new runs are possible given this new set of equations, including re-introducing α and β-specific values and alternative assumptions concerning the set of constraints.

7. Conclusions

The task of modelling export flows through British ports, first examined by the Ministry of Transport in 1966, has provided us with a useful problem to test the set of equilibrium models developed recently for retailing, in a different public planning context.

We have seen that the benefit or reward of undertaking numerical experiments has been to enable us to refine our theoretical assumptions and make inroads into producing more realistic models - in this case especially through introducing port-specific parameter values.

Again, it is worth emphasising that these methods were not available in 1966 and therefore obviously not available to the Ministry of Transport. However, we would argue that whatever models are used careful thought and refinement is constantly required if spurious results are to be avoided.

References

Beaumont, J.R., Clarke, M. and Wilson, A.G. (1981) The dynamics of urban spatial structure: some exploratory results using difference equations and bifurcation theory, *Environment and Planning A, 13,* 1473-1483.

Clarke, M. (1981) A note on the stability of equilibrium solutions of production constrained spatial interaction models, *Environment and Planning A, 13,* 601-605.

Clarke, M. (1984) Integrating dynamic models of urban structure and activities: an application to urban retail systems, PhD Thesis, School of Geography, University of Leeds (forthcoming).

Clarke, M. and Wilson, A.G. (1982) The analysis of bifurcation phenomena associated with the evolution of urban spatial structure, Working Paper 324, School of Geography, University of Leeds.

Clarke, M. and Wilson, A.G. (1983) The dynamics of urban spatial structure, progress and problems, *Journal of Regional Science 23/1,* 1-8.

DOT and NPC (1980) *Inland origins and destinations of UK International trade,* 1978 Department of Transport and National Ports Council, London.

Harris, B. and Wilson, A.G. (1978) Equilibrium values and dynamics of attractiveness terms in production constrained spatial interaction models, *Environment and Planning A, 10,* 371-388.

Heggie, I.G. (1969) Are gravity and interactance models a valid technique for planning regional transport facilities? *Operational Research Quarterly, 20,* 93-110.

Huff, D.L. (1963) Defining and estimating a trading area, *Journal of Marketing, 28,* 34-38.

Lakshmanan, T.R. and Hansen, W.G. (1965) A retail market potential model, *Journal of the American Institute of Planners, 31,* 134-143.

Macgill, S.M., Brookes, S.M., Coelho, J.D. and Clarke, M. (1979) A non-linear programming package, Computer Manual 7, School of Geography, University of Leeds.

Manners, G. (1966) Bristol, South Wales and the Bridge, *New Society, 10,* Feb. 1966, 7-10.

MOT (1962) *Report of the Committee of Inquiry into the major ports of Great Britain* (Chairman, Viscount Rochdale) Cmnd 1824, HMSO, London.

MOT (1966) *Portbury: reasons for the Minister's decision not to authorize the construction of a new dock at Portbury, Bristol,* Ministry of Transport, HMSO, London.

NPC (1965) *Port development: an interim plan,* National Ports Council, London.

NPC (1969) *Port progress report, 1969*, National Ports Council, London.

NPC (1980) *Annual digest of port statistics, 1979*, National Ports Council, London.

Senior, M.L. (1983) The British Ministry of Transport's study of the Portbury Dock proposal, 1966: a reappraisal of the spatial analysis, *Environment and Planning C, Government and Policy, vol. 1,* 85-105.

Tanner, M.F. and Williams, A.F. (1967) Port development and national planning strategy; the implications of the Portbury decision, *Journal of Transport Economics and Policy, 1,* 315-324.

Van der Burg, G. (1969) *Containerization: a modern transport system*, Hutchinson, London.

Wilson, A.G. (1969) Heggie on gravity and interactance models; a rejoinder, *Operational Research Quarterly, 20,* 491-492; 496.

Wilson, A.G. (1981) *Catastrophe theory and bifurcation: applications to urban and regional systems*, Croom Helm, London.

Wilson, A.G. (1983) Making urban models more realistic: some strategies for future research, Working Paper 358, School of Geography, University of Leeds.

Wilson, A.G. and Clarke, M. (1979) Some illustrations of catastrophe theory applied to urban retailing structure, in Breheny, M. (ed.) *Developments in urban and regional analysis*, Pion, London.

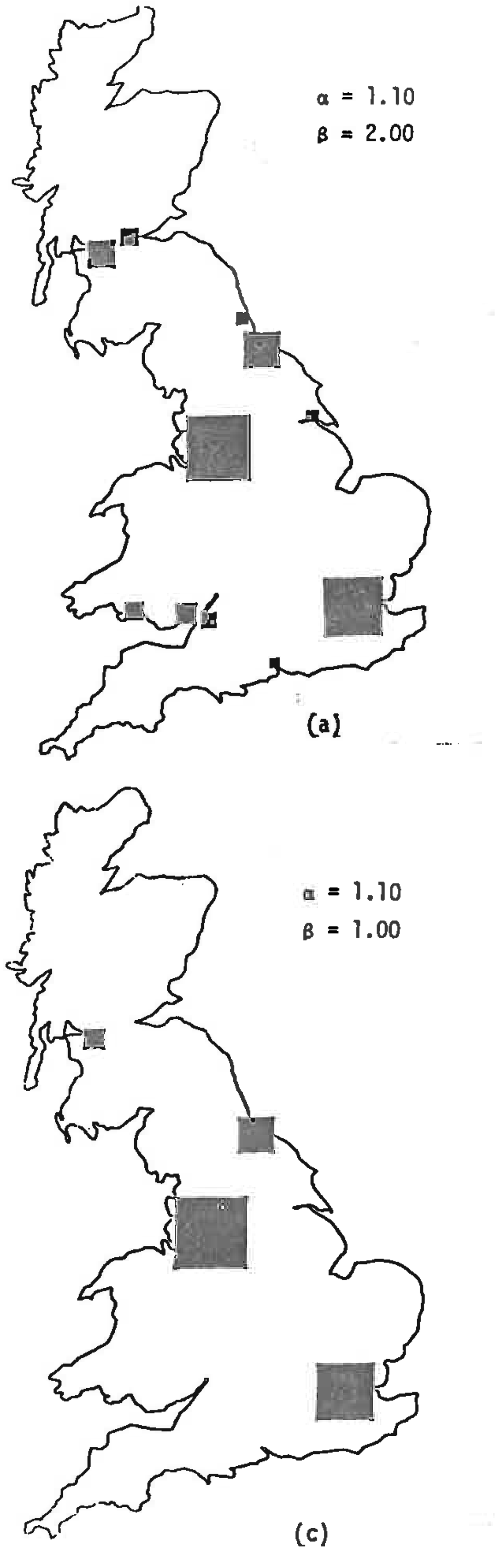


FIGURE 1 : β variation around α = 1.1

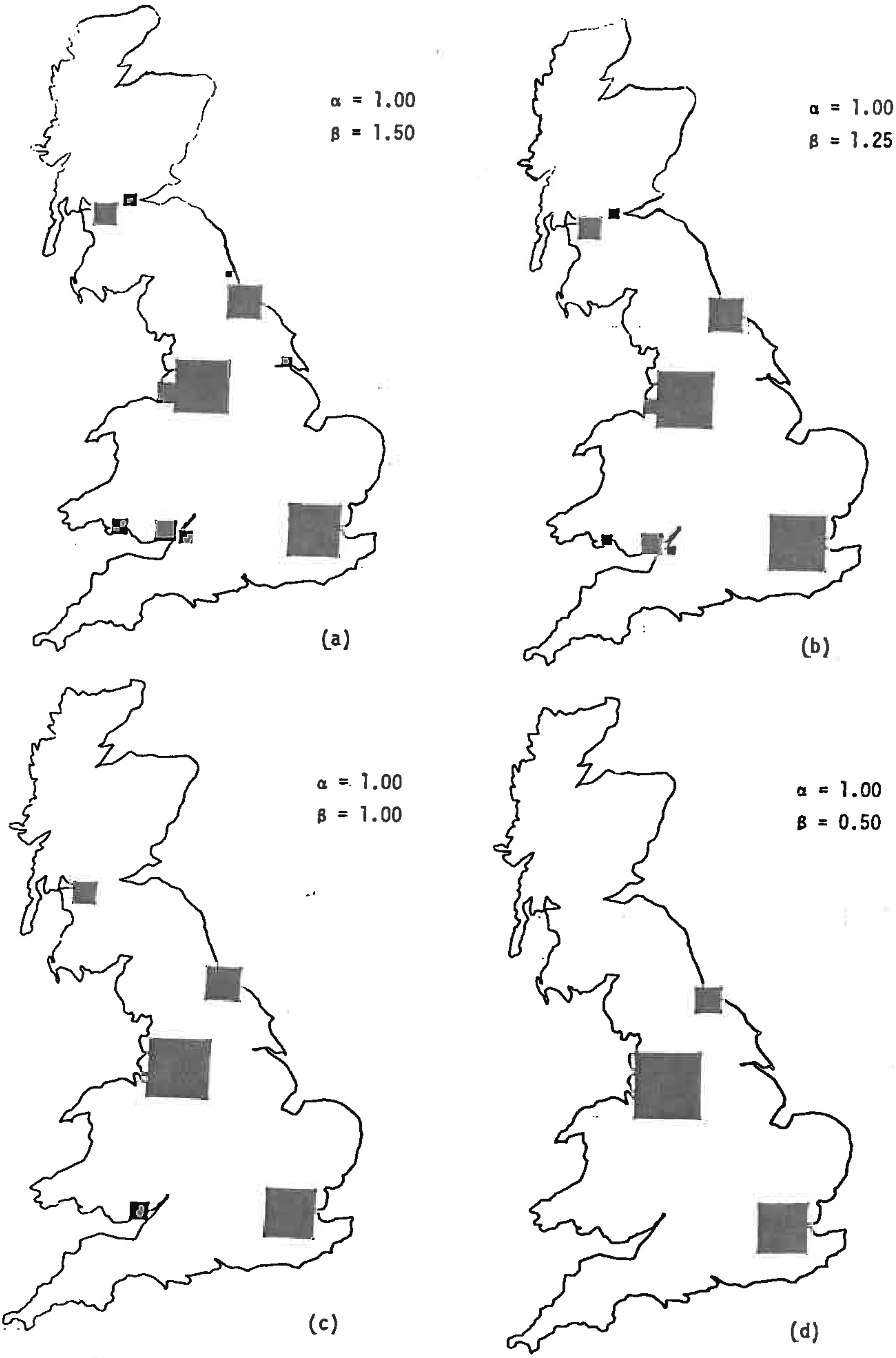


FIGURE 2 : β variation around α = 1.0

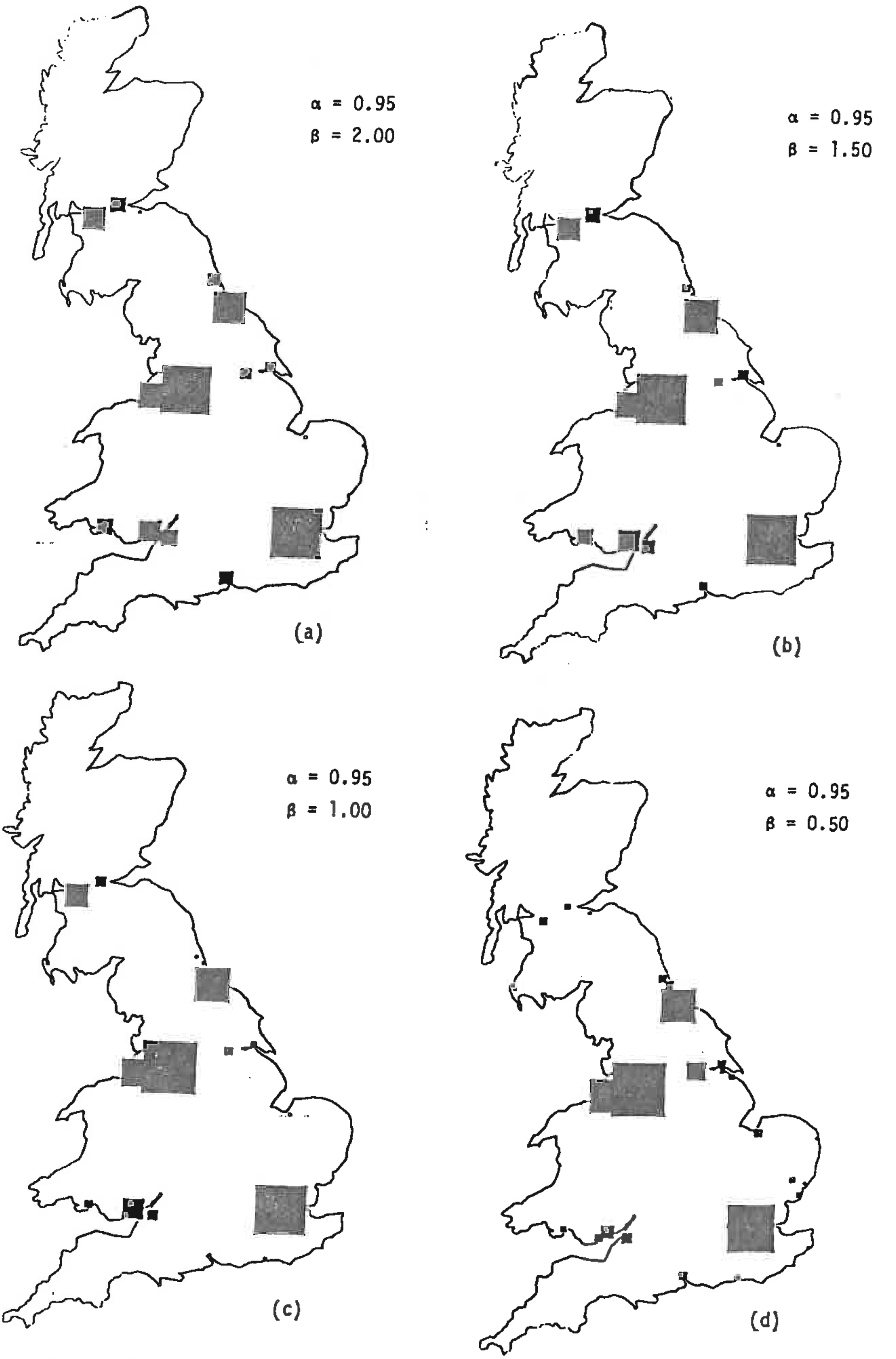


FIGURE 3 : β variation around α = 0.95

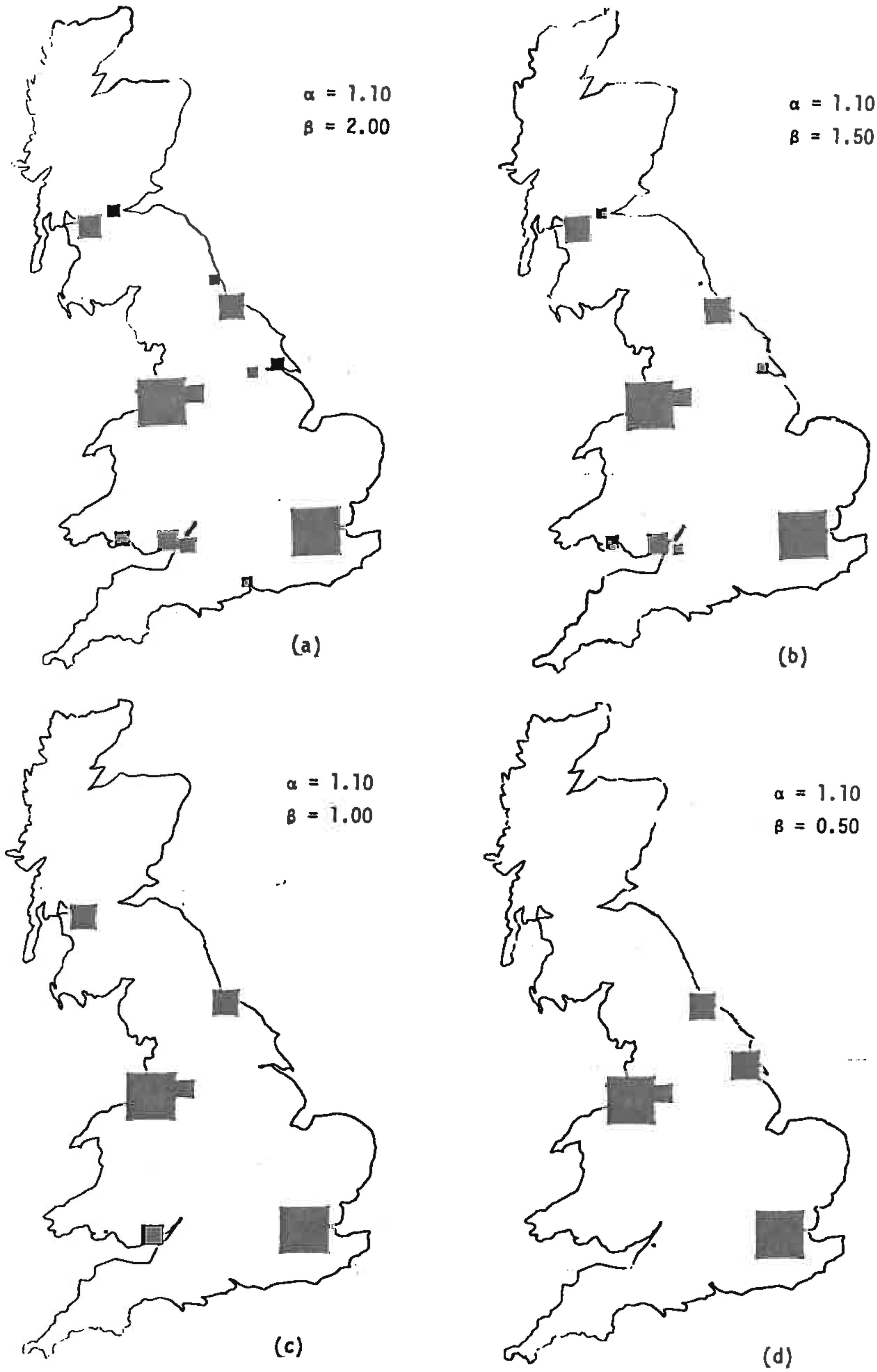


FIGURE 4 : β variation around α = 1.1 for port size constrained at 20% above 1980 throughputs

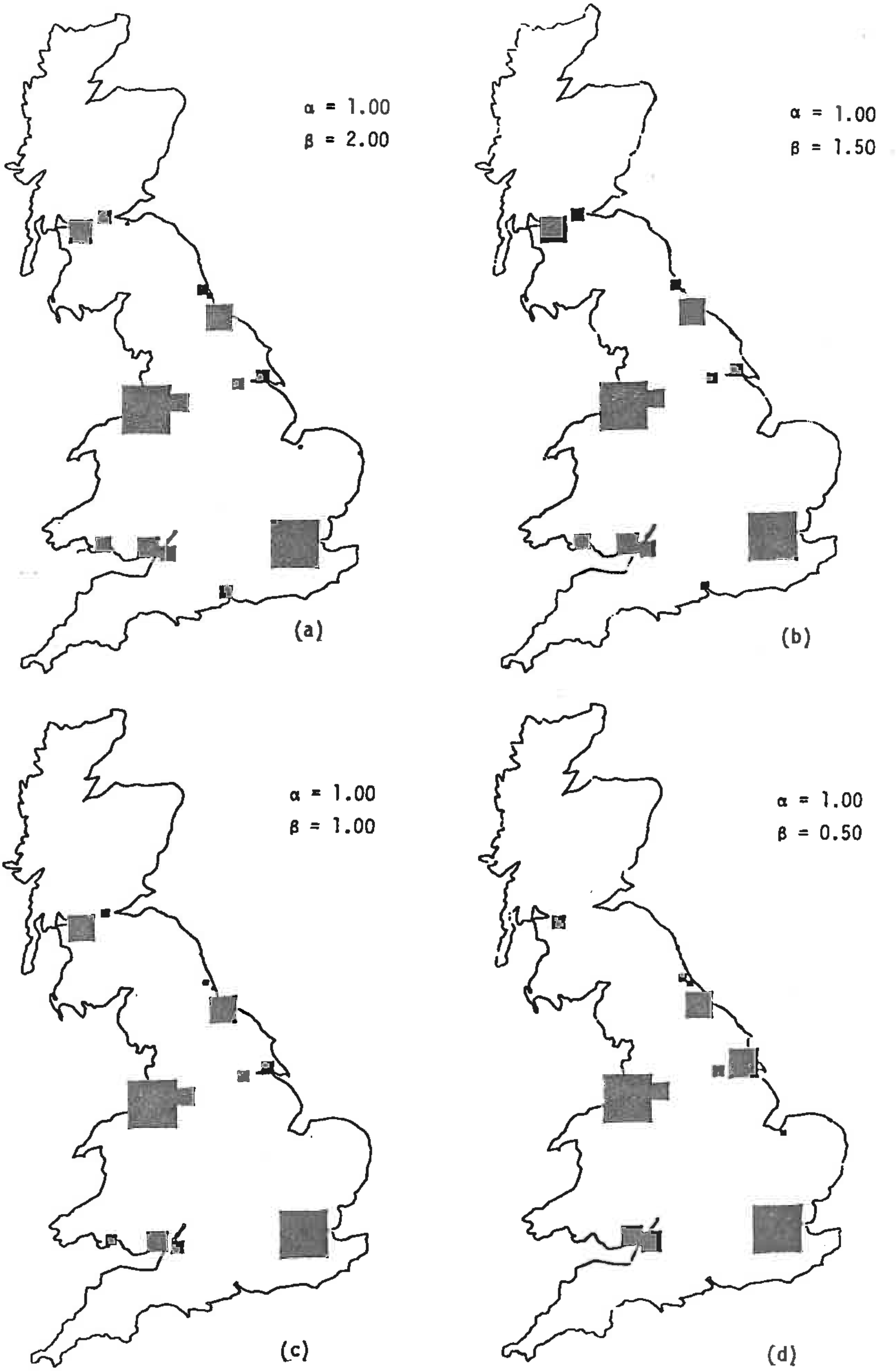


FIGURE 5 : β variation around α = 1.00 for port size constrained at 20% above 1980 throughput

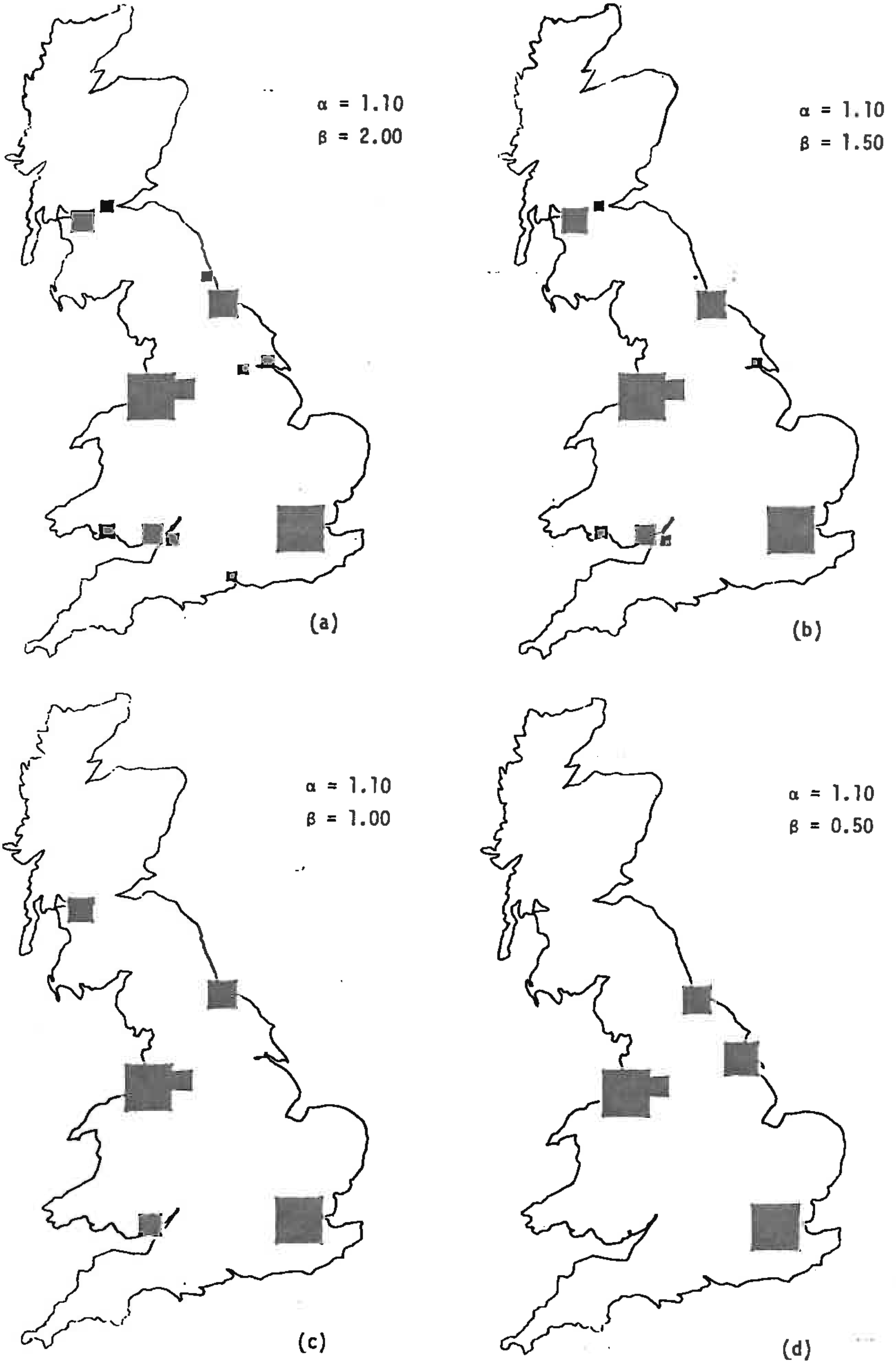


FIGURE 6 : β variation around α = 1.1 for port size constrained at 50% above 1980 throughput

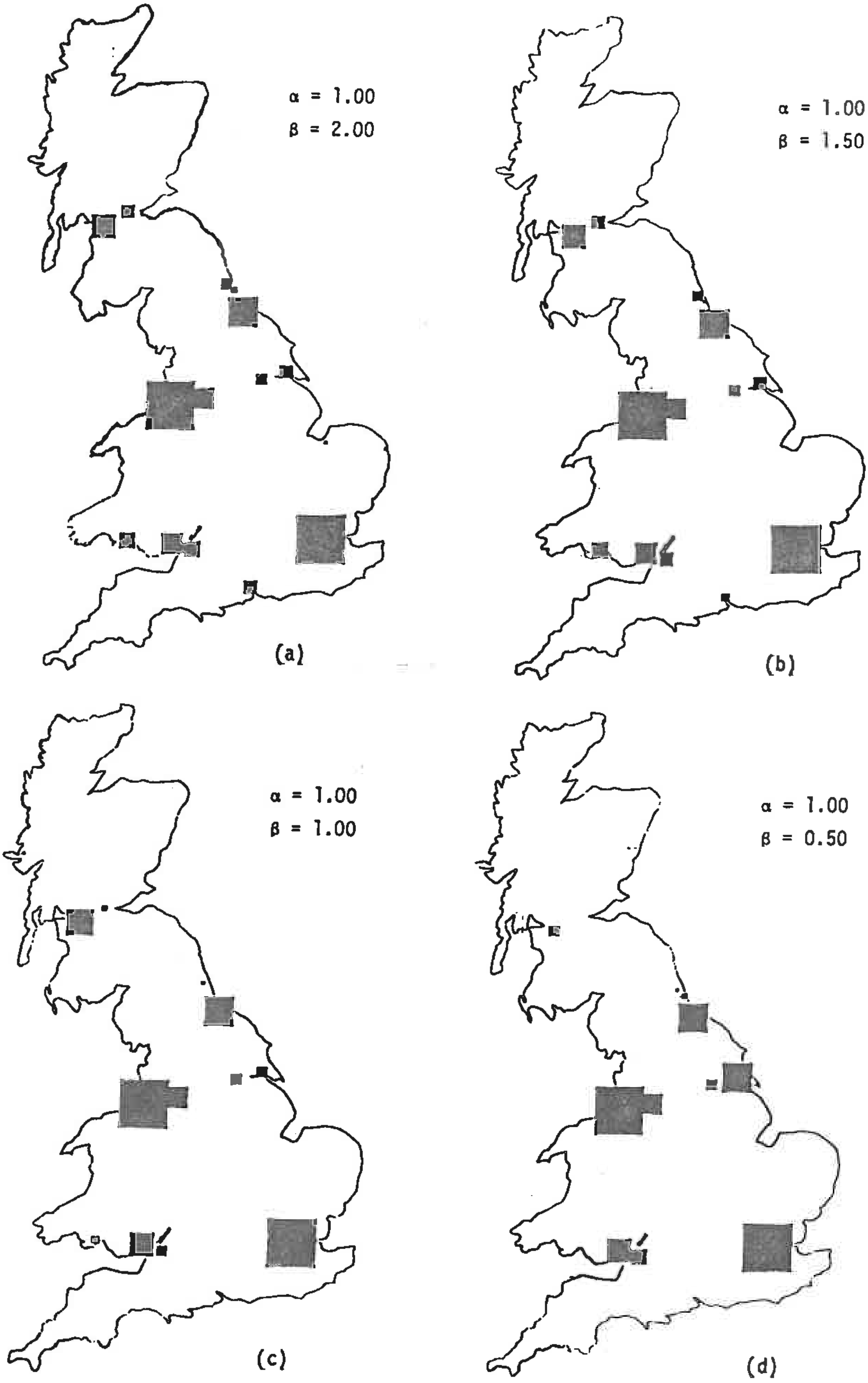


FIGURE 7 : β variation around α = 1.0 for port size constrained at 50% above 1980 throughput

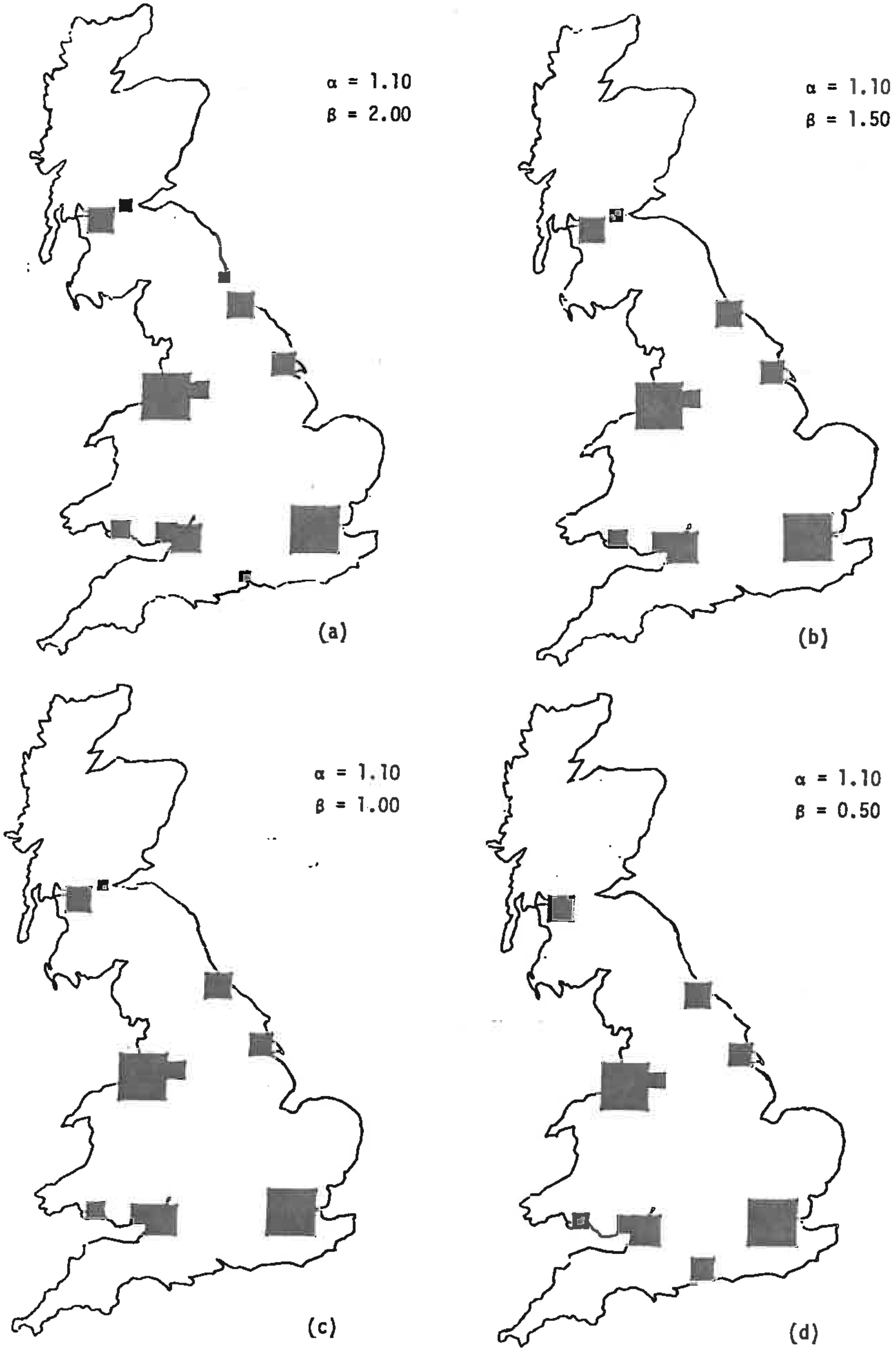


FIGURE 8 : β variation around α = 1.1 for non-linear mathematical programming package

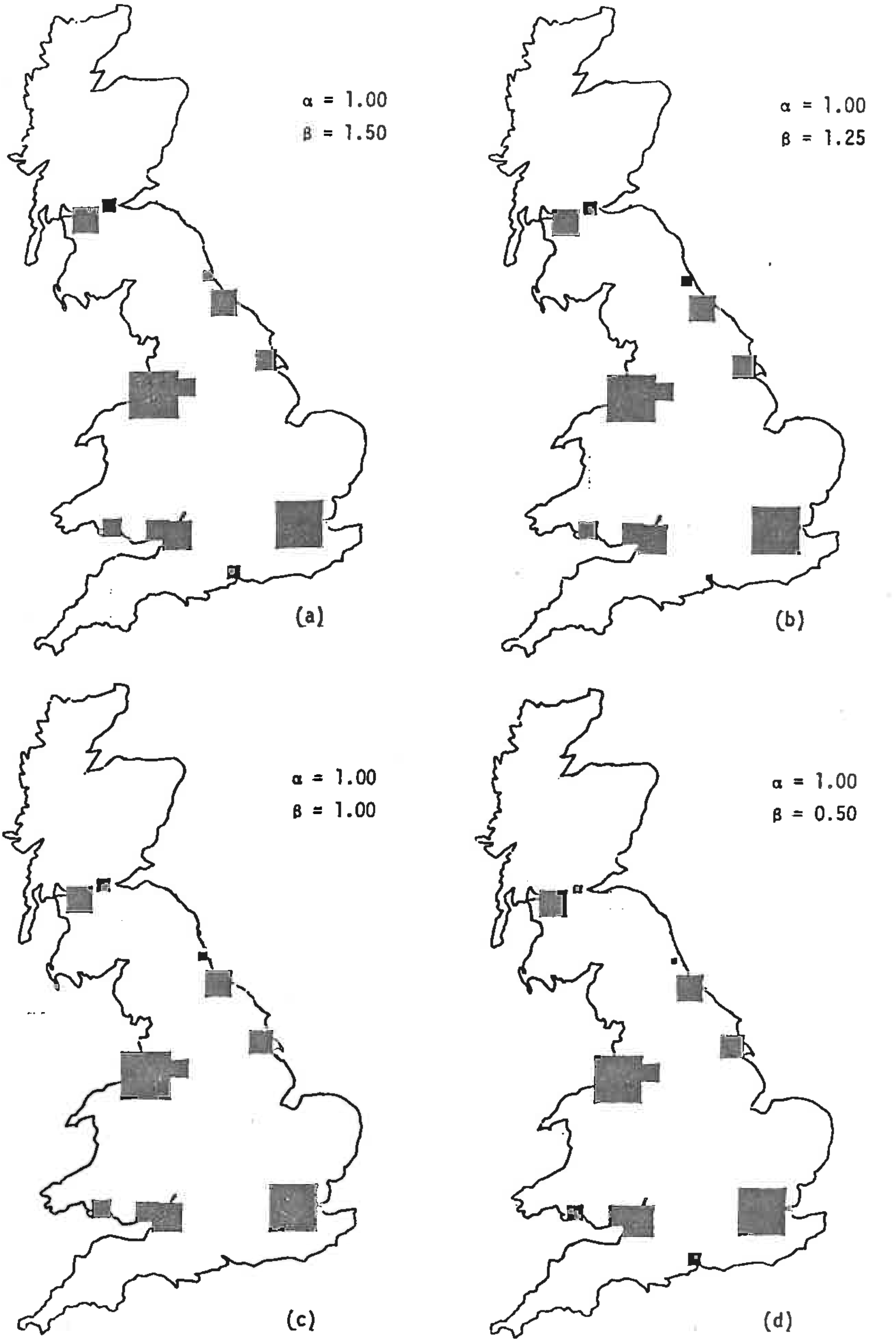


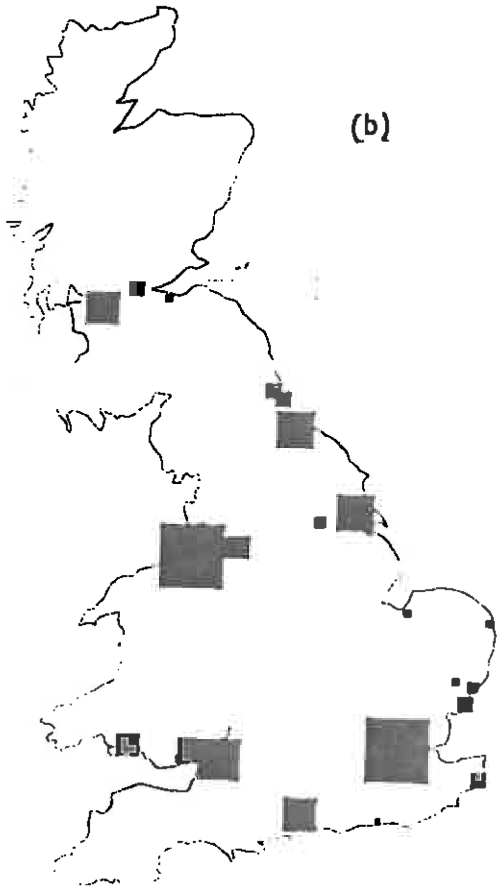
FIGURE 9 : β variation around α = 1.00 for non-linear mathematical programming using 1980 data

FIGURE 10 :

β-SPECIFIC PARAMETER VALUES

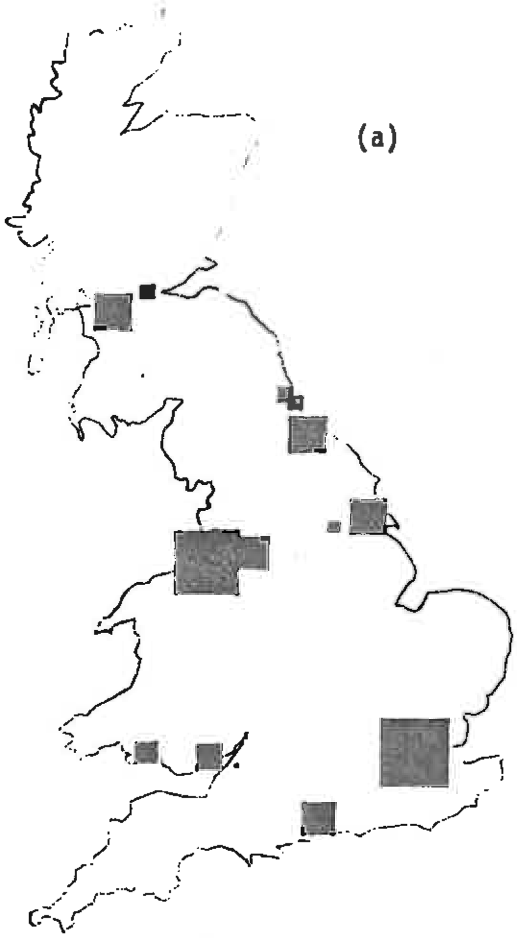
(a)

LONDON	1.52
DOVER	1.34
SHOREHAM	1.33
SOUTHAMPTON	1.20
BRISTOL	1.62
NEWPORT	1.42
CARDIFF	1.21
SWANSEA	1.24
LIVERPOOL	1.47
MANCHESTER	1.62
GLASGOW	1.16
GRANGEMOUTH	1.12
LEITH	1.34
NEWCASTLE	1.18
SUNDERLAND	1.13
TEES	1.92
HULL	1.20
GOOLE	1.25
IMMINGHAM	1.24
GRIMSBY	1.30
KINGS LYNN	1.24
YARMOUTH	1.32
FELIXSTOWE	1.33
IPSWICH	1.30
HARWICH	1.30



(b)

LONDON	1.50
DOVER	1.33
SHOREHAM	1.32
SOUTHAMPTON	1.14
BRISTOL	1.18
NEWPORT	1.33
CARDIFF	1.22
SWANSEA	1.18
LIVERPOOL	1.45
MANCHESTER	1.61
GLASGOW	1.19
GRANGEMOUTH	1.17
LEITH	1.30
NEWCASTLE	1.15
SUNDERLAND	1.14
TEES	1.91
HULL	1.17
GOOLE	1.23
IMMINGHAM	1.23
GRIMSBY	1.29
KINGS LYNN	1.23
YARMOUTH	1.31
FELIXSTOWE	1.32
IPSWICH	1.30
HARWICH	1.30



(a)

β value for Bristol = 1.62

(b)

β value for Bristol = 1.18

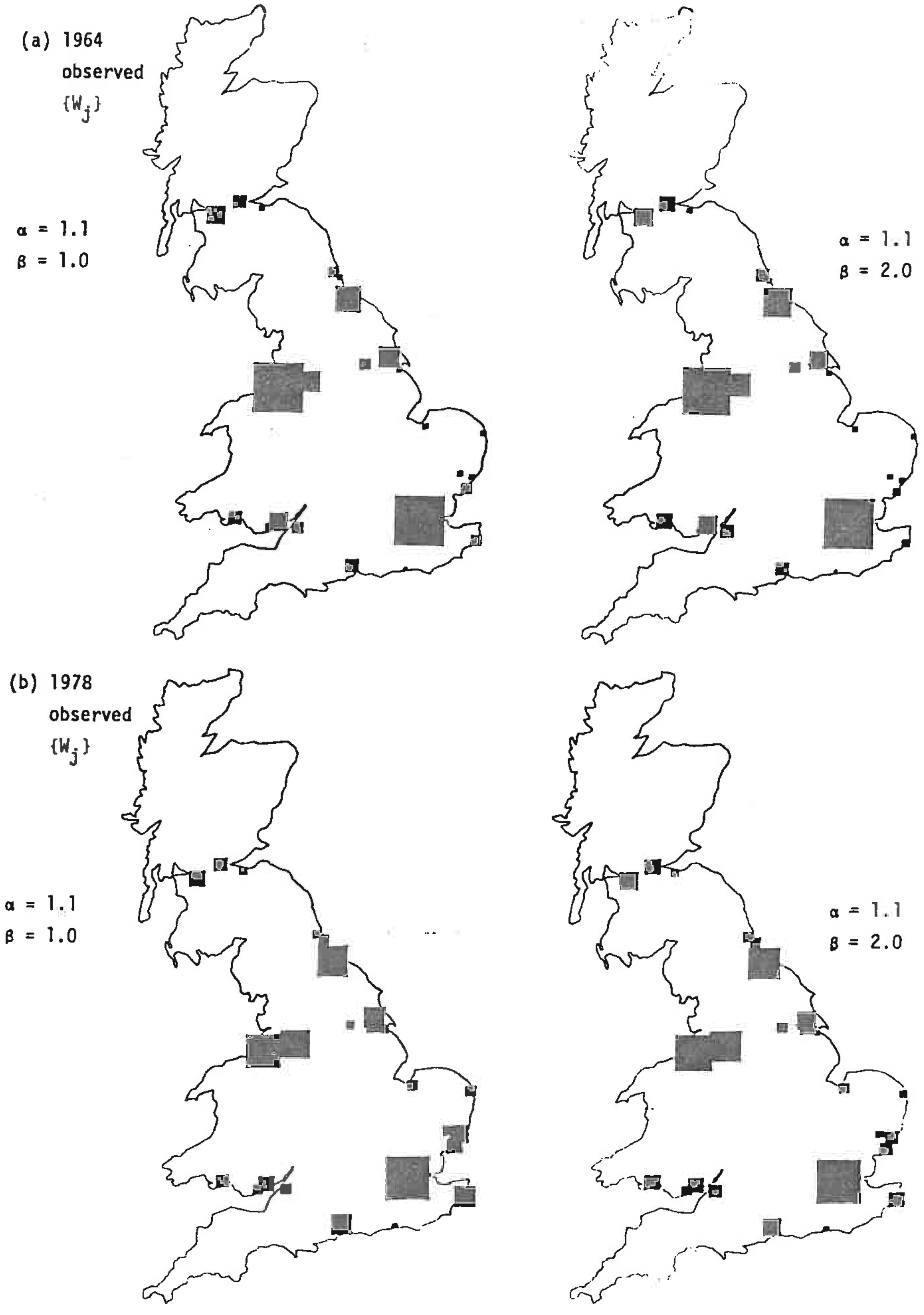
FIGURE 11 : β specific equilibrium solutions

TABLE 1 : α specific values

1.	London	0.99	14.	Newcastle	0.97
2.	Dover	1.13	15.	Sunderland	1.00
3.	Shoreham	1.13	16.	Tees	0.89
4.	Southampton	1.06	17.	Hull	1.03
5.	Bristol	0.99	18.	Goole	0.97
6.	Newport	0.90	19.	Immingham	1.07
7.	Cardiff	0.97	20.	Grimsby	1.09
8.	Swansea	0.94	21.	King's Lynn	1.07
9.	Liverpool	0.93	22.	Yarmouth	1.15
10.	Manchester	0.89	23.	Felixstowe	1.12
11.	Glasgow	0.84	24.	Ipswich	1.12
12.	Grangemouth	0.87	25.	Harwich	1.12
13.	Leith	1.02			

(to 2 decimal places)

FIGURE 12 : α specific values

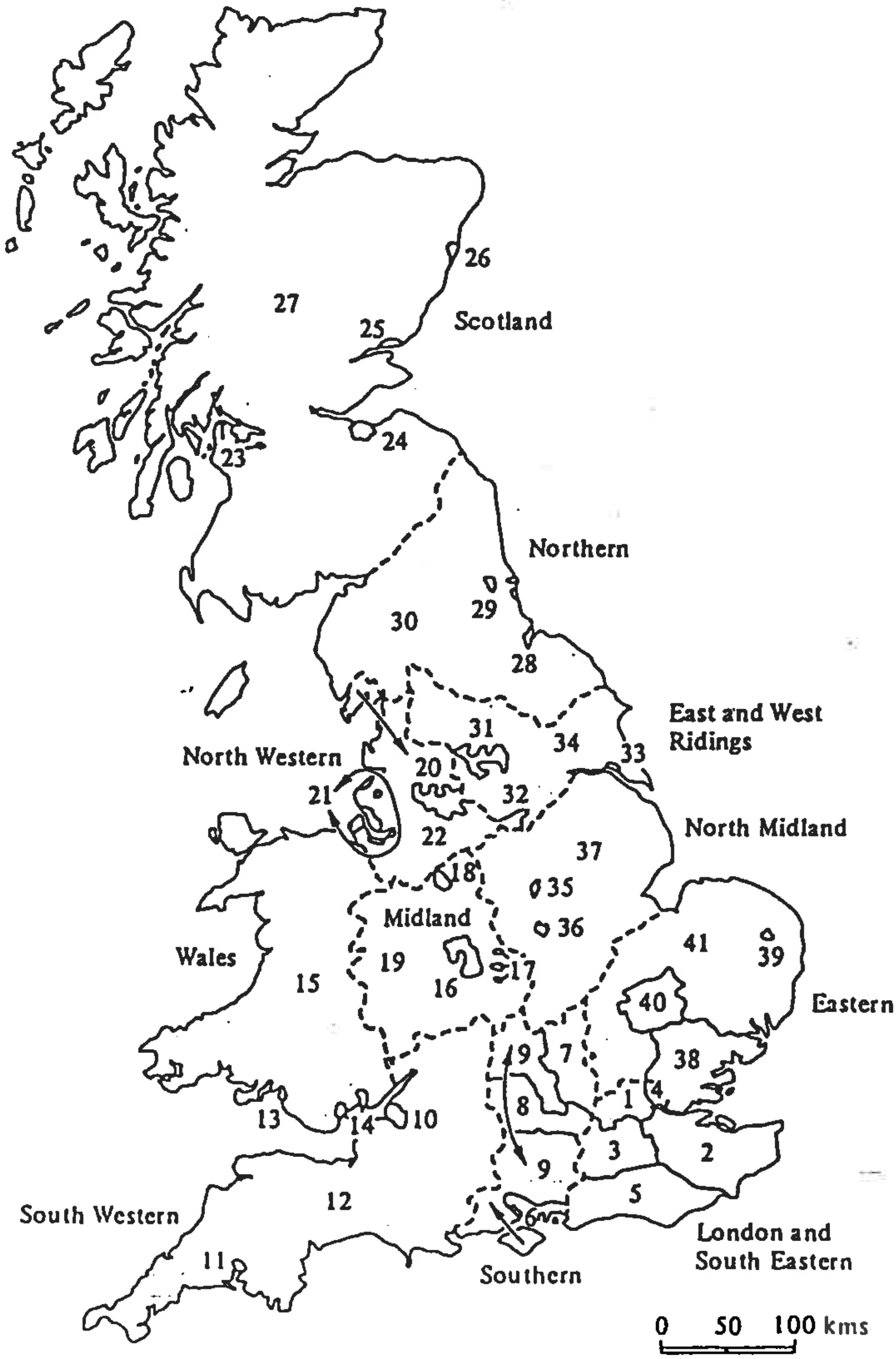


<u>FIGURE 13</u> : Incorporating 'inertia' into the models

APPENDIX A. <u>Map of Exporting Zones</u>

(see Appendix B for identification of zones by number)

from M. Senior (1983), p. 87.



APPENDIX B. Export Zones and Projection Totals for 1980 from M. Senior (1983), pp. 104-5.

London and South Eastern	1 London (that is, London Administrative County, Middlesex, Metropolitan Hertfordshire)	1712.9	1871.7
	2 Kent	422.1	1114.8
	3 Surrey	234.0	618.0
	4 Metropolitan Essex	130.4	142.5
	5 Sussex	92.5	244.3
Southern	6 Southampton/Portsmouth (including Havant, Gosport, Fareham)	115.3	304.5
	7 Buckinghamshire	93.4	246.7
	8 Berkshire	87.4	230.8
	9 Oxfordshire, rest of Hampshire, Isle of Wight	240.4	634.9
South Western	10 Bristol	52.4	215.2
	11 Plymouth	3.6	14.8
	12 remainder	213.0	875.0
Wales	13 Swansea/Port Talbot	422.3	722.3
	14 Cardiff/Newport	497.2	850.4
	15 remainder	396.6	678.3
Midland	16 Birmingham (including Walsall, Dudley, Wolverhampton, Solihull, Brownhills)	833.1	1114.4
	17 Coventry (including Kenilworth, Nuneaton)	260.7	348.7
	18 Stoke-on-Trent (including Newcastle-under-Lyme, Kidsgrove)	91.1	121.9
	19 remainder	447.7	598.9
North Western	20 Manchester (including Salford, Stockport, Bury, Rochdale, Oldham, Bolton, Glossop, Ashton-under-Lyne, Alderley Edge, Stalybridge)	640.9	895.1
	21 Liverpool (including Birkenhead, Wallasey, Southport, Runcorn, Ormskirk, Ellesmere Port, Wirral)	562.1	785.0
	22 remainder	2062.5	2880.4
Scotland	23 Glasgow (including Paisley, Motherwell, Hamilton, Airdrie, Coatbridge, Greenock, Dumbarton)	843.7	1479.5
	24 Edinburgh (including Musselburgh, Dalkeith)	71.7	125.7
	25 Dundee	33.9	59.4
	26 Aberdeen	13.5	23.7
	27 remainder	454.2	796.5
Northern	28 Teesside (that is, Middlesbrough, Stockton, West Hartlepool)	944.2	2110.0
	29 Tyneside (that is, Newcastle, Gateshead, South Shields, Sunderland)	268.6	600.2
	30 remainder	282.2	630.6
East and West Ridings	31 Leeds/Bradford (including Halifax, Huddersfield, Shipley, Wakefield, Keighley)	435.3	972.8
	32 Sheffield (including Rotherham)	467.6	1045.0
	33 Hull	114.7	256.3
	34 remainder	491.5	1098.4
North Midland	35 Nottingham	195.4	436.7
	36 Leicester	98.0	219.0
	37 remainder	612.6	1369.0
Eastern	38 Non-Metropolitan Essex	277.5	732.9
	39 Norwich	82.2	217.1
	40 Cambridgeshire	76.8	202.8
	41 remainder	511.1	1349.8
Total		15886.3	29234.0

APPENDIX C. 1980 Export-capacity Scenario for the Ports of Britain and the Minimum Export Capacity Required for Actual 1978 Non-fuel Exports from M. Senior (1983), p. 98.

	Port	1980 export-capacity scenario (thousands of tons)	1978 non-fuel exports
1.	London	6544	4762
2.	Dover	289	1894
3.	Shoreham	12	133
4.	Southampton	1853	1569
5.	Bristol	2750	300
6.	Newport	1150	526
7.	Cardiff	97	366
8.	Swansea	848	472
9.	Liverpool	6594	2516
10.	Manchester	863	1654
11.	Glasgow/Clyde	1938	592
12.	Grangemouth	367	524
13.	Leith	97	255
14.	Newcastle	235	230
15.	Sunderland	26	437
16.	Tees	1763	2369
17.	Hull	2462	1339
18.	Goole	211	230
19.	Immingham	499	1255
20.	Grimsby	63	210
21.	King's Lynn	61	389
22.	Yarmouth	79	479
23.	Felixstowe	109	1398
24.	Ipswich	50	435
25.	Harwich	275	1038

APPENDIX D. The Location of British Ports

KEY

1. London
2. Dover
3. Shoreham
4. Southampton
5. Bristol
6. Newport
7. Cardiff
8. Swansea
9. Liverpool
10. Manchester
11. Glasgow/Clyde
12. Grangemouth
13. Leith
14. Newcastle
15. Sunderland
16. Tees
17. Hull
18. Goole
19. Immingham
20. Grimsby
21. Kings Lynn
22. Yarmouth
23. Felixstowe
24. Ipswich
25. Harwich