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| **Author(s)**| Denny, Kevin; Ridge, Michael                               |
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The Implications of a Switch to Locally Varying Business Rates

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Abstract:

It has been nearly 2 years since the UK government reformed the system of local business rates to introduce a uniform business rate (UBR), but the debate continues over the merits of the new system. The change across regions in the revenues raised by the uniform system of business rates introduced in 1990 was due to 2 distinct components: a UBR effect and a reassessment of rateable values effect. Four alternative models of locally varying business rates were analyzed. These models are distinguished by alternative assumptions about resource equalization. A return to a system similar to the pre-1990 varying rates system would unfairly burden businesses in areas of low population. An improved model would take into account the degree of business concentration within a local authority. Using a model that relates local business tax rates to expenditure per establishment rather than per capita appears to be a more appropriate way of achieving horizontal equity.

I. INTRODUCTION

Although it is nearly two years since the Government reformed the system of local business rates to introduce a uniform business rate, the debate still continues over the merits of the new system. The importance of local business rates should not be underestimated. The non-domestic rates' yield of close to £10 billion in England in 1990-91 accounted for 30 per cent of local authorities' net financing. By comparison, the yield from mainstream corporation in the UK in 1990 will be around £12 billion.

Prior to April 1990, local authorities had the power to set business rate levels, subject to the requirement that the business rate poundage should be related to expenditure according to a formula determined by the Department of the Environment. In 1990 locally varying non-domestic rates were replaced by national non-domestic rates (NNDR). The introduction of NNDR meant that central government set a uniform business rate (UBR).(1) At the same time, the revised business rate bills were also reflecting the revaluation of non-domestic rateable values. These changes to local business tax caused a substantial redistribution of the local tax burden on businesses both across regions and across sectors.

In arguing for the UBR in its 1986 Green Paper Paying for local Government (Department of the Environment, 1986), the Government pointed out that the introduction of the UBR would:

(a) remove 'arbitrary' variations in the amounts demanded of businesses by local authorities;

(b) allow for greater stability in rate payments over time--given that increases in the UBR cannot be set higher than the prevailing annual change in the retail price index (RPI);

(c) lead to a 'radical simplification' of the local authority grant equalisation system.

In April 1991 the Government carried out a further review of local authority financial arrangements. This review concentrated almost entirely on reforming local domestic taxation. The Government kept to its original position on the USR.
By contrast, both the Labour and Liberal Democratic Parties have argued for a return to locally varying rates, as have all the local authority associations as well as the Institute of Directors. The claimed benefits from locally varying rates are manifold, ranging from the suggestion that partnership and consultation between local authorities and businesses would improve substantially under varying rates, to the view that extending the local tax base would lead to a greater stability in local authority finances. Moreover, it has been argued that, like the domestic sector, businesses benefit from levels of services that vary across authorities and that their contribution should, in part, reflect this.

It is not the aim of this paper to analyse the debate over uniform versus locally varying rates. Rather, this paper will attempt to:

(a) understand more clearly the impact of the 1990 reforms on the business sector, focusing on the distinction between the impact of the USR effect and the revaluation effect;

(b) examine the implications for the business sector and local authorities of a move from the current system with the USR to a system of locally varying business rates. We identify some pitfalls in returning to the pre-1990 system of locally varying rates and explore a number of alternatives.

In Section II we describe the regional impact on businesses of the 1990-91 reforms. In this section we distinguish between the effect of introducing the uniform business rate and the reassessment of non-domestic rateable values. Section III explains the principles underlying the four models of locally varying non-domestic rates that we intend to explore. Section IV describes the results of a move away from the UBR system to the alternative models set out in the previous section. In Section V we summarise our findings and draw conclusions.

II. THE BURDEN OF THE 1990 REFORMS

The change across regions in the revenues raised by the uniform system of business rates introduced in 1990 was due to two distinct components: a uniform business rate effect and a reassessment of rateable values effect. That there was a need for a revaluation there can be little doubt. The previous revaluation was in 1973 and there had subsequently been considerable variations in property values, both across regions and across sectors. As a result, the preexisting rateable values could no longer be held to reflect the rental values of the premises as the logic of the rates system demanded. The freezing of the rateable values since the early 1970s had benefited those regions which had experienced greater prosperity, principally the South, largely at the expense of the North and Midlands. Figure 1 illustrates the regional redistribution of the business rate burden as a result of the 1990 reforms and alter the transitional arrangements have worked through. It shows how the gains and losses are split between the USR effect and the revaluation effect.
Since the uniform business rate was chosen to be revenue-neutral (that is, to yield the same level of revenue in real terms as the previous varying rate system), it follows that the change due to the UBR effect has to be approximately dual to minus the change due to the revaluation. On average, rateable values were increased roughly eightfold and as a consequence poundages were reduced by a similar proportion from an average level of 278p in the pound to a poundage of 34.8p.

There is, however, considerable variation between these effects across regions. As one would expect, in the South, excluding London, the changes in the rate bills were largely dictated by the upward revision of the rateable values, whereas in the Midlands and the North the move to the USR accounted for a large part of the fall in rate bills. The exception to this pattern is clearly Inner London, where rate bills soared essentially due to the removal of 'multipliers' which in the past had artificially kept effective rate poundages low. The variation in the impact of the reform is strongly influenced by the sectional composition of businesses across regions: those types of properties that have tended to fall in value (factories and warehouses) are concentrated in the industrial Midlands and North, while the services sector, which has performed strongly in the 1980s, is predominantly in the South.(3)

III. MODELLING LOCALLY VARYING BUSINESS RATES

Section II showed how the substantial redistribution of local business rates burdens in April 1990 could be decomposed into a uniform business rate effect and a revaluation effect.

At first sight it might be thought that the impact of a return to locally varying rates would simply be the reverse of the UBR effect that we identified in Section II. This will not be the case for a number of reasons. Firstly, under the locally varying rate system in operation prior to 1990, a large number of authorities had attached to their rate poundage a 'multiplier' set by
central government. The effect of the multipliers was to keep the tax rates in Inner London and the Metropolitan areas lower than they would have been otherwise. Since it would be arbitrary to return to the pre-1990 multipliers, the calculations in this paper assume that no such multipliers will be attached to the poundages set by local authorities (although it is straightforward to extend the model to include them).

A second reason for the asymmetry is that local authorities' spending patterns will have changed since 1989. In 1990 there were considerable alterations made to the system for determining grants to local authorities. Revenue support grant (RSG) was allocated on the basis of an assessment of each local authority's needs. These needs assessments, called standard spending assessments (SSAs), were altered substantially from the previous year. This change is likely to have had the effect of altering the pattern of spending across local authorities.

We also need to consider whether the pre-1990 system of locally varying non-domestic rates is the most appropriate system to return to. We examine later in this section four alternative models which have substantially different distributional impacts.

In developing a locally varying business rates model, a number of assumptions are required. Should the level of central government grant be increased, decreased or remain at current levels? If additional spending by local authorities is to be financed from both the domestic and non-domestic sectors then what proportion will these sectors contribute? Should the calculations of rate poundages include the assumption of full resource equalisation, partial, or perhaps no resource equalisation? We discuss these issues below.

In Section IV we shall examine the results of a move away from the uniform business rate to four alternative models of locally varying rates. What distinguishes the models is the different methods of resource equalisation underlying them. Resource equalisation of taxable resources is required to introduce an element of horizontal equity into the structure of local taxes. Horizontal equity in this context requires that businesses face the same local tax rate--i.e. rate poundages--when situated in local authorities with similar levels of service provision. Resource equalisation of taxable resources is required to introduce an element of horizontal equity into the structure of local taxes. Horizontal equity in this context requires that businesses face the same local tax rate--i.e. rate poundages--when situated in local authorities with similar levels of service provision.

In general it is assumed that the overall level of revenue support grant will remain unchanged. There will, however, in three of the models be a major redistribution of revenue support grant across local authorities to allow for resource equalisation. Nevertheless, it follows that the total sum of gains and losses in grant will be zero. We will show, however, that this assumption can be restrictive, as it requires that some local authorities make what we describe as 'negative grant contributions'; that is, they are net contributors to the exchequer. The assumption of grant neutrality is relaxed in each model in order to calculate any revenue implications that might arise for the exchequer.

It is an assumption of the models that at the aggregate level, additional local authority spending is financed half by local domestic taxpayers and half by the non-domestic sector. Note that it is these restrictions of grant neutrality and equal aggregate marginal shares which set the parameters for both the domestic and non-domestic sector tax rates (see the Appendix).

The first varying rate model in most respects has the features of the pre-1990 system of non-domestic rates. Like all the models that follow, this 'traditional' model of resource equalisation relies heavily on what are currently called standard spending assessments. These
standard spending levels vary across local authorities and are defined as the cost to the local authority of providing a standard level of service. If a local authority spends at its standard spending assessment, it is assumed in the model that the local authority will set a standard rate poundage and a standard local tax rate.

For any local authority, as it increases its spending per capita above its SSA, this traditional model requires that tax rates increase at the same rate. So, for example, if any two authorities are spending exactly the same amount in per capita terms above their standard spending assessments, then they will set the same rate poundage. This method of equalisation is often referred to as 'marginal equalisation'.

A weakness of this model is that equal increases in expenditure per capita across any two authorities may yield substantially different benefits to their non-domestic sectors. This is because population is implicitly used as the measure of benefits to businesses. The example in Table 1 illustrates the deficiency in the traditional model.

The table contrasts two local authorities, the Inner London Borough of Kensington and Chelsea and the Metropolitan District of Rotherham. In the example, both local authorities are assumed to spend L100 per head above their standard spending assessment. Clearly, with Rotherham having more than double the population of Kensington and Chelsea, its additional total spending above SSA is twice as great. We recall that with the traditional model, both authorities will be setting the same rate poundage given that both are spending at L100 above SSA. However, taking into account the number of establishments in each authority, it can be seen that additional spending per business establishment is three times higher in Rotherham than in Kensington and Chelsea.

| Traditional Model: An Illustrative Example |
|-------------------------------------------|
| Spending per capita above SSA | Relevant population (thous.) | Total additional spending above SSA | No. of establishments (thous.) | Additional spending per establishment |
|---------------------------------------|-------------------------------|-----------------------------------|-------------------------------|-------------------------------------|
| Kensington and Chelsea | £100                          | 87                               | £8.7m                         | 8.3                                 | £1,048                              |
| Rotherham                           | £100                          | 189                              | £18.9m                        | 6.0                                 | £3,150                              |

Source: CIPFA, 1990.

To take account of the size of the business sector, we propose using additional spending per non-domestic establishment as opposed to per capita spending.

Therefore, what distinguishes the second model—the 'establishment' model—from the traditional model is the way in which rate poundages change with increases in spending. Under the traditional model, rate poundages increase proportionately with per capita spending. With the establishment model, rate poundages increase with spending per non-domestic establishment in the authority.
However, a criticism that might be made of the establishment model is that it does not take into account the size of businesses in an authority. For example, the model implicitly assumes that a corner shop counts for as much as Ford's of Dagenham. To overcome this problem, we have examined a third model, the employment-based model, which attempts to take into account the relative size of establishments by using the total level of employment in an authority.

The fourth model is a more restricted--but far less complicated--equalisation model in that it only attempts to equalise resources at standard spending. The objective of the grant allocation would be to ensure that all authorities are in a position where, if they choose to spend at the standard level, they would all be able to set the same rate poundage. It is a feature of this model that once an authority spends above its standard level then it will have to finance half of its additional spending from the non-domestic sector. It follows, therefore, that authorities with a low rateable value base will have to set higher rate poundages than higher rateable value authorities in order to finance their marginal spending. In short, there is no attempt in this 'partial equalisation' model to enforce horizontal equity above standard spending.

In the following section we take the four models discussed here and analyse the regional distribution of the additional local business tax burden that is implied.

IV. THE DISTRIBUTIONAL EFFECTS OF MOVING TO LOCALLY VARYING RATES

In Section III we identified four alternative models of locally varying business rates: the traditional model, the establishment model, the employment model and the partial equalisation model.

The models incorporate local authority data from two main sources. Data on 1991 'standard spending assessments' and 'spending above SSA' are from the Department of Environment. Local authority data on non-domestic rateable values, hereditaments, number of charge payers etc. are from CIPFA (1990). Results were aggregated to cover the eight economic regions in England. However, within those regions, eight metropolitan areas were identified and examined separately (see the map). The models examine an increase in net spending above total standard spending by approximately L2.4 billion--close to the 1991 situation.
The traditional model enforces 'marginal equalisation', so that the rate poundage rises proportionately with expenditure per adult. Get neutrality implies that the total level of revenue support grant to local authorities remains constant. However, imposing grant neutrality leads to a situation where negative grant payments have to be made. For example, a very high rateable value authority may find that as it increases spending over its standard spending, it quickly reaches a 'grant exhaustion' (that is, its grant falls to zero because it is raising substantial revenues from the business sector). In these circumstances there are two possible options: the first is to make provision for central government to receive any non-domestic income above that required. That is, high rateable value would make contributions to a grant pool for allocation to less well-sourced authorities. The second option is to keep the authority's overall grant level at zero once it becomes grant-exhausted; it is then in a position to take advantage of its business tax base without any further marginal grant loss. However, if this were to happen there would be a partial loss in horizontal equity with the authority in a position where, for the same tax rate, it can provide a higher level of service than elsewhere, or for a similar level of spending, it can set a lower tax rate.

If the latter option of precluding negative grant payments is preferred then there are at least two possible policy responses that could arise:

(i) One may increase the overall level of grant to compensate for the lack of negative grant payments. This is an expensive mute and, due mainly to the distortionary role played by the City of London under the traditional model, would cost the exchequer close to £1 billion. It would reduce the proportion of additional spending raised from the business sector from the current assumed 50 per cent contribution to an approximate 7 per cent contribution.
(ii) In order to keep the overall level of grant the same, the rate poundage schedule can be adapted so that poundages would increase the tax burden on most authorities other than those very high rateable value authorities that became grant-exhausted.

Of course, the above options are not mutually exclusive. They are avoidable, however. For it is the arbitrary nature of the traditional model that to a great extent causes the problem of negative grant payments. We shall see when examining the alternative models that the negative grant payment problem can be less serious.

In the following we assume no negative grant payments and preserve grant neutrality by applying (ii), i.e. adapting the rate poundage schedule. This is roughly equivalent to increasing authorities' rate poundages by a number equal to the total negative grant payment divided by the total rateable value of the rest of the country.

**FIGURE 2**
The Traditional Model: Percentage of Additional Rate Burden across Regions

![Bar chart showing percentage of additional rate burden across regions.]

Figure 2 shows that with the traditional model, most of the increase in local business tax revenue will fall on businesses in the South. (Figure 2) Inner London and the South-East bear nearly 50 per cent of the additional burden. Table 2 indicates that at 1991 prices the additional burden on Inner London and the South-East would be £295 million and £266 million respectively. (Table 2) Of course, different assumptions about the proportion contributed to marginal spending would scale these figures up or down.
We have already suggested that there are pitfalls with this model. The problem rests with the notion of horizontal equity. In this traditional model there is an implicit assumption that equal increases in expenditure per head above standard spending across local authorities do in some form confer equal benefits on business in each authority. However, this is difficult to reconcile with the fact that, for example, in the City of London what amounts to high spending per head in an authority with a small population is in fact very low spending when distributed among the large number of business establishments. It appears, then, that to get to an appropriate situation of horizontal equity, a varying rates model ought to be taking into account the degree of business concentration within local authorities.

| Regions and metropolitan areas | 1990-91 rate burden (£m) | Traditional model (£m) | Establishment model (£m) | Employment model (£m) | Partial equalisation model (£m) |
|--------------------------------|--------------------------|------------------------|--------------------------|-----------------------|---------------------------------|
| East Anglia                    | 341                      | 14.526                 | 9.937                    | 9.901                 |
| East Midlands                  | 550                      | 57.91                  | 58.651                   | 84.874                |
| Greater Manchester             | 369                      | 45.099                 | 51.173                   | 76.267                |
| Inner London                   | 2,492                    | 347.057                | 205.465                  |                       |
| Merseyside                     | 151                      | 26.072                 | 28.482                   | 43.141                |
| North                          | 246                      | 60.413                 | 62.025                   | 81.165                |
| North-West                     | 338                      | 67.052                 | 70.181                   | 89.579                |
| Outer London                   | 998                      | 139.488                | 128.181                  | 89.711                |
| South Yorkshire                | 164                      | 37.165                 | 45.425                   | 60.260                |
| South-East                     | 2,213                    | 204.253                | 138.017                  |                       |
| South-West                     | 718                      | 86.473                 | 91.976                   | 107.834               |
| Tyne and Wear                  | 123                      | 26.773                 | 24.707                   | 41.116                |
| West Midlands                  | 343                      | 10.380                 | 9.582                    | 12.461                |
| West Midlands Metropolitan     | 370                      | 56.195                 | 50.165                   | 76.967                |
| West Yorkshire                 | 288                      | 31.170                 | 41.494                   | 58.123                |
| Yorkshire and Humberside       | 229                      | 28.596                 | 31.900                   | 40.205                |
| TOTAL                          | 9,941                    | 1,215.711              | 1,215.711                | 1,215.711             |
We attempt to improve upon the traditional model by relating how local authority expenditure to the number of non-domestic establishments in a local authority. This model forces rate poundages to rise proportionately with expenditure per establishment in the authority. In this model the negative grant payment problem is reduced substantially. If the grant neutrality assumption is not imposed then the required increase to the revenue support grant would be close to £100 million in 1990-91 prices compared with the £1 billion under the traditional model. Therefore, there is little need for ad hoc adjustment of the rate poundage schedule.

In Figure 3 and column 3 of Table 2 it can be seen how the establishments-based equalisation model would distribute the additional burden on the business sector across the regions. The pattern is similar to the traditional model except for the increased burden on Inner London. Areas that benefit particularly well with this model relative to the traditional model are East Anglia, East Midlands, West Midlands, the South-East and South-West.

Figure 4 highlights the results from the employment-based model, which are similar to those from the previous model. The pattern is similar to those from the previous model. The largest increases are in the north and north-west of the country. The benefits from this model are more apparent at the more disaggregated level where within regions it allows the model to take into consideration establishment size across local authorities. Again, if the grant neutrality assumption is not imposed then the increase in the revenue support grant would be a relatively small £30 million in 1990-91 prices.
The fourth model we consider is one in which many attempt to provide marginal equalisation in the business sector is removed. In Figure 5 we see that the burden on Inner London is reduced to significantly less than 20 per cent. (Figure 5) In general the South benefits in this model because its predominantly high rateable values allow its authorities to set lower rate poundages than under either marginal equalisation model. Note that there is no marginal grant under such a system so no ad hoc alterations are necessary to deal with the negative grant payments from high rateable value authorities.
The concern about this approach, however, is that businesses in high-rate authorities may be tempted to relocate in low-rate authorities, and thereby cause rents to increase in the already high rateable value areas. Nevertheless, having stated this it should also be added that there is very little knowledge on how business decisions are affected by local taxation, and what evidence exists is mixed (see Bennett (1986) and Jackman (1987) for a discussion, Crawford, Fothergill and Monk (1985) and Taylor and Twomey (1988) for British evidence, and Papke (1991) for a US study). Compared with the marginal equalisation models, however, the administrative simplicity of the partial equalisation model makes it attractive.

V. CONCLUSIONS

In this paper we have described the consequences of the 1990 reforms, concentrating on the distinction between the revaluation effect and the UBR effect. We went on to examine four alternative models of locally varying business rates. These models are distinguished by alternative assumptions about resource equalisation. A return to a system similar to the varying rates system pre-1990 unfairly burdens businesses in areas of low population. There is a lack of horizontal equity in the system in that expenditure is not related sufficiently to the size of the business sector. This is an anomaly of the system. We have argued that an improved model would take into account the degree of business concentration within a local authority. Using a model which relates local business tax rates to expenditure per establishment rather than per capita appears to be a more appropriate way of achieving horizontal equity. Using employment as the base refines the model further. However, marginal equalisation models are well known for being complicated and tend not to be widely understood. The move to a partial equalisation model would allow predetermined lump-sum grant payments to authorities, thereby simplifying the grant allocation process considerably. In theory, partial equalisation would lead to horizontal inequity at marginal spending. In practice, it is far from clear how seriously this distortion will affect business decisions. There is a need for further research into this area to help clarify this issue.

APPENDIX
This Appendix briefly describes the formal structure of the models that we consider. The basic equation describing the with authority’s spending at its standard spending assessment is given by

\[ E^*_i = \bar{cc} n_i + \bar{i} RV_i + \bar{g}_i, \]  

A1

Spending over SSA is funded by a change in the Community Charge, \( \Delta cc \), a change in the rate poundage, \( \Delta t \), and variations in the level of rate support grant, \( \Delta g \):

\[ E_i - E^*_i = \Delta cc_i n_i + \Delta t_i RV_i + \Delta g_i, \]  

A2

where

- \( E^*_i \) is standard spending assessment;
- \( \bar{cc} \) is Community Charge at standard spending;
- \( n_i \) is adult population;
- \( \bar{i} \) is rate poundage at standard spending;
- \( RV_i \) is rateable valuation;
- \( \bar{g}_i \) is level of rate support grant at standard spending;
- \( E_i \) is level of expenditure.

We assume that the proportion of each authority's spending above standard spending funded by the domestic sector is half (at present the proportion is one) and that half the aggregate overspend is funded by the non-domestic sector. However, in some authorities the business sector will pay for more than half the remaining overspend (in which case grant will fall) and in others it will pay less (grant rises). We ensure that the total level of grant provided by the Government is unchanged. To impose horizontal equity at marginal spending requires that for any two authorities with the same relative overspend, the increase in the poundage is the same. The key word here is 'relative'; we first consider the situation when it applies to population (i.e. Community Charge payers) and then consider the case of it applying to the number of establishments in the non-domestic sector. Finally we consider using employment in the authority. The first case implies:

\[ \Delta t_i = \alpha \frac{(E_i - E^*_i)}{n_i}, \quad \alpha > 0. \]  

A3

Our assumption about half the overspend of each authority being met by the Community Charge payers of that authority implies:

\[ \Delta cc_i = \frac{E_i - E^*_i}{2n_i}. \]  

A4
Substituting (A.4) and (A.3) into (A.2) and rearranging gives:

\[ \frac{E_i - E_i^*}{2} - \alpha \left( \frac{E_i - E_i^*}{n_i} \right) RV_i = \Delta g_i. \]

Revenue or grant neutrality implies that the sum of the right-hand side terms over authorities equals zero. Hence we can solve for alpha:

\[ \alpha = \frac{\sum_i(E_i - E_i^*)}{2 \sum_i \left( \frac{(E_i - E_i^*) RV_i}{n_i} \right)}, \]

Now in general, central government would not know local authorities' spending in advance so it cannot set the tax schedule such that grant neutrality holds exactly. However, to the extent that the Government has a good idea what each authority spends, it can ensure that the system is approximately revenue-neutral. In practice, central government might use the previous year's expenditure figures adjusted for inflation. Since the estimate of \( \alpha \) depends on all the local authorities in England, it is likely to be fairly robust to fluctuations in spending by individual authorities. In our simulations, of course, we know expenditures by local authorities ex post, so we can calculate precisely the required slope of the tax schedule. In the model where overspend relative to establishments is the criterion for resource equalisation, we simply replace \( n \) sub \( i \) above with the number of establishments. Similarly, in the employment model we use the level of total employment. Note that if the marginal grant is sufficiently negative, the total level of grant to an authority can be negative; we refer to this as 'grant exhaustion'; that is, \( g_i + \Delta g_i < 0 \).

The final model that we consider is where we relax the notion of horizontal equity and allow individual authorities to exploit their different rateable values at marginal spending. In such a model there is no change in grant at the level of the authority so half the overspend is funded by the business community of each authority:

\[ \frac{E_i - E_i^*}{2} = \Delta t_i RV_i. \]

Clearly in this case there is a tendency for poundages and rateable valuations to be in inverse proportions.

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FOOTNOTES

1 This paper does not consider Scotland or Northern Ireland where different arrangements prevail, or Wales where some of the data were not available.

2 See Ridge and Smith (19) for an explanation of this decomposition.

3 This discussion refers to the long-run impact of the changes after the transitional arrangements, introduced by the Government to ease the introduction of the new system, have worked through (see Ridge and Smith (1990). p. 48).

4 Multipliers also operated, but to a lesser extent, in some authorities outside these areas. In London, a further complication arises because multipliers were also used to implement an additional scheme of 'resource discounts'.

5 King (1984) and Ridge and Smith (1991) give detailed accounts of the rationale behind the equalization of taxable resources.

6 The results relating to the distribution of business rate payments in the models presented in this need do not depend on the form of local domestic tax that is in place.

7 In the modelling process we use 'relevant population' (that is, those currently on the community charge register) as the proxy for population.
8 Once these authorities become grant-exhausted, they are free to set their own rate.

9 Technically, establishments are referred to as non-domestic sector hereditamants. For details of the model see the Appendix.

Kevin Denny and Michael Ridge, Institute for Fiscal Studies.

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