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Migration and Tax Yields in a Devolved Economy*

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Abstract:

Households may migrate between jurisdictions to secure preferred mixes of collectively supplied services and taxation. But devolution of taxes to sub-national jurisdictions could reduce expected tax revenue if some move to lower tax regimes, constraining devolved government policy. This paper develops an indirect approach to establish lower bound tax revenue impacts of possible tax changes by devolved governments. We estimate and aggregate migration responses to existing tax differentials between smaller, component administrative areas of the devolved jurisdictions. Because such existing taxes may have different bases from proposed devolved taxes, appropriate corrections are made in a model of the devolved economy. This model also establishes how the tax base and therefore the tax yield of the devolved economy, as well as the output per capita, would be changed by implementing different tax rates, given the migration responses estimated. The model is used to assess the fiscal possibilities for Wales created by the UK *Government of Wales Act 2014*.

Keywords: Migration, Fiscal Decentralisation, Tax Revenue.

JEL classifications: R23, J61, H11, H22, H71, H72, H77

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Migration and Tax Yields in a Devolved Economy

1. Introduction

Households may migrate between jurisdictions to secure preferred mixes of collectively supplied services and taxation (Tiebout, 1956; Fox et al, 1989; Day, 1992; Nelson, 2008). Either because of such migration or because of intrinsic, spatially diverse preferences, devolution or decentralisation of public spending to lower tier governments may therefore allow a better satisfaction of needs. Yet there is evidence that decentralising both public spending and tax revenues lowers economic growth in OECD countries (Rodríguez-Pose et al, 2009; Rodríguez-Pose and Ezcurra, 2011), though Spain appears to be an exception (Gil-Serrate, Lopez-Laborda and Mur, 2011). Income disparity also seems to be sensitive to fiscal devolution (Rodríguez-Pose and Ezcurra, 2010). The processes involved, however, are not clear.

While the sensitivity of tax yields to tax rates has generally focussed on the induced changes in the supply of effort (Meghir and Phillips, 2008; Saez et al, 2012), it is possible that in some circumstances tax-induced migration may be a significant contributor to tax yield. If so then it could place a constraint upon devolved public finance and redistributive policies, and perhaps explain some adverse outcomes from decentralisation (Xu and Warner, 2016). This may be the reason why, despite an increase in the sub-national government share of public spending in a majority of OECD countries, there has been no corresponding rise in devolved tax revenues (Journard and Kongsrud, 2003). Although in Switzerland little migration is induced by tax policies, because of the feedback through the housing market (Liebig and Sousa-Poza, 2006; Liebig, Puhani and Sousa-Poza, 2007), a study of Denmark's 'tax stealing' (Kleven et al, 2014) shows that induced migration can be important. In any event, to incentivise efficient allocation there is a strong case that at least some of the tax revenue to finance decentralised spending should also be raised locally (Sanguinetti and Tommasi, 2004).

Without historical data on different tax rates in devolved jurisdictions behavioural responses cannot be directly estimated¹. Therefore we develop an indirect approach to establish lower bound tax revenue impacts of possible tax changes by devolved governments. The principle is to estimate and aggregate migration responses to existing tax differentials between smaller, component administrative areas of the devolved jurisdictions. Because such existing taxes may have different bases from proposed devolved taxes, appropriate corrections are made in a model of the devolved economy. This model also establishes how the tax base and therefore the tax yield of the devolved economy would be changed by implementing different tax rates, given the migration responses estimated.

¹ This is why Foreman-Peck and Lungu's (2009) simulation of an income tax change in the Welsh economy based on a time series model only shows the effect conditional on an identical tax change in the rest of the UK economy.

Whether in any particular case tax-induced migration is a serious constraint on tax revenue will depend on the size of the spatial units and the distribution of the population because they will influence the volume of consequent migration and commuting. The UK has no experience of national tax devolution from which to gauge revenue outcomes; Scotland has not used its right to make a small change in income tax. But the recent extension of income taxation rights to the devolved government of Wales (with *the Government of Wales Act*, 2014) creates another possible opportunity for tax-induced migration. A large Welsh state sector and the closeness of Welsh and English population centres (Holtham, 2010) are likely to ensure the Welsh tax receipts respond primarily to the relocation of workers or commuting and only secondarily to changes in the supply of effort. About half the population of Wales lives within 25 miles of the border with England and on the other side there are four and a half million residents within 25 miles.

In the present implementation we estimate the migration responses to Local Authority (LA) property taxes in England and Wales and infer tax yields of different income tax rates in Wales. Three income types of individual are distinguished corresponding to the three rates of income tax². Each type is assumed to live in houses of markedly different value and hence to pay a different LA property tax rate. Their behaviour will diverge in willingness to relocate in response to tax rate differentials between places. This has potentially diverse consequences for tax revenue changes if any of the three income tax rates alters. The effect of hypothetical income tax changes are deduced from property tax differentials by correcting for their dissimilar impacts on taxpayers' budgets. The tax revenue outcomes are then derived by simulating the consequences of a tax change in a model of the entire Welsh economy. The results are that for the Additional (40%) and Higher (45%) tax rates any assumed permanent or persistent cut will always eventually raise tax receipts, and any rise will always eventually reduce tax receipts. For Basic Rate (20%) tax changes the hypothesis of no tax-induced migration cannot be rejected. That is, increases in this tax rate in Wales will always raise tax revenue proportionately and conversely for a tax reduction.

2. Some Spatial Implications of Fiscal Devolution

Tax devolution creates the opportunity to change income tax rates. Whether a cut or a rise in tax rates will increase or lower tax receipts and by how much in many cases is not obvious. Businesses and higher income individuals may move if tax differentials open up between jurisdictions, and in particular if they open up between Wales and England. So because of migration it is possible that tax revenue would eventually increase as a result of a tax rate cut. High income, high tax rate individuals are likely to be more sensitive to tax differentials and

² To keep the modelling manageable we do not distinguish between households and individuals.

hence with a higher or additional rate tax cut Wales might attract such people who could be advantageous for Welsh economic growth and development.

The Holtham Report (2010, chapter 6) estimates the effects of increasing a higher income tax rate distinguishing, ‘mechanical’, ‘behavioural’ and ‘migration’ tax revenue impacts. The ‘mechanical’ effect involves simply multiplying the extra tax rate by the tax base – the incomes of the higher rate taxpayers in Wales. The behavioural effect is intended to capture changes in the supply of effort, disincentivised by the marginal tax rate. The key coefficient is the elasticity of reported taxpayer income to one minus the marginal tax rate. If effort and therefore earnings are diminished by a higher marginal tax rate then the coefficient is positive. Because the tax base then falls there is an offset to the extra revenue generated by the ‘mechanical effect’. The ‘taxable income elasticity’ (TIE) that Brewer, Saez and Shephard (2010) report in the Mirrlees Review is 0.46 for the top one per cent of earners, based on the top rate changes from the 1970s and 1980s.

For men with high levels of education, labour force participation is virtually unresponsive to tax rate changes (Meghir and Phillips, 2008). But the literature on taxable income suggests that there may be significant costs of taxation, mainly a result of the shifting of income and consumption to non-taxable forms, as opposed to changing the supply of effort.

The HMRC (2012, Box 3.1) analysis of the revenue yield of the rise in the UK tax rate from 40 to 50% concludes that possibly the behavioural effect was so large that it more than offset the mechanical effect, and tax receipts fell. They include migration effects with the behavioural effect and observe that international labour mobility has increased in recent years, as both legal barriers and general migration costs were reduced.

The concern for Wales – with its large state sector and distinctive geographical location – is likely to be much less the supply of effort and much more the relocation of workers or commuting. For this reason we focus on the tax revenue consequences of induced migration, which provides a lower bound to the behavioural responses to a devolved tax change.

An illustration of the possible migration effects of higher rate income tax changes is that a five percent increase in the Higher Rate of tax for an individual or household earning £80000 would cost almost £2000 a year. Over ten years with a five percent discount rate this is about £15000, which might more than counterbalance moving costs. In which case, all the tax revenue paid by that individual or household would be lost to Wales. There is also the disincentive of a tax rate increase to moves into the jurisdiction that might otherwise have taken place.

For higher earners the revenue impact of tax-induced mobility would be greater. If only 150 of Wales's highest earners moved out of Wales (10% of the total number earning over £250,000 per year) no additional revenue would be raised from Welsh residents as a result of a one pence higher rate tax increase (Holtham, 2010, para 6.22). Conversely cutting the higher rate could potentially increase Welsh tax revenue, although there could be problems of determining residential location and second homes.

Contrary to the Holtham Report's (2010, p33) claim that 'no empirical UK data exist that would enable us to tell how Welsh or English citizens would behave in a world where tax rates differed between them', there is some data – which this study utilises. We consider the sensitivity of migration between LA areas to 'council tax' differentials as a source of information about the response of migration to future possible devolved tax differentials. We then derive estimates of the tax revenue consequences for Wales.

Council tax is levied upon domestic housing (and also, as 'business rates', upon commercial property) and is specific to each LA (there are in total 348 LAs in England and Wales). The amount payable on a property depends primarily on the valuation band to which it is allocated. Band D dwellings form the base case for the tax. Other property bands are multiples of this rateable value. The highest English band is rated at 18/9 of Band D and the lowest is 6/9 of Band D. Hence with a common tax rate in the pound across properties there is some progressivity in the tax. More than 70 percent of Welsh dwellings are in Band D or lower³.

In England the average Band D tax in 2014 was £1493 (standard deviation £122). The lowest rate was for Westminster at £678, presumably because there were so many high value properties, and the highest rate was levied by Weymouth (£1726). For Wales in 2014/15 the average was £1298 (standard deviation £137), with a minimum of £1005 (Pembrokeshire) and a maximum of £1591 (Blaenau Gwent).

House prices and rents can be a vital influence on migration decisions. High earnings and employment encourage migration to a region but because of the commute/migrate trade-off, their effect in raising relative house prices discourages immigration (Cameron and Muellbauer, 1998). Owner occupier migrants to a region pay both the tax and the house price but, while they may have to borrow for the house, they do not need to borrow for the capitalised value of the property tax. So if they are credit constrained a lower house price may be a stronger motivation to migrate than the offsetting higher property tax.

LA property taxes lower house prices and in some instances LA spending may raise them (Rosenthal, 1999; Cheshire and Sheppard, 2003). House prices (and therefore rents) will reflect some sort of market average of preferences for what is provided by the LA and for what

³ Residential property in Wales is valued in nine bands: A-I.

must be paid for them in taxation. In practice LA taxation is redistributive. Some residents gain and some lose. The goods and services supplied are not pure public goods, contrary to the Tiebout model. A local government may tax and spend on state education but persons with no children or who send children to private school will not benefit from it and would gain materially from being in a jurisdiction that spends less on education and consequently taxes less. LA tax and spending characteristics should then to some extent be reflected in house prices and so will other migration and commuting considerations, especially expected economic opportunities for earning and employment. Given the heterogeneity of the population therefore, controlling for house prices, we may still find some migration response to differences in local tax rates.

The Research Questions

The main research question is:

What are the effects of migration in response to divergences between the different income tax rates in Wales and England (Basic Rate, Higher Rate and Additional Rate) and how is devolved tax revenue affected?

It would be straightforward to answer this research question, if we had historical data of different income tax rates in Wales and England. However, such differential rates have never been created in UK history⁴. A naïve solution is to use another country's experience to shed light on the UK scenario (e.g. Liebig and Souza-Poza 2006 on Switzerland), but because of different institutional and economic conditions this purely empirical approach is not reliable. At the other extreme, one could build and utilize a purely theoretical model, such as undertaken by HMRC (2013). Nevertheless, these models are not capable of capturing the tax effect on within-UK migration flows. Any judgement on this matter without a strict link with data is inevitably arbitrary. In view of the drawbacks of both empirical and theoretical modelling approaches, we address the main research question by answering two research sub-questions.

We consider the data availability problem of the purely empirical approach by noting that local tax rates (council tax) vary significantly, despite a nationwide income tax rate. We make use of within-UK migration data to estimate an econometric model of the effects of council tax differences on migration between LA jurisdictions (a complete list of data sources is provided in Appendix A). This allows us to answer the first research sub-question:

⁴ This is why Foreman-Peck and Lungu's (2009) simulation of an income tax change in the Welsh economy based on a time series model only shows the effect conditional on an identical tax change in the rest of the UK economy.

(R1) What are the effects of different council taxes on the net migration flow into Wales?

But income taxes are quite different from property taxes. We therefore must establish the relationship between the effects of council tax and income tax in the second research sub-question so that we can estimate the effect of council tax differences on migration and derive the effect of income tax differences on migration. Therefore, the second research sub-question is:

(R2) What is the relationship between the effects of different council taxes and different income taxes?

This we answer by simulating our economic model. Combining the two results we obtain a first round effect of income tax changes on migration and therefore on tax revenue. But this alone is not a sufficiently rigorous answer to our central research question. It does not take into account second round effect of income tax changes. If, for example, a devolved income tax is raised, this at first allows an increase in government spending as well as increasing emigration. It affects the whole economy and therefore the tax base. The net effect on tax revenue depends not only on migration, but also on wage changes and the alteration in household behaviour induced by the tax rise. We must therefore again simulate the theoretical economic model to see the effects of income tax devolution on the tax revenue and other aspects of the Welsh economy.

3. The Econometric Model

The econometric model is developed to make full use of the observable data on council tax differences. The core is the gravity model which is popular in the transport flow, international trade and migration/commuting literature. Although this model is usually regarded as an empirical econometric exercise, some papers (such as Anderson and van Wincoop, 2003; Persyn and Torfs, 2016) have attempted to provide a theoretical basis in terms of rational individual behaviour.

The key features of the gravity model specification are that bilateral migration flows from an origin location to a destination location are positively related to the ‘masses’ of the two locations (i.e. populations) and negatively related to the ‘distance’ (both geographic and other socio-economic distance). In our case, after controlling for other factors such as these, we are primarily interested in the effect of council tax differences on the migration flow.

In this model migration is a continuing process, not a once and for all movement in response to, say, the emergence of a tax differential. A tax differential will permanently affect migration flows with the consequence that there will be a cumulative effect on the number of indi-

viduals involved and on the tax base⁵. A common assumption is that migration flows are too small to influence populations significantly over the estimation period.

The council tax effect directly estimated from the gravity model is actually not what ultimately we require – we need the effect of income tax differences, which cannot be observed. Consequently we translate the effect of the council tax differences into the effect of the income tax differences later.

To be able to analyse the effects on the three types of taxpayers, we make use of the distribution of income tax at regional level to estimate the shares of each household type in each migration flow at LA level. Where subscripts o and d indicate respectively origin and destination, if there are m_{od} migrating from LA o to LA d , and we have information on the distribution of income tax for the region to which a LA belongs, then we can use this distribution to calculate the shares of the three types of individuals in m_{od} to obtain m_{od}^i , where $i = 1, 2, 3$.

To find the marginal effects of council tax differences on migration, we estimate in Table 2:

$$m_{od}^i = F(\text{Population}_d, \text{Population}_o, \text{Council Tax Rate Differences}_{d-o}, \text{House Price Differences}_{d-o}, \text{Economic Opportunity}_{d-o}, \text{Geographic Distance, Euclidean Distance, Region Dummies}_d, \text{Region Dummies}_o, \dots) \quad (1)$$

Relative taxation in equation (1) is not the jurisdictions' council tax rates but an estimate of the tax paid by each taxpayer type as a proportion of their average house price. It is unlikely that tax differentials are caused by (as well as, or instead of, a cause of) migration because of central government financial equalisation. The Rate Support Grant (including Business Rates and specific grants) that accounts for three quarters of LA revenues is allocated on a needs basis and is intended to prevent that. Moreover, the volume of annual net migration is small⁶.

The majority of working age individuals that move house each year migrate within LA areas (Dixon, 2003), and therefore such moves are likely to be the principal (exogenous) determinant of (relative) house prices in equation (1). The expected sign on relative house prices would be positive if house prices reflect future earnings prospects in the area (but Cameron and Muellbauer (1998) find a negative effect). Identification of the house price variable is questionable but it serves primarily as a control for taxation.

⁵ The simulations reported later cumulate what are essentially static effects. Truly dynamic simulations would take into account expectations about the persistence of the tax differential, as well as investment.

⁶ For the whole Wales, the net migrant flow is only 1070.

‘Squared Euclidean distance’ is a measure of dissimilarity between authorities based on 42 Census variables. Similar pairs of LAs could be geographically far apart. ‘Economic opportunity’ in equation (1) includes unemployment, wages and job density variables.

A descriptive summary of the bilateral migration across the 348 LAs in England and Wales is given in Table 1⁷. Between about half the LA pairs there was no migration in 2014.

Descriptives	Migration = 0	Migration > 0	All Sample
Number of Observation	60,618 (49.8%)	60,138 (50.2%)	120,756 (100%)
Mean	0	46.36	0.50
Standard Deviation	0	154.27	0.50
Minimum	0	10	0
Maximum	0	5610	5610

Table 1 Descriptive Statistics of Within-England and Wales Migration in 2014

Given that the dependent variable (migration) to be explained is a count variable, it is usually appropriate to use a generalized linear model such as Poisson regression or Negative Binomial regression (preferred in the case of over-dispersion). To be able to capture the over-dispersion and the excessive zeros in the count data of migration, we adopt the zero-inflated negative binomial (ZINB) model developed by Lambert (1992) and Greene (1994). This is essentially a bivariate equation system, with one logit equation modelling the probability of having intrinsic zero counts and a negative binomial equation modelling the determinants for the non-intrinsic zero counts and non-zero counts.

⁷ The migration flows are based on the changes of NHS registrations within the UK. Migration originating or ending outside England and Wales is not taken into consideration.

	Migration Flow	Type 1	Type 2	Type 3
gravity model regressors	d(tauH)	-0.0008	-0.0059***	-0.0029**
	ln(population_o)	0.6261***	1.1022***	0.6567***
	ln(population_d)	0.6344***	1.1218***	0.7002***
	within same region	1.2793***	1.6378***	0.7616***
	geographic distance	-0.0083***	-0.0134***	-0.0075***
	Euclidean distance	-0.0349***	-0.0145***	-0.0287***
region_d base = Wales	North East	0.2071***	0.3648***	0.1541***
	North West	-0.1769***	-0.2853***	-0.2094***
	Yorkshire	-0.0743*	-0.1351**	-0.1025***
	East Midlands	-0.0920**	-0.0761	-0.0718***
	West Midlands	-0.2572***	-0.3357***	-0.2271***
	East	-0.1064***	-0.1162*	0.1109***
	London	-0.0732*	-0.3300***	0.1507***
	South East	-0.1187***	-0.1831***	0.1303***
	South West	0.2153***	0.4354***	0.3204***
region_o base = Wales	North East	0.2467***	0.4998***	0.2174***
	North West	-0.1125***	0.0035	-0.0468*
	Yorkshire	-0.0136	0.1289**	0.024
	East Midlands	-0.0591	0.2188***	0.0790***
	West Midlands	-0.1829***	-0.0309	-0.0436*
	East	-0.1443***	0.5073***	0.2244***
	London	0.0147	1.0660***	0.6803***
	South East	-0.2176***	0.9902***	0.2974***
	South West	0.1476***	0.6094***	0.2689***
economic regressors	d(house price)	0.0004***	0.0008***	-0.0002
	d(wage)	-0.0015*	-0.0028	-0.0067*
	d(job density)	0.0043*	0.0051*	0.0050***
	d(unemployment)	0.0019	0.0023	-0.0037
	d(inactivity)	-0.0014	-0.0007	0.0006
	_cons	-10.6786***	-24.2176***	-15.5379***
No. of Observations		120756	120756	120756
Log-Likelihood		-299609	-185286	-107342
AIC		599340	370693	214806
BIC		599932	371285	215398
Count R-Squared		12.00%	41.77%	66.82%

Table 2 Migration and Council Tax ZINB Estimation Results

Note: *** indicates statistical significance at 1%, ** at 5% and * at 10%. ‘d’ denotes destination and ‘o’ origin LA area. ‘d(.)’ is an operator denoting ‘destination – origin’ (as in d(tau) for example). The count R-squared is defined as the ratio between the number of correctly fitted counts (rounded to integers) and the total number of observations.

The three separate estimation results of the ZINB model for the three types of individuals are compared in Table 2. The key findings of the econometric model are:

- A higher council tax rate results in a lower in-migration flow, though the effect on the lowest income type (type 1) is not statistically significant. Young adults were most likely to move, with the biggest single peak (those aged 19) reflecting moves to start higher education (ONS, 2015). Students are not liable for council tax, but are included in the data for the econometric model, which may explain the statistical insignificance of the tax differential for type 1 migrant flows.
- The gravity model is verified: (log) populations of origin and destination have similar positive effects and distances have negative effects on migration flow.
- The positive coefficient on house price difference for type 1 and type 2 taxpayers is in line with expectations of earnings and employment being captured in those prices for these groups. By contrast, the insignificant coefficient for type 3 households is consistent with the movements of very high earners being largely independent of local economic conditions.
- Labour market factors have very weak effects on migration flow, with job density playing a more important role than wage, most likely because they are captured by house prices.
- The low count R-squared for type 1 individuals compared to type 2 and type 3 most probably is to be explained by the large number of students in the data for this regression.

In addition to the model implications it should be noted that the data shows Wales to be a (net internal) migration destination, with a net inflow of 1070. The gross cross-border movements are of course much greater.

This estimated econometric model can be used to simulate the effects of different council tax rates on migration flows of the three types of taxpayer. With the help of the answer to research sub-question (R2), we can then translate the effects of council tax differences into the effects of income tax differences.

4. The Optimally Calibrated Economic Model

The economic model is designed to focus on the effects of income tax on the economy. It is a Computable General Equilibrium (CGE) model similar to the one used by HMRC (2013). The demand side is assumed to have three types ($i = 1, 2, 3$) of individuals in terms of wage (w_i), while the supply side is simplified to only one sector. The composite product (Y) can be used for private goods (z_i) or ‘public’ goods (G) provided by both central and local governments. An important contributor to individual wellbeing or utility is housing or accommoda-

tion (h_i) which is not produced as part of Y and for simplicity its provision is assumed to be fixed.

One important issue in using such an economic model is how to assign reasonable values to the structural parameters. Some of them have direct counterparts in reality, such as the tax rates (Table 3), which can be directly used. Others do not have particular values but must lie in some plausible range, such as the elasticity of substitutions in utility functions and production functions. We adopt the optimal calibration technique to estimate the structural parameters, such that the total (squared) gap between the simulated variables (model) and the observed variables (data) is minimised in the status quo. In our case, since the number of observables is just equal to the number of unknown structural parameters (see Appendix B for details), the identification condition is satisfied.

The Household

The three types of individuals are a low income (type 1), a middle income (type 2) and a high income (type 3) – corresponding to the three bands of income tax (τ_{IT}). They are respectively Basic Rate taxpayers (currently 20% @£10,600~£42,385), Higher Rate taxpayers (currently 40% @£42,385~£150,000) and Additional Rate taxpayers (currently 45% @£150,000+). Different types also face different National Insurance (NI) rates (τ_{NI}), the bands of which are not exactly the same as income tax bands. The combined bands of income tax rates and NI rates in 2014 (to match the other data source) are shown in Table 3.

Thresholds ω^*	Income Bands ω_i		Employee Rates		Employer Rates
	Lower	Upper	τ_{IT}	τ_{NI}	τ_{NIF}
	0	8,064	0%	0%	0%
ω_{NI1}^*	8,064	8,112	0%	12%	0%
ω_{NIF}^*	8,112	10,600	0%	12%	13.80%
ω_{IT1}^*	10,600	42,385	20%	12%	13.80%
$\omega_{NI2}^* = \omega_{IT2}^*$	42,385	150,000	40%	2%	13.80%
ω_{IT3}^*	150,000	∞	45%	2%	13.80%

Table 3 Combined Bands for Income Tax Rates and NI Rates

All individuals are assumed liable for council tax. The different rates of council tax for the three types of individual are calculated by estimating the average house price of each type and allocating the Band payments appropriately. From the LA-level distribution of council tax bands (i.e. the numbers of properties in each tax bands for each LA) and the distribution of taxpayers (i.e. the numbers of individuals paying for different income tax rates), we conclude that the type 1 are paying council tax bands A-D, type 2 are paying bands E-G, while type 3 are paying H-I. The effective council tax rates are then calculated from the weighted

average of council taxes divided by the corresponding house prices, with the weights being the shares of properties in each council tax bands. This detailed calculation is possible because we use the extended Monte Carlo method to simulate the property prices in the previous step, and it is therefore straightforward to work out the average property prices for each band (see Appendix C).

Only the low-income individuals (type 1) are assumed to face the uncertainty of unemployment and the possibility of inactivity in the labour market, because of low skills or disability. Type 1 individuals are also the main beneficiaries of the income redistribution (ω) such as unemployment and in-work benefits. The model for all three types is detailed in Appendix B.

For all the three types, their after-tax income ω_i is calculated strictly according to the current progressive rates of income tax and NI contribution. The thresholds of the bands are described in Table 3. The consumption VAT tax rate is assumed to be the same for all individuals. Moreover, private consumption (z) is assumed to have a nested structure for consumption and housing, while the ‘public’ goods (G) are assumed to be the same across all three types of residence in Wales, but may vary across the UK due to different budget arrangements.

The Producer

The supply side of the economy consists of one production sector with one composite output (Y), which can be used for either private goods c_i or ‘public’ goods G . Firms pay a corporation tax (τ_F) and the corporate NI contributions (τ_{NIF}). Exogenous/fixed investment is assumed absorbed by the total factor productivity A . The labour market is assumed to be segmented because workers possess different skills. The constant elasticity of substitution among the three types of labour (σ) should be close to 0, i.e. labour types are complements rather than substitutes.

Modelling Government in Wales

Total devolved government tax revenue consists of the LA tax revenue and national tax revenue. In practice, the latter is collected by the UK central government and then an adjusted sum is transferred back to the devolved government of Wales according to the Barnett formula. After the tax devolution, the devolved government may control some of the tax revenue (mainly from income tax) and the remaining transfer from the central government will be reduced accordingly. If the Holtham (2010) Own Base Deduction model is followed, when devolved tax rates are set above central government rates, an estimate is made of the additional revenue (‘mechanical effect’) that this would raise from Welsh taxpayers and the sum is added to the devolved tax revenues. Conversely, a decision to lower rates relative to the UK reduces the estimated Welsh tax take (‘mechanical effect’) and central government cuts Welsh

government revenue by that amount. For present purposes central government spending, which accounts for about half of government expenditure in Wales, is exogenous.

In addition to income tax (which contributes the most to the total tax revenue), we also consider in our model explicitly national insurance (NI) contributions (paid by both employees and employers), VAT tax, council tax and corporation tax. These account for more than 82% of the total tax revenue in Wales. The ‘other’ category is mainly product-specific duties which are not to be devolved anyway and are already partially accounted for by the consumption tax.

On the expenditure side, there are two main public spending areas: (i) income redistribution ω (e.g. pensions and welfare) and (ii) ‘public’ goods G (e.g. NHS, education, transport, general government). These two components account for about 90% of the public spending in Wales.

5. The Relationship between Council Tax and Income Tax

We can simulate the effect of an income tax difference by translating it into a council tax difference. The effects of council tax difference (observable) and the effects of income tax difference (unobservable) can be equivalent if the magnitudes are carefully selected. The problem is illustrated in Figure 1.

A price change can be divided into income and substitution effects in consumer theory. We must work out an ‘indifference curve’ between the council tax rate and income tax rate, along which the taxpayers have the same utility. The trade-off ratio between the two rates is then used as the relationship between the impacts of the two types of taxes.

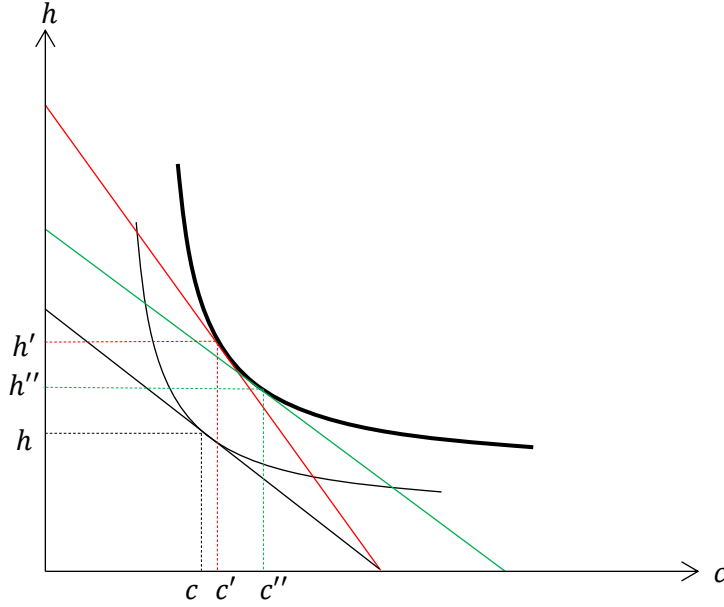


Figure 1 The Relationship between Income Tax and Council Tax

To illustrate, consider the decision of a type i individuals. Assume the utility level of the status quo is $u_0(z(c, h), G)$. If there is a council tax difference (e.g. a cut in council tax in Wales), moving to Wales means a rise in utility $u'(z'(c', h'), G)$. To find an equivalent income tax having a similar effect, we need to keep the new utility level unchanged while shifting the original budget constraint in parallel (no price distortions), i.e. $u''(z''(c'', h''), G)$. The relative magnitudes of the council tax (resulting in the pivot) and income tax (resulting in the shift) can be used to translate the effect of one to the other, such that $u'(z'(c', h'), G) = u''(z''(c'', h''), G)$. The economic model can be used to simulate these two situations, implying the relationship shown in Figure 1.

6. Simulation of Induced Migration

There are two approaches to simulating the counterfactual effects on the migration net flows into Wales of different tax rates: (A) based on marginal effects and (B) based on fitted values. The fundamental difference between the two approaches is the use of averaging. The first approach (A) estimates an average marginal effect for all the LAs in Wales and then multiplies it by the number of LAs to obtain the aggregate effects on Wales. In contrast the second approach (B) directly estimates the effects for each LA and sums the individual impacts without taking the average.

Moreover, approach (A) averages the values of all the other regressors (apart from 'dtau') across all the LAs to estimate the average marginal effects, while approach (B) keeps the values of all the other regressors as they are during simulation. Approach (B) is preferred be-

cause it requires fewer assumptions and has less chance of error accumulation. Both approaches have been undertaken, however, for comparative purposes.

The right panel of Figure 2 contains the simulated elasticities of income tax rate changes on migration net flows using approach (B). (The two approaches turn out to give very similar results, providing a robustness check on our methodology). The panel shows the implied responses of the net migration flows into Wales (vertical axes, thousands) after the changes in the income tax rates (horizontal axes). As expected high earners are tax-sensitive judging by the effect on migration. The right hand side graphs below (derived from the econometric model) show that type 1 (Basic Rate tax payers, M1 black) are more responsive to the Basic Rate changes. But type 3 (Additional Rate tax payers, M3 blue) are much more sensitive to the Higher Rate and Additional Rates changes. In the bottom right hand panel, where the Additional Rate does not have an effect on M1, and M2, their lines coincide; the black line (dM1) is behind the red line (dM2).

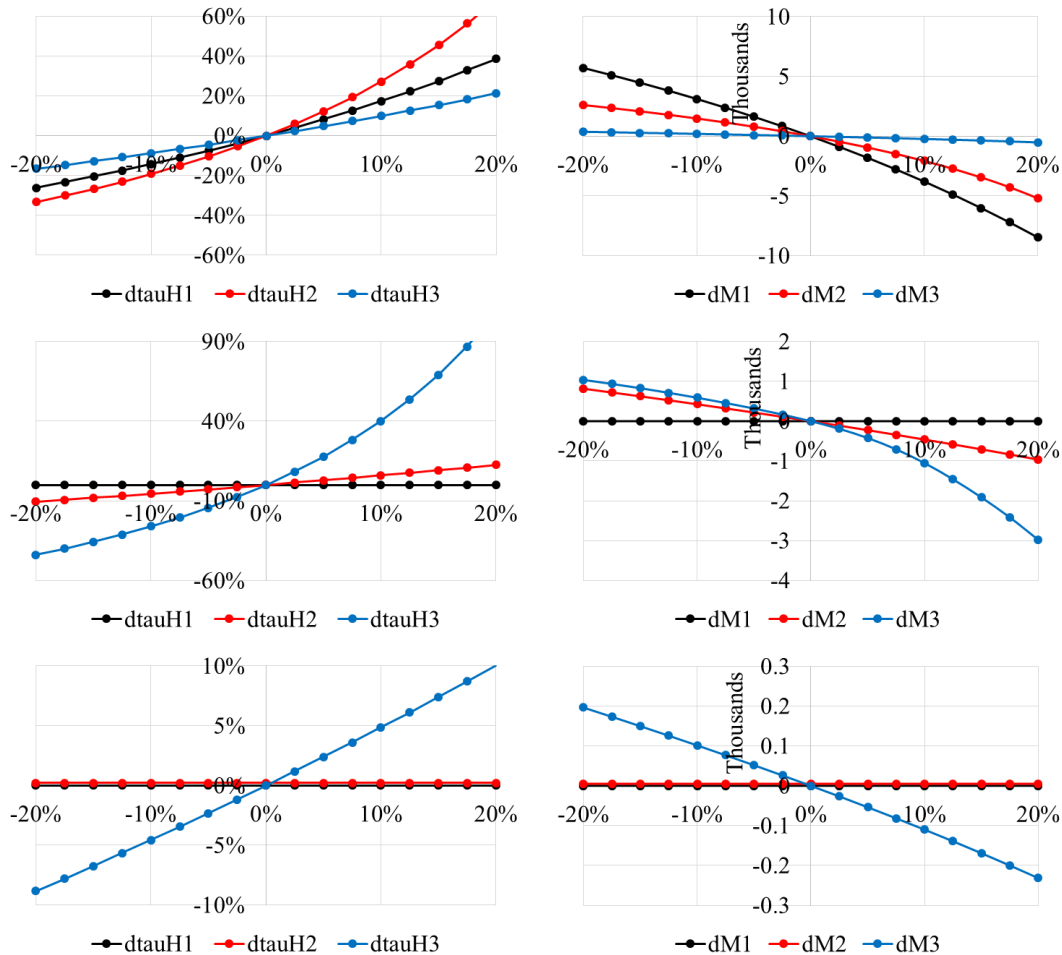


Figure 2 The Effects of Changes in (implied) Income Tax Rates on Migration($\tau_{IT1}, \tau_{IT2}, \tau_{IT3}$)

The net flow of migrants is the sum of bilateral flows between LAs in Wales and in England – ignoring flows between LAs in the same country. So the asymmetry in the magnitudes of

the two countries' population is taken into account during the aggregation of LAs, and the considerable symmetry of responses to cuts and increases in tax rates is quite surprising.

The left panel of Figure 2 shows the relationship between changes in income tax rates (on the horizontal axes) and changes in council tax rates (vertical axes). A change in τ_{IT1} (the Basic Rate of income tax) affects all three types of individuals, a change in τ_{IT2} will affect types 2 and 3, and τ_{IT3} only affects type 3. By contrast, the effect of council tax is selective and exclusive to each type, e.g. τ_{H1} only affects type 1 and τ_{H2} only affects type 2. Therefore, to obtain the equivalent effect of a change in income tax, we need to utilise all three council tax rates.

The richest (type 3, τ_{H3}) are not very responsive to the change in the base income tax rate, because most of their income is not in the lowest tax bracket (first panel LHS Figure 2). Instead, type 1 taxpayers are more sensitive to this change, but type 2 are the most responsive. Sensitivity depends on which taxable income component is the greater part of total income for the taxpayer type. Changes in the Higher Rate (40%) have a marked effect on Additional Rate taxpayers (45%). Their average income in Wales is £180,000. Consequently, almost £110,000 of their income (£150,000-£42385, Table 1) would be subject to a different tax rate if the Higher Rate changed. By contrast only £30,000 would be affected by an Additional Rate change.

7. Simulation of Devolved Tax Changes and Tax Revenue Yield

With the structural parameters identified or estimated in the economic model and the estimated migration flows in the econometric model, we are able to simulate the effects of income tax rates changes in the economic model.

We simulate the whole model by re-solving the system of equations, after manually re-setting the income tax rates differently from the *status quo*, ranging from 20 percentage points lower than the prevailing rates to 20 percentage points higher. At the same time, the implied changes in migration due to the changes are estimated using the econometric model with the help of the relationship between income and council tax rates implied by the economic model. To keep the exercise reasonably simple, we also fix the wage levels for type 2 and type 3 individuals, on the grounds that their wages are less affected by the local tax policies but more by the national macroeconomic conditions. The wage of type 1 individuals, nevertheless, is endogenously determined, together with other variables such as tax revenue.

We simulate a time horizon of ten years, starting with the *status quo* as observed in 2014. The baseline case in these scenarios is not a forecast, but a basis with which to compare the reve-

nues from different tax changes⁸. The following three figures depict the relationship between different income tax rates and the total tax revenue over the 10-year horizon. In each of the three figures the top diagram shows the three dimensional relationship, the left and right lower panels show two dimensional slices of the upper diagram.

In Figure 3 lower left panel the broken red line gives the status quo tax rate. Total tax revenue will fall if the Basic Rate drops – the mechanical effect dominates; the lighter blue lines (in the long run) are higher up than the darker lines (in the short run) – the partial offset due to the migration effect. If the Basic Rate is raised beyond about 27% (where the lines converge) the total revenue position is reversed, falling with the passage of time. The lower right panel gives a different representation of the same pattern. Tax rates lower than the present Basic Rate increase total revenue faster and conversely for higher rates.

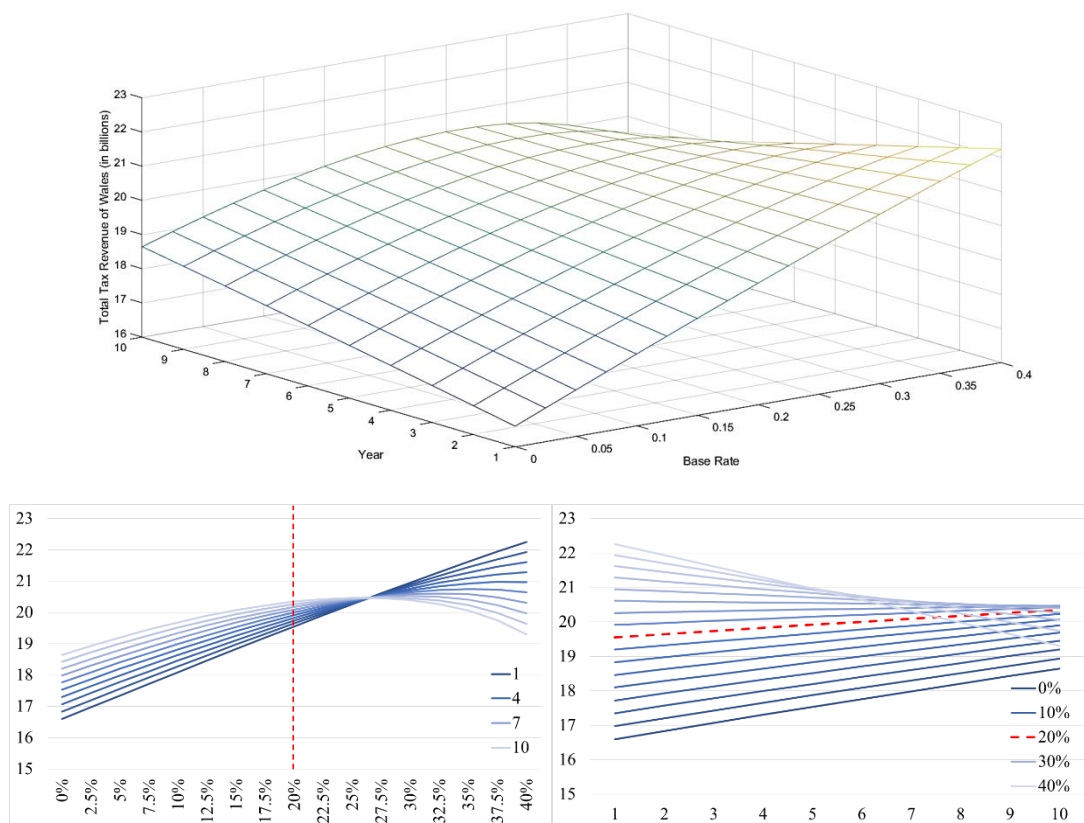


Figure 3 The Relationship between the Basic Rate and Tax Revenue

The back left dimension of the upper panel shows a Laffer curve – the tendency for tax receipts first to rise and then to fall as tax rates rise – with a turning point after five years or so. This effect would be triggered sooner if there was an intensive margin in our model, an opportunity for Welsh workers to change their effort, or hours of work. For tax to have a big

⁸ The rise in tax revenue in the baseline case is generated by the consequences of the net immigration into Wales. The model itself does not allow for technical progress or capital accumulation.

disincentive impact on the labour market there must be cumulative effects over time through the extensive margin (the migration effect). It should be borne in mind that the estimated migration response to tax change in this simulation was not statistically significantly different from zero (Table 2). The Laffer curve does not hold for the changes in Higher and Additional Rates, because the effects are selective or exclusive (and so smaller⁹ than those apparently triggered by Basic Rate changes).

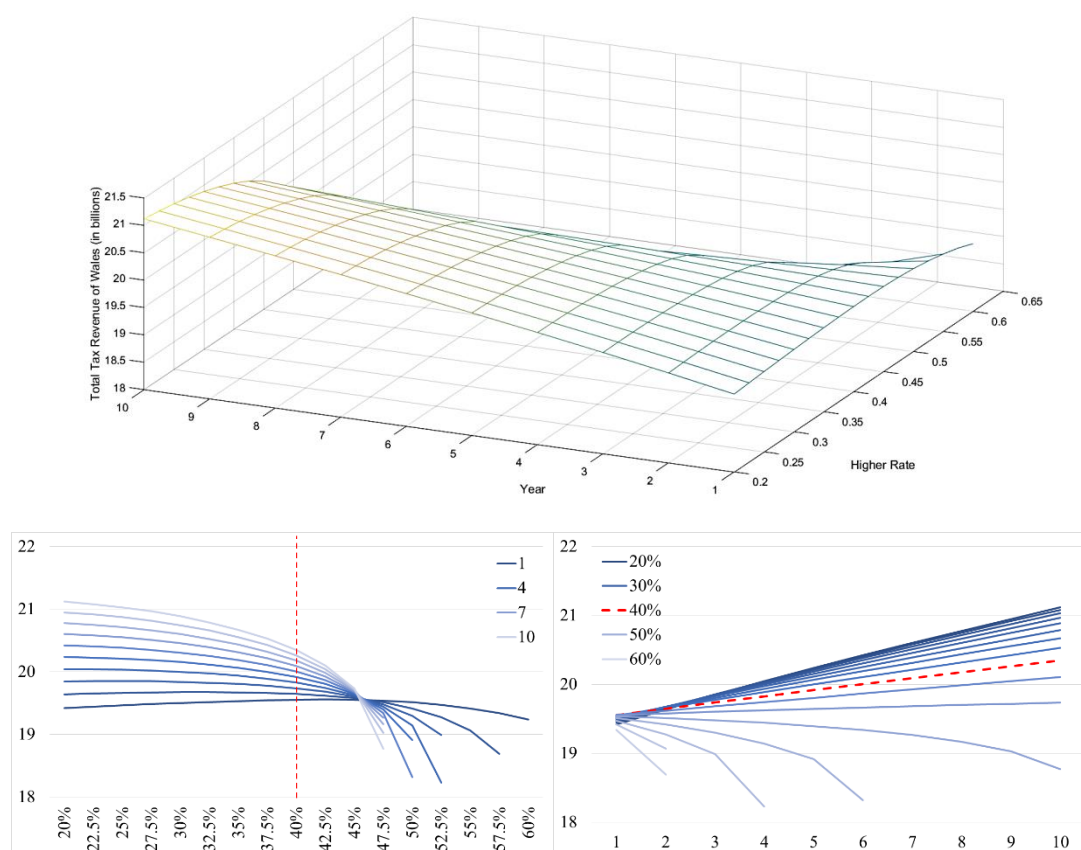


Figure 4 The Relationship between the Higher Rate and Tax Revenue

For the Higher Rate (Figure 4) in the short run (1-3 years), a big cut in higher rate will reduce tax receipts, but in the long run such a reduction still raises tax receipts. The lower right panel (just) shows the cross-over of the status quo red broken line and the darker lower rates. The lower left panel show that Higher Rate cuts (to the left of the status quo line) can reduce tax revenue initially but eventually revenue increases relative to the status quo even for cuts down to 20%.

⁹ Smaller, not small. Inspection of the vertical axes of the three 3D graphs shows that the Basic Rate one has the biggest distance, while the other two have similar and smaller distances.

For the Additional Rate (Figure 5), from the back left dimension of the upper panel it is apparent that any cut will always raise tax receipts, and any rise will always reduce them. A longer time horizon will just make this relationship more prominent as is apparent from the lower right panel where the darker lines, representing lower rates than the 45% status quo, rise more strongly than the broken red line. The lower left panel shows that tax rates to left of the status quo line down to 25% eventually always generate more revenue than the status quo.

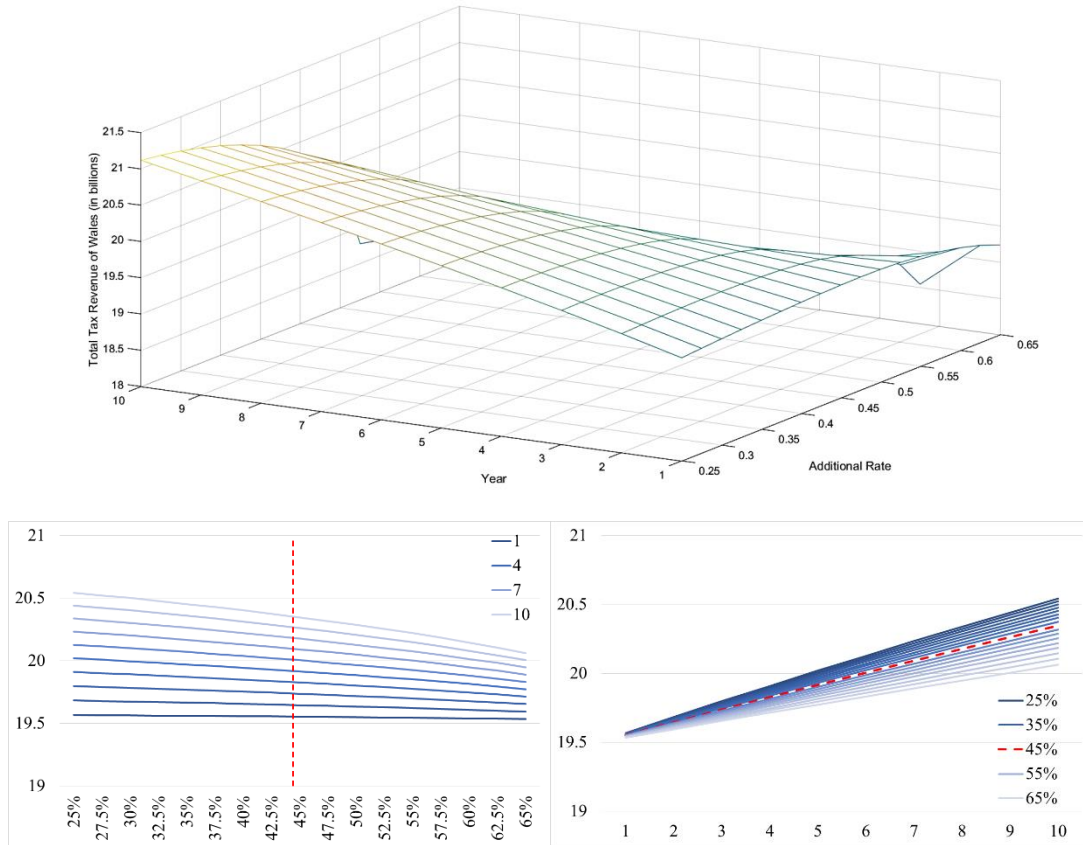


Figure 5 The Relationship between the Additional Rate and Tax Revenue

One contribution of this paper is to elicit an additional “economic effect” of income tax difference, in addition to the three effects proposed by the Holtham report. The income tax difference results in a new competitive equilibrium of the economy, in which all the endogenous economic variables (e.g. consumption, output, wage, etc.) will have changed. To understand the difference between the economic effect and the other three effects, an accounting identity for income tax revenue (TR) is helpful:

$$TR = \sum_i \tau_i \times (hour_i \times pop_i \times wage_i) \quad (2)$$

The term inside the brackets of equation (2) is the income tax base. The mechanical effect is derived from the changes in τ_i . The behavioural effect is obtained from alterations in working hours (intensive margin) due to the tax (dis)incentive. The migration effect is calculated from

population (extensive margin) change due to migration. In contrast, the economic effect is obtained from the wage response to induced changes in the whole economy. Total tax revenue also depends on other taxes in the model, the revenues from which are all responsive to the new equilibrium levels of output, consumption and wages.

To illustrate, a tax cut reduces government spending, and this affects household's utility, but is perhaps partly or more than counter-balanced by greater private goods spending. In addition, there is a supply-side response as the composition of the labour force changes through tax-induced migration. The net effect is not apparent without the simulation of the economic model. The effects on output is shown in Figure 6 and Appendix D.

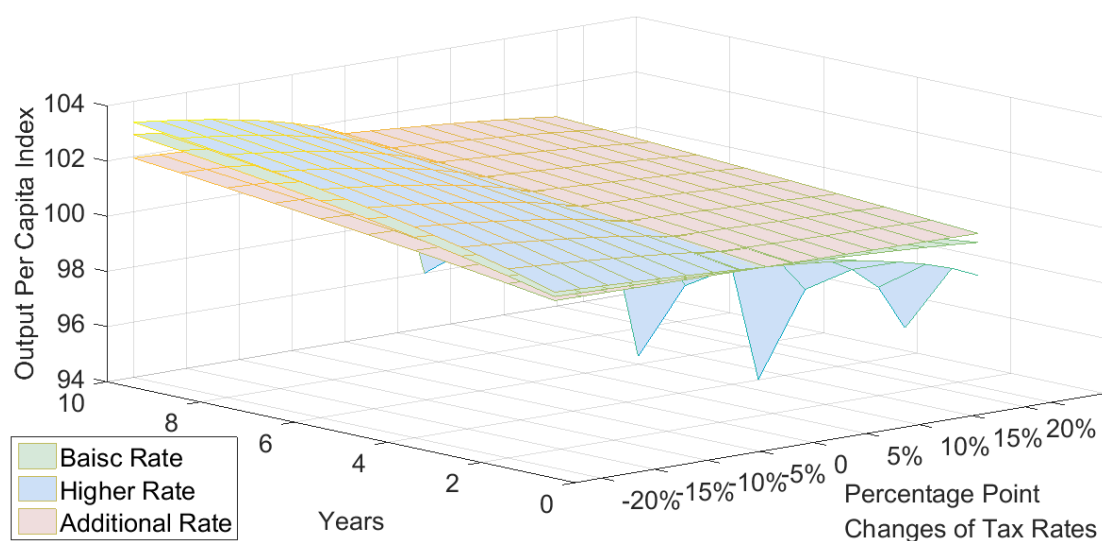


Figure 6 The Effect of Income Tax Changes on Output per Capita

Figure 6 shows that output per capita broadly follows the pattern indicated by the tax yield. Reduction of the Higher Rate has the strongest effect in increasing output per capita, while increases in the Additional Rate have the weakest effect in reducing output per capita. If we reduce the Higher Rate to 35%, tax revenue would rise by 1.6% after ten years (Figure 4), while output per capita would rise by 0.7% (Appendix D). Increasing the higher rate above 60% would clear Additional Rate payers out of Wales, and therefore output per capita falls sharply. Figure 6 shows output per capita in the penultimate year before all type 3 individuals have emigrated; in those penultimate years the output per capita is down by around 6%. However, when the Basic Rate is reduced from 20% to 15%, the output per capita rises by about 0.4% over the ten years, but the tax revenue falls by 1.3%.

8. Conclusion

Migration in response to tax differentials may impose a constraint on the economic policies of devolved governments. But without past experience to build on these governments cannot

be sure whether they are so constrained and, if they are, to what extent. The purpose of this exercise has been to show how existing sub-national (LA) taxation and migration in the UK can be used to estimate tax yields as a result of income tax devolution to much larger government jurisdictions. The focus must be principally on the Higher (40%) and Additional (45%) income tax rates because no statistically significant council tax effect on migration was estimated for Basic Rate (20%) taxpayers. This may have been because moving costs for Basic Rate payers are large relative to likely tax differentials or because the majority of young movers are students not liable for council tax.

The method developed can be employed for different sub-national taxes from those considered here. For instance the migration effects of a LA sales tax might be aggregated into larger devolved government units to infer the migration impact of an income or property tax at the higher level of government. A caveat is that extrapolation beyond the range of variation of the smaller sub-national tax may be hazardous for the larger devolved tax jurisdiction. Even so, the proposed method is likely to be the most reliable available approach to projecting tax yields when tax rates diverge.

In the present focus on the income tax possibilities for the devolved Welsh government we confirm the more impressionistically derived results of the Holtham Report (2010). These are that Higher and Additional Rate income taxpayers would be sensitive to devolved Welsh tax changes. In an extreme case, if the Welsh Higher Rate rises by 20 percentage points then more than half of the 5000 Additional Rate payers would leave Wales in the first year, according to the modelling. If the Welsh Additional Rate rises then the net inflow to Wales will be reduced but will remain positive, while if the Basic Rate rises there will be only a very small net outflow of taxpayers. The contrasting responses to the three tax rates are due to the different importance of the income within each tax bracket. Taxable income within the Higher Rate bracket is the greater part of the highest (type 3) income category (the estimated wage of Welsh type 3 individuals is around £180,000), and the Basic Rate and Additional Rate incomes are much less substantial proportions.

The tax yield results are a lower bound on responsiveness to income tax rates because no allowance has been made for possible tax-induced changes in the supply of effort or in tax evasion and avoidance. The general conclusion is that the ‘behavioural response’ to Welsh income tax changes will more than offset the ‘mechanical effect’; for likely changes in the Additional and Higher Rates, tax cuts increase tax revenue and tax hikes reduce it. Therefore considered simply in terms of additional tax revenue generated, a reduction in the higher rates of income tax and/or an increase in the lowest rate¹⁰ is required as a long term policy.

¹⁰ If the lack of statistical significance is ignored then the Basic Rate cannot be raised above 27%.

These tax yield results take into account second round effect of income tax changes whereby the tax base is altered not just by migration, but by wage changes and the induced alterations in household and firm behaviour. Output per capita of the economy generally moves in the same direction as the tax yield but Basic Rate reductions can increase output per capita while lowering tax revenue. However, the second round, or economic, effects of tax changes are dependent on the assumed model of the economy, and the model here is static and very simple.

Of course none of this necessarily applies to decentralised governments with different distributions of population relative to their borders. Estimates of the migration response to tax differentials will depend not only on populations but on the nature of the relevant tax and the taxpayer base. Consequently comparisons of elasticities across countries will be of little use. But the method adopted here may perhaps be adapted to provide information for other decentralised governments about tax-induced migration without their needing to undertake the experiment of actually changing devolved tax rates.

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Appendix A: The Data Sources

We have used the following data sources in this study:

- (a) **HMRC (2015)**. A disaggregation of HMRC tax receipts between England, Wales, Scotland & Northern Ireland: Methodology Note.
- (b) **HMRC (2014)**. Income tax liabilities statistics: number of individual income taxpayers by region (Table 2.2) and share of total income for percentile groups (Table 2.4).
- (c) **Department for Communities and Local Government (2015)**. Band D council tax for LA's.
- (d) **Department for Communities and Local Government (2011)**. Number of all chargeable dwellings.
- (e) **ONS (2016)**. Geometric centroid for each LA from GIS.
- (f) **ONS (2015)**. Regional accounts: gross value added (GVA) measure, Welsh economic region and year.
- (g) **ONS (2014)**. House price statistics for small areas: median sale price by dwelling type and LA.
- (h) **ONS (2014)**. Labour market statistics: population, employment, unemployment, inactivity and job density.
- (i) **ONS (2014)**. Migration statistics unit: internal migration between English and Welsh LAs.
- (j) **ONS (2012)**. Small area income estimates: total household weekly income.
- (k) **ONS (2011)**. Squared Euclidean distance matrix at LA level.
- (l) **Stats Wales (2015)**. Number of all chargeable dwellings.
- (m) **Welsh Government (2015)**. Council tax levels by billing authority and band.

The data are used for two purposes: (A) calibration of the economic model, or/and (B) estimation of the econometric model. There are three ways of using the data: first, direct use as one of the regressors in the econometric model; second, calibration of the parameters in the economic model by matching the model-implied endogenous variables with the observed endogenous variables; third, as the basis to implement an Extended Monte Carlo (EMC) simulation procedure (detailed in Appendix C) to generate the data needed for the econometric or economic models. The variables used in the analysis, the data sources and the techniques are summarised in the following table.

Variable	Source	Purpose	Technique
Council tax distribution	(d) (l)	(B)	EMC
Council tax rates	(c) (m)	(A) (B)	Derived
Euclidean distance	(k)	(B)	Direct use
Geographic distance	(e)	(B)	Pythagoras theorem
Government spending	(a)	(A)	Calibration
House price	(g)	(B)	EMC
Inactivity	(h)	(A) (B)	Calibration, Direct use
Income tax distribution	(b)	(A) (B)	Calibration, EMC
Job density	(h)	(B)	Direct use
Migration flow	(i)	(A) (B)	Direct use
Output	(f)	(A)	Calibration
Population	(h)	(B)	Direct use
Tax revenue	(a)	(A)	Calibration
Unemployment	(h)	(A) (B)	Calibration, Direct use
Wage	(j)	(A) (B)	EMC

Appendix B: The Economic Model

The Household

There are three types ($i = 1, 2, 3$) of households and wages (w_i). The composite product (Y) is composed of private goods (z_i) and public goods (G) provided by both central and local governments. Housing (h_i) and other consumption (c_i) constitute total consumption of private goods. τ s are tax rates and u is unemployment chances.

The problem of a representative type 1 household is:

$$\max_{z_1, c_1, h_1} u_1(z_1, G) = \left[\alpha_1 z_1^{\frac{s_1-1}{s_1}} + (1-\alpha_1) G^{\frac{s_1-1}{s_1}} \right]^{\frac{s_1}{s_1-1}}, \text{ subject to:}$$

$$(H1.1) \text{ Budget Constraint: } (1-u)\omega_1 + u\omega = p(1+\tau_c)c_1 + p_{H1}(1+\tau_{H1})h_1$$

$$(H1.2) \text{ Income: } \omega_1 = \omega_{NI1}^* + (\omega_{IT1}^* - \omega_{NI1}^*)(1-\tau_{NI1}) + (w_1 - \omega_{IT1}^*)(1-\tau_{NI1} - \tau_{IT1})$$

$$(H1.3) \text{ Private Goods Nesting: } z_1 = \left[\beta_1 c_1^{\frac{ss_1-1}{ss_1}} + (1-\beta_1) h_1^{\frac{ss_1-1}{ss_1}} \right]^{\frac{ss_1}{ss_1-1}}.$$

Similarly, the problem of the middle-income households (type 2) is:

$$\max_{z_2, c_2, h_2} u_2(z_2, G) = \left[\alpha_2 z_2^{\frac{s_2-1}{s_2}} + (1-\alpha_2) G^{\frac{s_2-1}{s_2}} \right]^{\frac{s_2}{s_2-1}}, \text{ subject to:}$$

$$(H2.1) \text{ Budget Constraint: } \omega_2 = p(1+\tau_c)c_2 + p_{H2}(1+\tau_{H2})h_2$$

$$(H2.2) \text{ Income: } \omega_2 = \omega_{NI1}^* + (\omega_{IT1}^* - \omega_{NI1}^*)(1-\tau_{NI1}) + (\omega_{IT2}^* - \omega_{IT1}^*)(1-\tau_{NI1} - \tau_{IT1}) \\ + (w_2 - \omega_{IT2}^*)(1-\tau_{NI2} - \tau_{IT2})$$

$$(H2.3) \text{ Private Goods Nesting: } z_2 = \left[\beta_2 c_2^{\frac{ss_2-1}{ss_2}} + (1-\beta_2) h_2^{\frac{ss_2-1}{ss_2}} \right]^{\frac{ss_2}{ss_2-1}}.$$

And the problem of the top-income households (type 3) is:

$$\max_{z_3, c_3, h_3} u_3(z_3, G) = \left[\alpha_3 z_3^{\frac{s_3-1}{s_3}} + (1-\alpha_3) G^{\frac{s_3-1}{s_3}} \right]^{\frac{s_3}{s_3-1}}, \text{ subject to:}$$

$$(H2.1) \text{ Budget Constraint: } \omega_3 = p(1+\tau_c)c_3 + p_{H3}(1+\tau_{H3})h_3$$

$$(H2.2) \text{ Income: } \omega_3 = \omega_{NI1}^* + (\omega_{IT1}^* - \omega_{NI1}^*)(1-\tau_{NI1}) + (\omega_{IT2}^* - \omega_{IT1}^*)(1-\tau_{NI1} - \tau_{IT1}) \\ + (\omega_{IT3}^* - \omega_{IT2}^*)(1-\tau_{NI2} - \tau_{IT2}) + (w_3 - \omega_{IT3}^*)(1-\tau_{NI2} - \tau_{IT3})$$

$$(H2.3) \text{ Private Goods Nesting: } z_3 = \left[\beta_3 c_3^{\frac{ss_3-1}{ss_3}} + (1-\beta_3) h_3^{\frac{ss_3-1}{ss_3}} \right]^{\frac{ss_3}{ss_3-1}}.$$

The Producer

There are three types of labour L_i , total factor productivity is A , and p output price. The representative producer's maximisation problem is:

$$\begin{aligned} \max \Pi = & pY - \left[\omega_{NIF}^* + (1 + \tau_{NIF})(w_1 - \omega_{NIF}^*) \right] L_1 (1-u) \\ & - \left[\omega_{NIF}^* + (1 + \tau_{NIF})(w_2 - \omega_{NIF}^*) \right] L_2 \\ & - \left[\omega_{NIF}^* + (1 + \tau_{NIF})(w_3 - \omega_{NIF}^*) \right] L_3 \end{aligned} \quad , \text{ subject to:}$$

$$(F1) \text{ Production Function: } Y = A \left\{ \gamma_1 \left[(1-u) L_1 \right]^{\frac{\sigma-1}{\sigma}} + \gamma_2 (L_2)^{\frac{\sigma-1}{\sigma}} + \gamma_3 (L_3)^{\frac{\sigma-1}{\sigma}} \right\}^{\frac{\sigma}{\sigma-1}}.$$

The Government

The budget constraint of the Welsh government (including central government transfer T_{UK}):

$$T_C + T_H + T_{IT} + T_{NI} + T_F + T_{UK} = pG + \omega L_1 u, \text{ where:}$$

$$(G1) \text{ Consumption VAT Tax: } T_C = p(\tau_C c_1 L_1 + \tau_C c_2 L_2 + \tau_C c_3 L_3)$$

$$(G2) \text{ Council Tax: } T_H = p_{H1} \tau_{H1} h_1 L_1 + p_{H2} \tau_{H2} h_2 L_2 + p_{H3} \tau_{H3} h_3 L_3$$

(G3) Income Tax:

$$\begin{aligned} T_{IT} = & (w_1 - \omega_{IT1}^*) \tau_{IT1} L_1 (1-u) \\ & + \left[(\omega_{IT2}^* - \omega_{IT1}^*) \tau_{IT1} + (w_2 - \omega_{IT2}^*) \tau_{IT2} \right] L_2 \\ & + \left[(\omega_{IT2}^* - \omega_{IT1}^*) \tau_{IT1} + (\omega_{IT3}^* - \omega_{IT2}^*) \tau_{IT2} + (w_3 - \omega_{IT3}^*) \tau_{IT3} \right] L_3 \end{aligned}$$

(G4) National Insurance Contribution:

$$\begin{aligned} T_{NI} = & (w_1 - \omega_{NI1}^*) \tau_{NI1} L_1 (1-u) \\ & + \left[(\omega_{NI2}^* - \omega_{NI1}^*) \tau_{NI1} + (w_2 - \omega_{NI2}^*) \tau_{NI2} \right] L_2 \\ & + \left[(\omega_{NI2}^* - \omega_{NI1}^*) \tau_{NI1} + (w_3 - \omega_{NI2}^*) \tau_{NI2} \right] L_3 \\ & + \tau_{NIF} \left[(w_1 - \omega_{NIF}^*) L_1 (1-u) + (w_2 - \omega_{NIF}^*) L_2 + (w_3 - \omega_{NIF}^*) L_3 \right] \end{aligned}$$

(G5) Corporation Tax: $T_F = \tau_F \Pi$.

Model Closure

The households and firms maximise their objective functions treating the following variables as exogenous: $w_i, \underline{\omega}, G, L_i, u, p_{Hi}$. To solve the model, we need to provide model closure conditions and specify which variables are exogenous.

- Wages (w_i). Imposing the labour markets clearing conditions will determine wages (equivalent to equating wages from the households' first order conditions (FOCs) and from the firms' FOCs).
- Government Spending ($\underline{\omega}, G$). Imposing the goods market clearing condition will determine the government spending, because the composite output is either used as private goods (c_i) or public goods (G):

$$Y = c_1 L_1 + c_2 L_2 + c_3 L_3 + G(L_1 + L_2 + L_3).$$

As a result, the welfare payment $\underline{\omega}$ will be automatically determined by the government budget constraint.

- Population (L_i) depends on net immigration (M_i) into Wales,

$$L_i = \bar{L}_i + M_i,$$

where \bar{L}_i is the original number of household type i and M_i is estimated using the econometric model detailed in the next section.

- Unemployment/Nonparticipation Rate (u). This can be left as exogenous, since the net migration is very small compared to the local population in Wales – the net migration in 2014 is 1070, while the total number of tax payers is 1.3 million. Therefore, the migration will not cause significant changes in the labour market.
- Goods Price (p) and House Price (p_{Hi}). As in the CGE modelling convention, both are fixed at 1, so that the quantities can be interpreted as the expenditures. Thus, c_i is interpreted as the total expenditure on consumption and h_i is the total expenditure on housing.

There are 27 competitive equilibrium conditions for the 27 endogenous variables: $c_1, h_1, \omega_1, z_1, u_1, c_2, h_2, \omega_2, z_2, u_2, c_3, h_3, \omega_3, z_3, u_3, w_1, w_2, w_3, Y, \Pi, T_C, T_H, T_{NI}, T_{IT}, T_F, G$ and $\underline{\omega}$. There are 10 exogenous variables: $u, L_1, L_2, L_3, \bar{L}_1, \bar{L}_2, \bar{L}_3, M_1, M_2$ and M_3 . Moreover, there are 11 parameters to be calibrated: $\beta_1, \beta_2, \beta_3, \sigma_1, \sigma_2, \sigma_3, \gamma_1, \gamma_2, \gamma_3, \sigma$ and A . Note that other preference parameters, such as $\alpha_1, \alpha_2, \alpha_3, s_1, s_2, s_3$, only exist to define unobservable endogenous variables, so they cannot (and need not to) be estimated based on the data. They can, however, be set at some reasonable values for completeness, but they do not affect the analysis whatsoever. Policy parameters such as τ 's and ω^* 's are all known and set at their actual values.

Using the technique of optimal calibration described in Section 4, the estimated structural parameters governing the behaviour of the households and firms are summarised in Table 4:

Parameter	Meaning	Estimate
β_1	Utility share of consumption (type 1)	0.4995
β_2	Utility share of consumption (type 2)	0.5094
β_3	Utility share of consumption (type 3)	0.5729
ss_1	CES between consumption and housing (type 1)	1.2769
ss_2	CES between consumption and housing (type 2)	1.7944
ss_3	CES between consumption and housing (type 3)	1.3877
γ_1	Income share of type 1 labour/individual	0.7510
γ_2	Income share of type 2 labour/individual	0.2126
γ_3	Income share of type 3 labour/individual	0.0364
σ	CES between the three types of labour	1.1218
A	Total factor productivity	98.8538

Table 4 Estimated Structural Parameters using Optimal Calibration

Appendix C: Extended Monte Carlo Simulation

The distribution of house price in Figure 6 is based on the 165,822 properties in England and Wales recorded by the Land Registry.

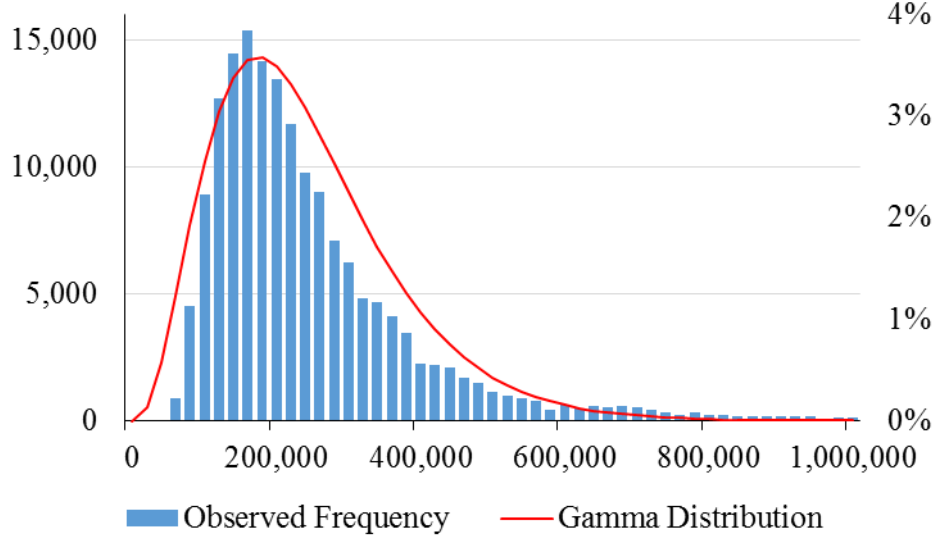


Figure 6 Distribution of House Prices in England and Wales (2010)

Note that we can use a gamma distribution to fit the house price data well, so the information contained in the observed distribution can be summarised by only two parameters parsimoniously. The two parameters (a, b) respectively characterise the shape (a) and the scale (b) of the gamma distribution.

$$\text{gamma}(X) = \frac{1}{b^a \Gamma(a)} X^{a-1} \exp\left(-\frac{X}{b}\right)$$

To facilitate the econometric and economic modelling later, we design an Extended Monte Carlo simulation procedure to generate the house prices (p_{H1}, p_{H2}, p_{H3}) for all three types of households.

Step 1: Estimate the shape parameter. Based on the observed numbers of properties across council tax bands at LA level, we can imply the shape of the distribution of house prices – because house prices are strictly increasing with council tax bands. Therefore, the estimated shape parameter \hat{a} of the distribution of council tax bands should be the same as that governing the shape of the gamma distribution of house prices.

Step 2: Derive the scale parameter. Note that the estimated scale parameter \hat{b} is not directly applicable to house prices because the horizontal axis of council tax bands are

A, B, C, etc. while that of house price is pounds. But we can make use of the observed median house prices in each LA and the relationship among median (\tilde{p}_H), mean (\bar{p}_H) and the two parameters of gamma distribution to derive the corresponding scale parameter.

$$\left. \begin{array}{l} \tilde{p}_H = \bar{p}_H \frac{3a-0.8}{3a+0.2} \\ \bar{p}_H = E[p_H] = ab \end{array} \right\} \Rightarrow b = \tilde{p}_H \times \frac{1}{a} \times \frac{3a-0.2}{3a-0.8}$$

Step 3: Simulate the data. In this way, we estimate a unique distribution of house prices in each LA by a parsimonious parametric model (i.e. \hat{a} and \hat{b}), based on which, we can simulate $N_S = 10^5$ observations of house prices.

Step 4: Obtain the quantities of interest. With the simulated data, it is easy to obtain the mean/median house prices for the three types of households. For example, we know that the proportion of type 1 household is 89%, then we can use the first 89% simulated house prices (sorted) to calculate the mean/median house price of type 1 household.

The Extended Monte Carlo procedure makes full use of the observed data before standard Monte Carlo simulation, so it has advantages of both bootstrapping and standard Monte Carlo re-sampling techniques. Similarly, this technique is applied to generating mean wages (w_1, w_2, w_3) of each household type in each LA.

Appendix D: Simulated Tax Revenue and Output per Capita

Year	10%	12.5%	15%	17.5%	20%
1	18.10	18.46	18.83	19.19	19.55
2	18.28	18.63	18.98	19.31	19.65
3	18.47	18.80	19.12	19.43	19.74
4	18.65	18.96	19.26	19.55	19.83
5	18.82	19.12	19.40	19.67	19.92
6	19.00	19.28	19.54	19.78	20.00
7	19.18	19.43	19.67	19.89	20.09
8	19.35	19.59	19.81	20.01	20.18
9	19.52	19.74	19.94	20.12	20.26
10	19.69	19.90	20.08	20.23	20.35

Table 5 Simulated Tax Revenue (in billions) after Basic Rate Cuts

Year	20%	22.5%	25%	27.5%	30%	32.5%	35%	37.5%	40%
1	19.55	19.91	20.26	20.61	20.95	21.29	21.62	21.94	22.25
2	19.65	19.97	20.29	20.59	20.89	21.18	21.45	21.70	21.93
3	19.74	20.03	20.31	20.58	20.83	21.06	21.27	21.46	21.61
4	19.83	20.09	20.34	20.56	20.77	20.95	21.10	21.22	21.29
5	19.92	20.15	20.36	20.55	20.71	20.84	20.93	20.97	20.97
6	20.00	20.21	20.38	20.53	20.65	20.72	20.75	20.73	20.64
7	20.09	20.26	20.41	20.51	20.58	20.61	20.58	20.49	20.31
8	20.18	20.32	20.43	20.50	20.52	20.50	20.41	20.24	19.98
9	20.26	20.38	20.45	20.48	20.46	20.38	20.23	20.00	19.64
10	20.35	20.43	20.47	20.46	20.40	20.27	20.06	19.75	19.30

Table 6 Simulated Tax Revenue (in billions) after Basic Rate Increases

Year	30%	32.5%	35%	37.5%	40%
1	19.50	19.52	19.53	19.55	19.55
2	19.68	19.68	19.67	19.66	19.65
3	19.84	19.83	19.81	19.78	19.74
4	20.00	19.97	19.94	19.89	19.83
5	20.16	20.12	20.06	20.00	19.92
6	20.31	20.26	20.19	20.11	20.00
7	20.46	20.39	20.31	20.22	20.09
8	20.60	20.53	20.43	20.32	20.18
9	20.75	20.66	20.55	20.43	20.26
10	20.89	20.79	20.67	20.53	20.35

Table 7 Simulated Tax Revenue (in billions) after Higher Rate Cuts

Year	40%	42.5%	45%	47.5%	50%	52.5%	55%	57.5%	60%
1	19.55	19.56	19.55	19.54	19.51	19.47	19.42	19.34	19.24
2	19.65	19.62	19.58	19.51	19.42	19.27	19.07	18.69	
3	19.74	19.68	19.60	19.48	19.30	18.99			
4	19.83	19.74	19.62	19.44	19.14	18.23			
5	19.92	19.80	19.65	19.40	18.91				
6	20.00	19.87	19.67	19.34	18.32				
7	20.09	19.93	19.68	19.27					
8	20.18	19.99	19.70	19.17					
9	20.26	20.04	19.72	19.03					
10	20.35	20.10	19.73	18.77					

Table 8 Simulated Tax Revenue (in billions) after Higher Rate Increases

Year	35%	37.5%	40%	42.5%	45%
1	19.56	19.56	19.56	19.56	19.55
2	19.67	19.66	19.66	19.65	19.65
3	19.77	19.76	19.75	19.75	19.74
4	19.87	19.86	19.85	19.84	19.83
5	19.97	19.96	19.95	19.93	19.92
6	20.07	20.06	20.04	20.02	20.00
7	20.17	20.15	20.13	20.11	20.09
8	20.26	20.24	20.22	20.20	20.18
9	20.36	20.34	20.31	20.29	20.26
10	20.45	20.43	20.40	20.38	20.35

Table 9 Simulated Tax Revenue (in billions) after Additional Rate Cuts

Year	45%	47.5%	50%	52.5%	55%	57.5%	60%	62.5%	65%
1	19.55	19.55	19.55	19.55	19.55	19.54	19.54	19.54	19.53
2	19.65	19.64	19.64	19.63	19.62	19.62	19.61	19.60	19.59
3	19.74	19.73	19.72	19.71	19.70	19.69	19.68	19.67	19.65
4	19.83	19.82	19.80	19.79	19.78	19.76	19.75	19.73	19.71
5	19.92	19.90	19.89	19.87	19.85	19.83	19.81	19.79	19.77
6	20.00	19.99	19.97	19.95	19.93	19.91	19.88	19.86	19.83
7	20.09	20.07	20.05	20.02	20.00	19.98	19.95	19.92	19.89
8	20.18	20.15	20.13	20.10	20.07	20.05	20.02	19.98	19.95
9	20.26	20.24	20.21	20.18	20.15	20.12	20.08	20.04	20.00
10	20.35	20.32	20.29	20.25	20.22	20.18	20.15	20.11	20.06

Table 10 Simulated Tax Revenue (in billions) after Additional Rate Increases

Year	10%	12.5%	15%	17.5%	20%
1	100.12	100.09	100.06	100.03	100.00
2	100.42	100.37	100.32	100.26	100.19
3	100.71	100.63	100.56	100.47	100.38
4	100.97	100.88	100.79	100.68	100.57
5	101.23	101.12	101.01	100.88	100.74
6	101.46	101.34	101.22	101.07	100.91
7	101.69	101.56	101.42	101.25	101.08
8	101.91	101.76	101.61	101.43	101.24
9	102.11	101.96	101.79	101.60	101.39
10	102.30	102.14	101.97	101.77	101.54

Table 11 Simulated Output per Capita (index) after Basic Rate Cuts

Year	20%	22.5%	25%	27.5%	30%	32.5%	35%	37.5%	40%
1	100.00	99.96	99.93	99.88	99.84	99.79	99.73	99.67	99.59
2	100.19	100.13	100.05	99.97	99.88	99.78	99.66	99.53	99.38
3	100.38	100.28	100.17	100.05	99.92	99.76	99.59	99.39	99.15
4	100.57	100.44	100.30	100.14	99.96	99.75	99.52	99.24	98.91
5	100.74	100.59	100.41	100.22	100.00	99.74	99.44	99.08	98.65
6	100.91	100.73	100.53	100.30	100.04	99.73	99.36	98.92	98.38
7	101.08	100.88	100.65	100.38	100.08	99.72	99.28	98.75	98.09
8	101.24	101.02	100.76	100.46	100.12	99.70	99.20	98.58	97.78
9	101.39	101.15	100.87	100.54	100.16	99.69	99.12	98.39	97.44
10	101.54	101.28	100.98	100.62	100.20	99.68	99.03	98.19	97.07

Table 12 Simulated Output per Capita (index) after Basic Rate Increases

Year	30%	32.5%	35%	37.5%	40%
1	100.22	100.17	100.12	100.06	100.00
2	100.59	100.51	100.42	100.31	100.19
3	100.93	100.82	100.69	100.55	100.38
4	101.24	101.11	100.95	100.78	100.57
5	101.53	101.37	101.20	100.99	100.74
6	101.79	101.62	101.43	101.20	100.91
7	102.04	101.86	101.65	101.40	101.08
8	102.27	102.08	101.86	101.59	101.24
9	102.48	102.29	102.06	101.77	101.39
10	102.69	102.49	102.24	101.94	101.54

Table 13 Simulated Output per Capita (index) after Higher Rate Cuts

Year	40%	42.5%	45%	47.5%	50%	52.5%	55%	57.5%	60%
1	100.00	99.93	99.83	99.72	99.56	99.37	99.12	98.81	98.40
2	100.19	100.05	99.86	99.61	99.25	98.73	97.92	96.29	
3	100.38	100.17	99.89	99.48	98.83	97.64			
4	100.57	100.29	99.91	99.31	98.22	94.02			
5	100.74	100.41	99.92	99.10	97.21				
6	100.91	100.52	99.93	98.84	94.28				
7	101.08	100.63	99.93	98.49					
8	101.24	100.74	99.93	98.01					
9	101.39	100.85	99.92	97.30					
10	101.54	100.95	99.90	95.99					

Table 14 Simulated Output per Capita (index) after Higher Rate Increases

Year	35%	37.5%	40%	42.5%	45%
1	100.03	100.03	100.02	100.01	100.00
2	100.26	100.25	100.23	100.21	100.19
3	100.48	100.45	100.43	100.41	100.38
4	100.68	100.66	100.63	100.60	100.57
5	100.88	100.85	100.82	100.78	100.74
6	101.07	101.04	101.00	100.95	100.91
7	101.26	101.22	101.17	101.12	101.08
8	101.43	101.39	101.34	101.29	101.24
9	101.60	101.56	101.50	101.45	101.39
10	101.77	101.72	101.66	101.60	101.54

Table 15 Simulated Output per Capita (index) after Additional Rate Cuts

Year	45%	47.5%	50%	52.5%	55%	57.5%	60%	62.5%	65%
1	100.00	99.99	99.98	99.97	99.96	99.95	99.94	99.93	99.92
2	100.19	100.18	100.16	100.14	100.12	100.10	100.08	100.06	100.03
3	100.38	100.36	100.33	100.30	100.27	100.24	100.21	100.18	100.15
4	100.57	100.53	100.50	100.46	100.43	100.39	100.35	100.30	100.26
5	100.74	100.70	100.66	100.62	100.57	100.52	100.47	100.42	100.36
6	100.91	100.87	100.82	100.77	100.72	100.66	100.60	100.54	100.47
7	101.08	101.03	100.97	100.91	100.86	100.79	100.72	100.65	100.57
8	101.24	101.18	101.12	101.06	100.99	100.92	100.84	100.76	100.67
9	101.39	101.33	101.27	101.20	101.12	101.05	100.96	100.87	100.77
10	101.54	101.48	101.41	101.33	101.25	101.17	101.07	100.97	100.86

Table 16 Simulated Output per Capita (index) after Additional Rate Increases