Devolving Fiscal Policy: Migration and Tax Yields

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Abstract: Devolution of taxes to sub-national jurisdictions could reduce expected tax revenue if some households move to lower tax regimes, constraining devolved government policy. This paper develops an indirect approach to establishing lower bound revenue impacts of possible devolved tax changes by allowing for tax-induced migration. The results suggest that limited tax devolution, such as conferred on Wales by the U.K. 2014 Act, could trigger substantial tax revenue and GVA spill-overs from migration on the devolved economy. The prospect may have, and perhaps should have, discouraged decentralisation of taxation to the same extent as decentralisation of spending in the OECD.

Keywords: Migration, Fiscal Decentralisation, Tax Revenue.

JEL: R23, J61, H11, H22

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1. Introduction

Households may migrate between jurisdictions to secure preferred mixes of collectively sup-plied 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 sat-isfaction of needs (Oates, 1972). Yet there is evidence that decentralising both public spending and tax revenues lowers economic growth in OECD countries[1] (Rodríguez-Pose et al, 2009; Rodríguez-Pose and Ezcurra, 2011) and in China (Zhang and Zou, 1998). Income disparity also seems to be sensitive to fiscal devolution (Rodríguez-Pose and Ezcurra, 2010). The pro-cesses involved may include agency problems, weaker governance structures, a reduction in the equalising role formerly exercised by central government and adverse effects of territorial competition (Rodríguez-Pose and Gill, 2005).

An aspect of territorial competition, tax-induced migration, may be an especially significant contributor. If devolved or decentralised taxation adversely affected tax revenues because households moved to avoid tax, then devolved public spending and redistributive policies could be severely constrained (Xu and Warner, 2016)[2]. This might be 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 of higher rate income (foreign) taxpayers can be important. This last finding is confirmed for interstate mo-bility of highly paid scientists within the U.S. (Moretti and Wilson, 2017) but much less so for the highest earners in total (Young et al, 2016). The highest earners in Spain are responsive to regional tax differentials but not sufficiently to entirely offset the revenue raising impact of tax increases (Agrawal and Foremny, 2018).

How problematic tax differentials are for devolved regimes depends on the mobility of the tax base and the nature and extent of central funding. The least mobile tax base is land and therefore a property tax is suitable for decentralised jurisdictions, as Yilmazkuday (2016) finds for U.S. states. In the United Kingdom (U.K.) in the form of 'council tax' this has been the favoured means of devolved financing for Local Authorities (LAs), of which there are 348 in England and Wales. In the absence of legal restrictions on movement, capital taxes are at the other end

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[1] Though Spain appears to be an exception (Gil-Serrate, Lopez-Laborda and Mur, 2011).
[2] 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).

of the base mobility spectrum. Highly mobile capital drives the Hatfield (2015) model of fiscal decentralisation and economic growth.

From a comprehensive survey of Tiebout model-inspired approaches to fiscal devolution, Boadway and Tremblay (2012) concluded that the unrealistic assumption of perfect labour mobility is a major drawback. But for devolved taxes on labour, or on sales, any substantial labour mobility is a potential problem for tax revenue. Wealthier persons paying the greater jurisdiction-specific taxes are likely to be the most prone to movement; they have more tax payments to avoid by relocation. This probably accounts for Yilmazkuday's (2017) result that any increase in US state dividend-income tax reduces revenues, whereas tax revenues are boosted by higher wage-income, sales or property taxes.

In the U.K. before 1997 the only decentralised source of fiscal revenue was LA property taxes, covering about 25 percent of their spending. Since 1997 three much larger devolved spending administrations have been created, Northern Ireland, Wales and Scotland, responsible for one sixth of the U.K. population. Limited decentralisation of taxes followed, of which a portion of the income tax rate, was the most important. The Scottish government reduced the lower tax rate and increased the higher rates in 2018. To examine the effects of future devolved income tax policies, this paper develops a generic method applied to the Welsh case[3]. The present paper estimates the revenue and GVA consequences of the exercise of fiscal autonomy in this instance of fiscal devolution.

At the centre of the approach is a Computable General Equilibrium (CGE) model of the devolved jurisdiction. Because the possibility of tax-induced migration might be critical to decentralised tax policy, the CGE model is supplemented with an econometric exercise. With no other U.K. experience of spatial variations in tax rates before 2018, LA property taxes are utilised to gauge future U.K. devolved government income tax-induced migration. Estimates of the tax revenue consequences for the devolved Welsh administration are obtained from the CGE model. Because existing (here, property) taxes have different bases from proposed devolved (here, income) taxes, appropriate corrections are made in the decentralised economy model. This model also establishes how the tax base and therefore the other economic variables of the devolved economy would be changed by implementing different tax rates, given the migration responses estimated. The approach can therefore contribute to evaluating the desirability of types of tax devolution before they have been implemented.

An advantage of this modelling process is that more accurate estimates of the effects of tax on migration can be obtained than if migration was estimated simply as part of the CGE model

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[3] An Act of 2014 (modified in 2017) conferred on the Welsh government additional tax powers.

(compare Gillespie et al (2001) and Rutherford and Torma (2010))[4]. This is because CGE models require empirically acceptable equation specifications and plausible ranges of parameter values which are not available in this, and many, devolution cases.

Simulation shows partial tax devolution permits a divergence of total tax generated as a consequence of devolved tax policy and tax receipts allowed to the devolved government. Fuller tax devolution, however, leaves the jurisdiction open to adverse asymmetric shocks. That some tax revenue to finance decentralised spending should be raised locally to give an incentive for efficient government resource allocation may be a sound principle (Sanguinetti and Tommasi, 2004). But the spill-over effects from induced migration could be a reason why taxes have been decentralised less than spending, as Journard and Kongsrud (2003) noted for the OECD, and perhaps why this is desirable.

The following section discusses the research questions and the method, section 3 outlines the CGE devolved economy model, the next section presents the estimated migration model with the tax coefficients, section 5 shows the migration implied by tax differentials and in section 6 there is a simulation of the tax differential full effects in the devolved economy model.

2. Some Spatial Consequences of Fiscal Devolution

Focussing on the devolved economy of Wales, the main research questions are:

> *What would be the effects on migration of divergences between the income tax rates in Wales and England and how would devolved tax revenue be affected?*

These questions could more easily be answered with historical data of different income tax rates in Wales and England. However, because such differential rates have never been created[5], the questions are addressed by two research sub-questions.

Within-U.K. migration data is used to estimate the effects of property (council) tax differences on gross migration between pairs of LA jurisdictions (a complete list of data sources is provided in Appendix A). After appropriate aggregation, this provides an answer to the first research sub-question:

> *(R1) What are the effects of property tax differentials on the net migration flow into Wales?*

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[4] Both these papers simply have net migration as a linear function of relative GDP or wages and relative unemployment rates.
[5] This is why Foreman-Peck and Lungu's (2009) simulation of an income tax change in the Welsh economy only shows the effect conditional on an identical tax change in the rest of the U.K. economy.

But income taxes have different bases from property taxes. It is essential to establish the relationship between the effects of property tax and income tax. Hence, the second research sub-question is:

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

Whether 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 relative to borders. The recent extension of limited income taxation powers to the devolved government of Wales (with 2014 Act) certainly creates a possibility of tax-induced migration. 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. Wales is highly integrated with the much larger English economy in both geographic and economic senses. Annual migration both in and out of the Welsh economy to the rest of the U.K. is around 50,000 for a population of about three million. Daily commuters into England number more than 80,000 (6% of the workforce) with about half the number commuting in the opposite direction (Turner 2014). There is a small and variable balance of immigration from England.

Three types of tax revenue effects from increasing an income tax rate have been distinguished: 'mechanical', 'behavioural' and 'migration' impacts (Holtham, 2010, chapter 6). The 'mechanical' effect involves simply multiplying, say, a higher tax rate by the tax base–the incomes of the taxpayers. The 'behavioural' effect is intended to capture changes in the supply of effort, influenced by the marginal tax rate. For this effect the key coefficient is the elasticity of reported taxpayer income to one minus the marginal tax rate (Brewer, Saez and Shephard, 2010). 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'.

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

A contribution of this paper is to elicit an additional 'economic effect' of income tax divergence, in addition to the foregoing three effects. The income tax difference results in a new equilibrium of the economy, in which all the endogenous economic variables (such as consumption output and all tax revenue) will have changed.

The existing devolved property tax, 'council tax', is levied upon domestic housing (and, as 'business rates', upon commercial property) and is specific to each LA. The present exercise distinguishes three income types of individual corresponding to the three rates of income tax[6]; they are Basic Rate (BR) taxpayers (20% @£10,600~£42,385), Higher Rate (HR) taxpayers (40% @£42,385~£150,000) and Additional Rate (AR) taxpayers (45% @£150,000+). The different types also face different National Insurance (NI, social security tax) rates (Appendix B).

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.

Higher LA property taxes tend to reduce house prices (as residence-based local income taxes would) and in some instances greater LA spending may raise them (Rosenthal, 1999; Cheshire and Sheppard, 2003). House prices (and therefore rents) will reflect a market average of preferences for what is provided by the LA and for what 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 schools will not benefit from this category of expenditure and would gain materially from being in a jurisdiction that allocated less to education and consequently taxes less. House price differentials in response to taxation will not eliminate tax-induced migration. Given the heterogeneity of the population, some migration response to differences in local tax rates may still be found–as for Canadian property tax-induced inter-municipal migration (Islam and Rafiquzzaman, 1991).

3. The Devolved Economy Model

The devolved economy computable general equilibrium (CGE) model is the simplest possible that can focus on the effects of migration induced by income tax differentials for the whole of Wales[7]. The model uses country level data (England and Wales, aggregated over the 348 local authority areas). Tax rates and wages are exogenous and tax revenues, housing and consumer expenditure and output, are endogenous. Migration becomes endogenous when the econometric model of tax-induced migration supplements the CGE model.

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[6] To keep the modelling manageable, we do not distinguish between households and individuals. In 2012, 55% of all taxpayers' income in Wales was earned by individuals earning less than £30,000 a year and less than 6% of the taxable income in Wales was earned by those earning £100,000 and above (Poole et al, 2016).

[7] This model does not consider tax-induced changes in the supply of effort or tax effects on savings and investments because these can be controversial. The simplicity of the model allows us to conclude that quantitatively the effects will be understated or downward biased.

The demand side of the model consists of the three types ($i = 1, 2, 3$) of individuals in terms of wages (and income tax rates), while the supply side is simplified to only one sector. The composite product can be used for private goods or 'public' goods provided by both central and local governments. An important contributor to individual wellbeing or utility is housing, or accommodation, which is part of the composite product.

Some of the model's structural parameters have real counterparts, such as tax rates, which can be imposed. Other parameters, such as the elasticity of substitutions in utility functions and production functions, merely must lie in some plausible range (see Appendix B). Where necessary the structural parameters are estimated so that the total (squared) gap between the simulated variables (model) and the observed variables (data) is minimised in the status quo. In the present case, since the number of observables is just equal to the number of unknown structural parameters (see Appendix B), the identification condition is satisfied.

The Household

All individuals are assumed liable for the property (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 payments appropriately. 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 band[8].

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

For all the three types, their after-tax income (or wage) is calculated with the then current rates of income tax and NI contribution. The consumption VAT tax rate is assumed to be the same for all individuals[9]. Private consumption is assumed to consist of other consumption and housing, while the 'public' goods are assumed to be the same across all three types of residences.

The Producer

The supply side of the economy consists of one production sector with one composite output, which can be used for either private or 'public' goods. Firms pay a corporation tax and the

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[8] This detailed calculation is possible because an extended Monte Carlo method is employed to simulate the property prices in the previous step, allowing the calculation of the average property prices for each band (Appendix C).

[9] Although the model allows that the proportion of income paid by lower income groups in VAT is lower than for higher groups.

corporate NI contributions. Exogenous/fixed investment is assumed absorbed by the total factor productivity. The labour market is assumed segmented to reflect the different skills of workers.

Devolved Government

Total tax revenue levied in the devolved economy consists of LA and national tax revenue. In practice, the latter is collected by the U.K. central government and then an adjusted sum is transferred back to the devolved government of Wales in the form of a block grant. After tax devolution, the devolved government is assigned some of the tax revenue (mainly from income tax) and the remaining transfer **from** the central government is reduced accordingly. The 2014 Act allows the devolved government to <u>lower</u> all, or any, of the three income tax bands by up to 10p in the pound but there is no upper limit. Tax liability is based on residence and only applies to non-savings and non-dividend income.

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 revenues. Conversely, a decision to lower rates relative to the rest of the U.K. reduces the estimated Welsh tax take ('mechanical effect') and central government cuts Welsh government revenue by that amount[10]. Central government spending, which accounts for about half of government expenditure in Wales, and the block grant, are exogenous.

In addition to income tax, the model explicitly includes all the principal sources of tax revenue: National Insurance contributions (a labour tax, paid by both employees and employers), VAT, council tax and corporation tax.

The Relationship between Council (Property) Tax and Income Tax

The effect of an income tax difference is simulated by translating it into a council tax difference. Council tax alters the *relative* prices of housing and all other goods. An equivalent income effect, or income tax, to the change in the council tax can be calculated by assuming an 'indifference curve' between housing and all other goods along which taxpayers have the same utility[11]. The two taxes affect taxpayers' budgets differently–council tax raises the relative price of housing whereas income tax does not. The income tax equivalent of a council tax difference corrects for the different budget gradients while maintaining the same level of utility. The CGE model is used to simulate these two situations.

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[10] The legislation recognizes that if the Welsh government sets a different rate of income tax there may be behavioural spillover that, if agreed by both governments, could warrant compensatory payments.
[11] Rather than the 'compensation' income to restore the original utility. That is, the Equivalent Variation must be found rather than the Compensating Variation.

4. The Migration Model

To parameterise the migration equation of the CGE model unbiassed estimates of the response to LA property tax differences are required[12]. These are obtained from estimating a migration gravity specification that Anderson (2011) derives from microeconomic foundations, analogous to the trade gravity models (Anderson and Wincoop, 2003). The gross migrant flow depends first on the pattern of a 'frictionless' world. Here migrants from an origin would be found in equal proportions to their share of the population in all destinations. The additional element represents the effect of bilateral 'frictions' that reduce migration, such as travel and information costs that increase with distance between origin and destination, and tax differentials between origin and destination.

Following Ortega and Peri (2013) we control for the multilateral resistance to migration that is induced by heterogeneity in the preferences for type 2 and type 3 migration because of their skills. This empirically corresponds to estimating these gravity equations with LA origin dummies. Type 1 migrants in the CGE model, unlike types 2 and 3, are vulnerable to unemployment, they have lower skills and wages. Their destinations can be more problematic because of the availability and price of more affordable housing. Hence their controls are LA destination dummies.

The CGE net migration model allows the comparison of two static equilibria before and after a tax change. It does not allow any conclusion about how long the equilibrating process takes. For consistency in the gravity migration specification a tax change or differential will reconfigure equilibrium population until net flows, but not gross flows, between all localities are zero. When m_{ij} is gross migration from i to j and N the number of localities, the equilibrium condition is:

$$\sum_{i=1}^{N} m_{ij} = \sum_{j=1}^{N} m_{ij} \;...(1)$$

Other key features of the gravity equation specification are that bilateral gross migration flows from an origin to a destination location are divided by the 'masses' of the destination and origin locations (i.e. populations) and negatively related to the 'distance'. This avoids the problem of reverse causation bias in the regression that for instance Mitze and Schmitz's (2015), Danish municipality migration study address using lagged regressors[13]. However, their dependent variable is net in-migration to a region from all other regions in aggregate, by skill group. While the present study similarly considers separate (income tax) categories of migrants, we accept Stilwell's (2005) point in his migration modelling survey that it is preferable to allocate mi-

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[12] A recent example studying internal migration is Stillwell et al (2016), who use census data. The NHS based data used here is for a more recent year, 2015, instead of 2011.
[13] Their partial adjustment formulation would not be consistent with our CGE model.

grants from each origin to each destination because there are frequently important links between certain origin and destination pairs. The static spatial structure is further controlled by whether the origin and the destination LAs belong to the same region.

To analyse the effects on the three income types of taxpayers, the distribution of income tax at regional level is utilised 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 there is information on the distribution of income tax for the region to which a LA belongs, then this distribution can be used to calculate the shares of the three types of individuals ($k = 1,2,3$) in m_{od} to obtain m_{od}^k.

The effects of council tax differences on migration are found from the estimated equation (2),

$$\frac{m_{od}^k}{P_o \times P_d} = f(council\ tax\ diff_{d-o}, \ln(distance), within\ dummy, LA\ dummies) \ \ldots(2)$$

Relative taxation in equation (2) is not the jurisdictions' council (property) tax rates but an estimate of the tax paid by each taxpayer type as a proportion of their average house price. Reinforcing earlier assessments of endogeneity, tax differentials are unlikely to be 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 accounted for three quarters of LA revenues in 2014 was allocated on a needs basis and was intended to prevent that.

Between about half the pairs of the 348 LAs in England and Wales there was no migration in 2014[14]. The distribution is therefore heavily weighted towards zero unlike the normal distribution. This makes Poisson regression appropriate, with the over-dispersion bias controlled by robust standard errors (Winkelmann and Zimmermann, 1992; Santos Silva and Tenreyro, 2011)[15].

Table 1 presents the separate estimates of the Poisson gravity migration model for the three types of individuals. The coefficients may be interpreted as elasticities[16]. The key findings are that a higher council tax rate differential (destination minus origin) between destination and origin results in a lower immigration flow. The ordering of the coefficients from smallest for the lowest income group (type 1) to the highest for type 3 taxpayers is consistent with expectations from the sums at stake. Young adults were most likely migrants, with the biggest single peak (those aged 19) reflecting moves to start higher education (ONS, 2014). Students are not

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[14] The migration flows are based on the changes of NHS registrations within the U.K. Migration originating or ending outside England and Wales is not taken into consideration.

[15] Chen (2016) adopts a Heckman selection model to address the same problem in a migration gravity model.

[16] Broadly comparable to Agrawal and Foremny's (2018, p26) high income mover and stayers' elasticity of 0.08 and Akcigit et al. (2016) 's 0.03.

liable for council tax but are included in the migration data. This accounts for the statistical insignificance of the distance variable for type 1s. It may also boost the standard error of the tax coefficient for type 1 migrant flows and contribute to a small response to the tax differential for these people.

Table 1 Migration and Property Tax Rate Poisson Estimation Results

Regressor	Type 1	Type 2	Type 3
property tax rate differential	-0.0117***	-0.0199***	-0.0290***
ln(distance)	0.0462	-1.7349***	-1.7365***
within the same region	1.9134***	0.5181***	0.4540***
intercept	-2.0606***	4.2948***	2.1487***
No. of obs.	120756	120756	120756
log-likelihood of the model	-142827	-36210	-10986
log-likelihood of the null	-233835	-70820	-17935
pseudo R^2	0.389198	0.488704	0.387455

Notes: *** indicates statistical significance at 1%, ** at 5% and * at 10%. LA dummies are omitted. The formula for calculating Pseudo R^2 is: 1-ll/ll_0, where ll is log-likelihood of the model and ll_0 is log-likelihood of the null hypothesis (i.e. a model with constant only).

The property tax effect directly estimated from the gravity model above must be translated into the effect of the income tax differences with the help of the CGE model; that is, to answer the research sub-question (R2). The next section is devoted to the specification, calibration and simulation of such a structural model.

5. Tax-Induced Migration

To measure the counterfactual effects on migration flows to Wales of tax rates differentials, the effect for each LA is directly estimated and the individual impacts summed[17]. The net flow of migrants is the sum of bilateral gross flows between LAs in Wales and in England–ignoring flows between LAs in the same country. In this manner any asymmetry in the magnitudes of the two countries' population is accounted for during the aggregation of LAs. The near symmetry of responses to cuts and increases in tax rates is explained by the specification of the migration equation and the distribution of population along the border. The most substantial concentration of money and income in England is in London and the South East of England, a considerable distance from the border. The migration equations show that type 2 and type3

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[17] The migration effect is calculated using the predicted/fitted values of the Poisson regression for new property tax rates, which reflect the equivalent effects of a given income tax change. For all pairs involving Welsh LAs, the values of the tax differential are adjusted, while keeping unchanged those only involving English LAs. The total migration effect for Wales is then found by aggregating across Welsh LAs with the relevant within Wales intra-LA effects excluded. This approach was checked against the alternative of estimating an average marginal effect for all the LAs in Wales and then multiplying it by the number of LAs to obtain the aggregate effect on Wales. The two methods give very similar results.

flows are lower between distant LA pairs; for much of the large English population, Wales is too far away to enter locational calculations.

Figure 1 The Effects of Changes in Income Tax Rates on Migration
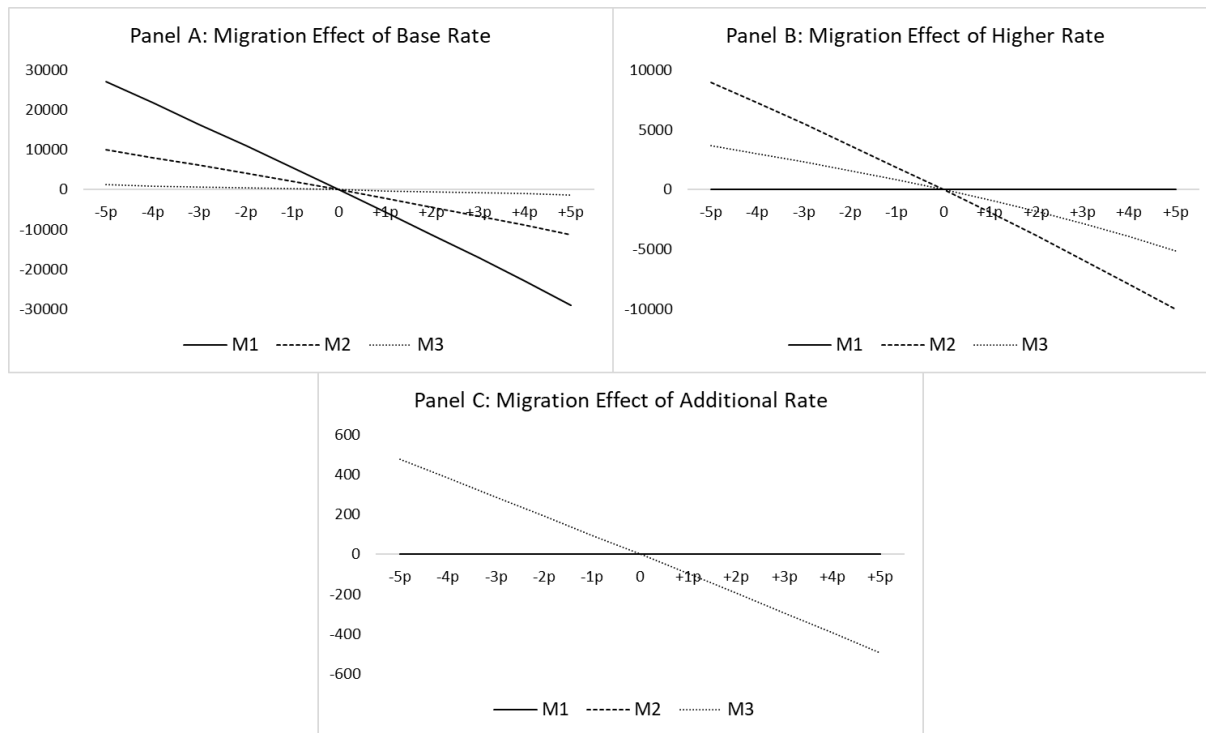
Notes: The panels show the relationships between changes in income tax rates (horizontal axes) and changes in migration flows into Wales (vertical axes).

A change in BR (Basic Rate of income tax, 20%) affects all three types of individuals, a change in HR (Higher Rate of income tax, 40%) will affect types 2 and 3, and AR (Additional Rate of income tax, 45%) only affects type 3. By contrast, the effect of council tax is selective and exclusive to each type; for instance, a specific property tax only affects type 1 individuals and similarly for type 2 and type 3 taxpayers. Therefore, to obtain the equivalent effect of a change in income tax, all three property (council) tax rates must be utilised.

Sensitivity of migration depends on which taxable income component is the greater part of total income for the taxpayer type. But movement volumes also depend on the number in the taxpayer category. So, the number of type 1 taxpayers (by far the largest group[18]) is most sensitive to a change in BR; a 1p increase in income tax triggers an eventual total out-migration of just under 6000 (panel A figure 1) but this is a very small proportion of type 1 taxpayers. By contrast only a little over 2000 of the wealthier type 2 eventually move out (Panel A figure 1) but type 2 are a much smaller group so their proportionate response is stronger. The richest

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[18] We estimate type 1 taxpayers at 1.2854 million, type 2 at 0.144 million and type 3 at 5000.

(type 3) are not very responsive to differences in the BR, because most of their income is not in the lowest tax bracket (and there are very few AR taxpayers).

Differences in the HR of tax have a marked effect on HR taxpayers (type 2) (Figure 1 Panel B); just under 2000 eventually relocate in response to a 1p rise. But the proportionate effect is stronger for type 3 (AR) taxpayers for whom under 1000 move. Almost £110,000 of their income (=£150,000-£42,385) would be subject to a different tax rate if the HR changed. They must have an income over one quarter of a million pounds to be similarly affected by a comparable AR change. As panel C Figure 1 shows, only a small number of (exclusively type 3) taxpayers move in or out in response to AR rate changes.

6. Impact of Devolved Tax Differentials on Tax Revenue and Output per Capita

The CGE model equations are re-solved after re-setting income tax rates ranging from 5p in the pound lower than the prevailing rates to 5p higher. The implied changes in migration are simulated using the gravity model with the help of the relationship between income and council tax rates indicated by the CGE model. Because Wales is a small open economy (the population of England is about eighteen time larger than Wales') and to keep the exercise reasonably simple, wage levels are fixed for all three types of individuals; their wages are ultimately set by migration and trade with the wide world. Local policies, such as tax, determine long run equilibrium population and the migration necessary to achieve it.

Net immigration to the decentralised economy raises private and/or government production, depending on the distribution between activities. The allocation ultimately is governed by household demand. By changing the tax bases, migration also influences all tax yields of central and local government, as well as devolved income tax yield. Here originate possible divergences of interest between central and devolved governments.

With the extent of the income tax devolution permitted, the offsetting migration responses from BR changes are small proportionately (Figure 2). The devolved government's income tax revenue is a percentage of total jurisdiction income tax revenue, so the total follows the same pattern as the devolved revenue. The 'mechanical effect' entirely dominates. In the status quo total tax revenue generated in Wales is £20.14 bn, income tax generated in Wales is £4.88 bn and income tax kept in Wales is £1.96 bn. Therefore, in Figure 2, if BR rises by 5p, income tax generated in Wales will rise by 8.02% (i.e. from £4.88 bn to £5.27 bn, about 2 percentage points less than the mechanical effect)[19]. Income tax kept by Wales will rise by 30% (from £1.96 bn

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[19] Compared with the mechanical effect of 10.44% and the migration effect of -2.42%. The income tax revenue is defined as: $IT \equiv (w1 - \kappa_{IT1}) \times \tau_{IT1} \times L_1 \times (1 - u) + [(\kappa_{IT2} - \kappa_{IT1}) \times \tau_{IT1} + (w2 - \kappa_{IT2}) \times \tau_{IT2}] \times L_2 + [(\kappa_{IT2} - \kappa_{IT1}) \times \tau_{IT1} + (\kappa_{IT3} - \kappa_{IT2}) \times \tau_{IT2} + (w3 - \kappa_{IT3}) \times \tau_{IT3}] \times L_3$, where numerical subscripts indicate taxpayer type, w wages, κ_{IT} is tax free income component, τ_{IT} is the income tax rate, u unemployment rate and L number of taxpayers. Using the total differentiation formula:

to £2.55 bn), but total tax revenue generated in Wales drops by 1.9% (from £20.14 bn to £19.76 bn). For income tax, the mechanical effect dominates migration effect, while for total tax revenue, migration effect dominates because the change in population also affects all the other tax revenues generated in Wales.

For HR changes, the asymmetric pattern between income tax generated in, and kept by, Wales occurs because the mechanical effect for devolved income tax is greater than the migration effect; the contribution share of tax change is greater for devolved income tax than for total income tax generated in Wales. Increases or decreases in the AR appear to have minimal effect on tax revenue because behavioural responses exactly offset mechanical effects (Figure 2).

Figure 2 Revenue and Productivity Effects of Changes in Income Tax Rates
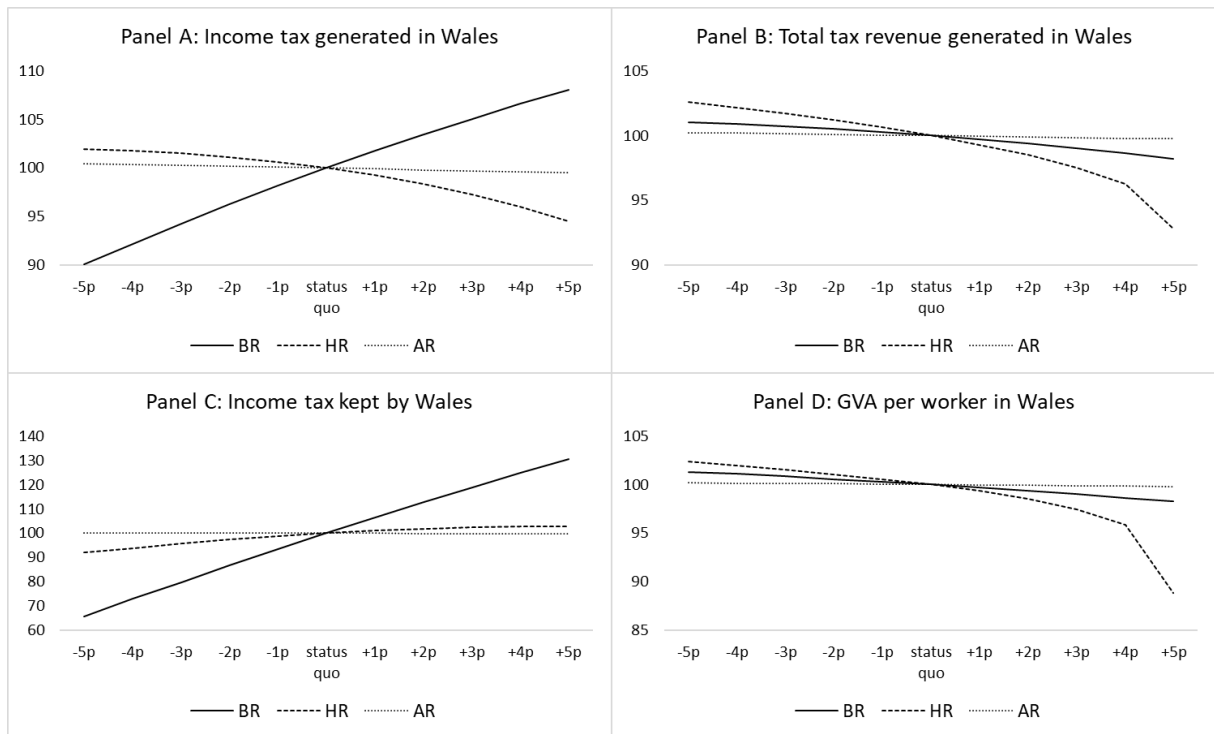
Notes: Panel A, 100 = £4.88 billion; Panel B, 100 = £20.14 billion; Panel C, 100 = £1.96 billion; Panel D: 100 = £37,881.

The response of GVA per worker in the jurisdiction is substantially different (Panel D). Tax-induced migration alters the proportions of taxpayer types in the population and, since they have different productivities, average productivity of the economy responds to tax changes (see

$$\Delta IT = \frac{\partial IT}{\partial \tau_{ITk}} \Delta \tau_{ITk} + \sum_{k=1}^{3} \frac{\partial IT}{\partial L_k} \frac{\partial L_k}{\partial \tau_{ITk}} \Delta \tau_{ITk}, \text{ where } k = 1,2,3.$$

For example, under fixed wages, if there is a change in BR (τ_{IT1}), then there are two simultaneous effects: a mechanical effect: the first term directly due to the rise in τ_{IT1}, and a migration effect: the second term indirectly due to the drop in L_1.

Appendix). A BR rate increase affects all taxpayers; the _proportional_ effect is greater on (higher productivity) type 2s than type 1s.

Panel B shows that the consequences for total tax revenue–not surprisingly–are very similar to those for output per worker. Since the central government bears the loss of total tax revenue from a BR or HR tax rise in this case, while decentralised government revenue increases, there is a divergence of interests between the two tiers of government in setting the HR and BR of devolved income tax. Tax-induced migration has a muted effect on devolved government revenues in this scenario because such a small proportion of revenue is decentralised. The 'externality' effects on the tax revenue generated by the devolved economy are greater, but devolved government revenues are largely insulated from them.

In principle this divergence might be resolved by full tax decentralisation, but other considerations are likely to militate against such a solution. They include the devolved revenue consequences of possible adverse asymmetric shocks that the central government wishes to alleviate. Instead of creating tax differentials, the efficiency objective of tax devolution would be achieved if the decentralised jurisdiction devoted policy to expanding the tax base.

As a robustness test of the model we simulated the model with an elasticity of substitution in consumption lower and higher than our estimated value by 10 percent (Appendix D). The revenues were within 2 percent of our best estimates except for HR changes, where increases of more than 2p could not be computed.

7. Conclusion

Given tax autonomy, decentralised governments may want to change the structure as well as the rates of their taxes. To predict possible outcomes, this paper has described and implemented a novel approach to estimating the fiscal consequences of possible tax rates set by devolved governments before they have exercised their policy freedom (and thus where no direct empirical evaluation is possible). The approach provides an indication of how important induced migration might be.

The method developed in this paper can be employed for different sub-national taxes from those considered here. For example, 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. Even though extrapolation beyond the range of variation of the smaller sub-national tax may be hazardous the proposed method is likely to be the most reliable available approach to projecting tax yields when future tax rates diverge.

The tax revenue results here 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 (including migration) response' to Welsh Higher Rate income tax changes will eventually offset the 'mechanical effect' for devolved government revenue. But an important caveat is that the present modelling does not permit a judgement about how long the return to equilibrium would take.

The extent of fiscally-induced migration will always depend upon the distribution of population relative to jurisdiction borders. Also, for taxpayers to be responsive, large enough sums must be at stake. Hence higher income taxpayers are more likely to move. Such earners will generally create more employment and output; their migration will have a larger impact than their numbers at first sight might suggest. Changes in devolved tax rates therefore may in some circumstances yield considerably more or less tax revenue than 'mechanical' estimates indicate. The potential mobility of the tax base may incentivise devolved economies to enhance the base directly rather than to alter higher income tax rates. In any event the possibility that the 'migration effect' dominates the 'mechanical effect' ensures that tax devolution looks less attractive to a decentralised government than simply delegated expenditure.

Limited or partial tax devolution dampens the fiscal impact of induced migration, or any tax base change, on the devolved government revenue. The consequences of devolved tax and tax base alterations in this instance are also felt by the central government revenues and the devolved economy. The incentives given to the devolved government to ignore these spill-over effects when choosing tax rates and policy are not efficient. But the risk of adverse tax revenue shocks restricted to the decentralised jurisdiction may still provide a rationale for central government not granting complete tax devolution.

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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 (2015, 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 CGE Model of the Devolved Economy

The Consumer

There are three types ($i = 1, 2, 3$) of consumers/taxpayers and wage (w_i for pre-tax wage, ω_i for after-tax wage). Everyone receives a lump-sum benefit (bf) from the government common to all types. Utility depends on the private goods (z_i), composed of housing (h_i) and other private consumption (c_i), and public goods provided by the local governments (G) such as education and healthcare. Note that the income redistribution, such as jobseeker's allowance $\underline{\omega}$ for the unemployed (u is the unemployment rate relevant only to type 1 low-income consumers), is paid directly by the central government, so it can be treated as exogenous. There are different types of tax rates (τs) under different income thresholds (κs), which are summarised in Table A1 (as of 2014).

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

Table A1 Combined Bands for Income Tax Rates and NI Rates

The maximisation problem of a low-income (type 1) consumer 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) Budget Constraint: $(1-u)\omega_1 + u\underline{\omega} + bf = p(1+\tau_C)c_1 + p_{H1}(1+\tau_{H1})h_1$

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

(H1.3) 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 maximisation problem of a middle-income (type 2) consumer 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) Budget Constraint: $\omega_2 + bf = p(1+\tau_C)c_2 + p_{H2}(1+\tau_{H2})h_2$

$$\text{(H2.2) Income:} \quad \omega_2 = \kappa_{NI1} + \left(\kappa_{IT1} - \kappa_{NI1}\right)\left(1 - \tau_{NI1}\right) + \left(\kappa_{IT2} - \kappa_{IT1}\right)\left(1 - \tau_{NI1} - \tau_{IT1}\right)$$
$$+ \left(w_2 - \kappa_{IT2}\right)\left(1 - \tau_{NI2} - \tau_{IT2}\right)$$

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

And the maximisation problem of a top-income (type 3) consumer is:

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

$$\text{(H3.1) Budget Constraint:} \quad \omega_3 + bf = p\left(1 + \tau_C\right)c_3 + p_{H3}\left(1 + \tau_{H3}\right)h_3$$

$$\text{(H3.2) Income:} \quad \omega_3 = \kappa_{NI1} + \left(\kappa_{IT1} - \kappa_{NI1}\right)\left(1 - \tau_{NI1}\right) + \left(\kappa_{IT2} - \kappa_{IT1}\right)\left(1 - \tau_{NI1} - \tau_{IT1}\right)$$
$$+ \left(\kappa_{IT3} - \kappa_{IT2}\right)\left(1 - \tau_{NI2} - \tau_{IT2}\right) + \left(w_3 - \kappa_{IT3}\right)\left(1 - \tau_{NI2} - \tau_{IT3}\right)$$

$$\text{(H3.3) Private Goods Nesting:} \quad z_3 = \left[\beta_3 c_3^{\frac{ss_3-1}{ss_3}} + \left(1 - \beta_3\right)h_3^{\frac{ss_3-1}{ss_3}}\right]^{\frac{ss_3}{ss_3-1}}.$$

The Producer

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

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

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

The Government

The budget constraint of the Welsh government is[20]:

$$T_H + \left(T_{ITWales} + B_{UK}\right) = G$$

The term in the brackets was the original block grant from Whitehall, which did not distinguish between the income tax kept in Wales ($T_{ITWales}$) and the other part (B_{UK}) before the devolution. However, after the 2014 Act, the two items could be explicitly separated to allow for different

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[20] Under the Wales Act 2017 the Welsh government can borrow up to £1 billion from central government but this must be used only for capital expenditure which is not considered in this static model.

income tax rates in Wales. In the status quo, the Welsh government is entitled to 10p in the pound of the yield of Welsh income taxes, i.e. the Basic Rate, the Higher Rate and the Additional Rate. For example, the Higher Rate is currently 40p in the pound, so 10p in the pound is kept by Welsh government as part of $T_{ITWales}$. If they decide to raise the Higher Rate in Wales to 41p in the pound, then 11p in the pound will be kept.

(G1) Council Tax Generated and Used in Wales:

$$T_H = p_{H1}\tau_{H1}h_1L_1 + p_{H2}\tau_{H2}h_2L_2 + p_{H3}\tau_{H3}h_3L_3$$

(G2) Income Tax Kept in Wales:

$$\begin{aligned}
T_{ITWales} = &\left(w_1 - \kappa_{IT1}\right)\left(\tau_{IT1} - 10\%\right)L_1\left(1-u\right)\\
&+\left[\left(\kappa_{IT2} - \kappa_{IT1}\right)\left(\tau_{IT1} - 10\%\right)+\left(w_2 - \kappa_{IT2}\right)\left(\tau_{IT2} - 30\%\right)\right]L_2\\
&+\left[\left(\kappa_{IT2} - \omega_{IT1}^*\right)\left(\tau_{IT1} - 10\%\right)+\left(\kappa_{IT3} - \kappa_{IT2}\right)\left(\tau_{IT2} - 30\%\right)+\left(w_3 - \kappa_{IT3}\right)\left(\tau_{IT3} - 35\%\right)\right]L_3
\end{aligned}$$

(G3) Income Tax Generated in Wales:

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

(G4) National Insurance Contributions Generated in Wales:

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

(G5) Consumption VAT Tax Generated in Wales:

$$T_C = p\left(\tau_C c_1 L_1 + \tau_C c_2 L_2 + \tau_C c_3 L_3\right)$$

(G5) Corporation Tax Generated in Wales:

$$T_F = \tau_F \Pi.$$

The total tax revenue generated in Wales is $T_{Wales} = T_H + T_{IT} + T_{NI} + T_C + T_F + T_O$, where T_O captures all other tax revenues. It only accounts for a little over 60% of the total government expenditure in Wales (including public goods, pension and welfare benefits).

The remaining expenditure is subsidised by English taxpayers, equivalent to a payment of almost £4000 to each person in Wales. We assume the UK government will fix the block grant, so G can be endogenously derived from the budget constraint.

Model Closure

To solve the model, we need to provide model closure conditions and specify which variables are exogenous. Consumers and firms maximise their objective functions treating the following variables as exogenous: w_i, G, L_i, u.

- Wages (w_i). Imposing the labour markets clearing conditions will determine wages (equivalent to equating wages from the consumers' first order conditions (FOCs) and from the firms' FOCs).
- Government Expenditure on Public Goods (G). The aggregate supply (Y) is demanded for consumption (of the three types of labour force and the pensioners PS), investment (I), or government expenditure on public goods (G). The gap between the supply and demand in Wales is filled by NT[21], which is the net transfer from the rest of the UK. Pensioners' consumption component PS is assumed to be fixed and investment I is assumed to be fixed as a proportion of GDP. Public goods (G) are endogenously determined in the Welsh government's budget constraint. Therefore, imposing the goods market clearing condition will determine the net transfer to Wales (NT) from the rest of the world.
$$Y = \left[\left(c_1 + h_1 \right) L_1 + \left(c_2 + h_2 \right) L_2 + \left(c_3 + h_3 \right) L_3 + PS \right] + I + G \left(L_1 + L_2 + L_3 \right) + NT.$$
- 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 consumer type i and M_i is estimated using the econometric model.
- Unemployment Rate (u). This is exogenous because the economy is modelled in long run equilibrium with unemployment at its equilibrium rate
- Goods Price (p) and House Price (p_{Hi}). Following CGE modelling convention, both are set to 1, so that the quantities can be interpreted as the expenditures[22]. Thus, c_i is interpreted as the total expenditure on consumption and h_i is the total expenditure on housing.

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[21] NT is not to be confused with B_{UK}. The latter is transferred to the Welsh government, so it balances the Welsh government's budget constraint. While the former is transferred from the English good market to the Welsh goods market, and it balances aggregate supply and aggregate demand in the goods market in Wales.

[22] Housing (like consumption, investment and G) is a part of Y. There is only one "homogenous" output which can be used for all purposes (including housing). This output is also the numeraire goods for denominating the other price (real wage) in the model.

There are 27 competitive equilibrium conditions for the 30 endogenous variables: $c_1, h_1, \omega_1,$ $z_1, u_1, c_2, h_2, \omega_2, z_2, u_2, c_3, h_3, \omega_3, z_3, u_3, w_1, w_2, w_3, \Pi, Y, I, NT, T_C, T_H, T_{NI}, T_{IT}, T_F, T_{ITWales}$, T_{Wales} and G. There are 12 exogenous variables: $B_{UK}, PS, u, L_1, L_2, L_3, \bar{L}_1, \bar{L}_2, \bar{L}_3, M_1, M_2$ and M_3. Moreover, there are 11 parameters to be calibrated: $\beta_1, \beta_2, \beta_3, ss_1, ss_2, ss_3, \gamma_1, \gamma_2, \gamma_3, \sigma$ 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 un-observable 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 τs, κs, bf and $\underline{\omega}$ are all known and set at their actual values.

Using the technique of optimal calibration, the estimated structural parameters governing the behaviour of the consumers and firms are summarised in Table A2:

Parameter	Meaning	Estimate
β_1	Utility share of consumption (type 1)	0.950
β_2	Utility share of consumption (type 2)	0.276
β_3	Utility share of consumption (type 3)	0.519
ss_1	CES between consumption and housing (type 1)	0.236
ss_2	CES between consumption and housing (type 2)	0.363
ss_3	CES between consumption and housing (type 3)	1.678
γ_1	Income share of type 1 labour/individual	0.639
γ_2	Income share of type 2 labour/individual	0.329
γ_3	Income share of type 3 labour/individual	0.032
σ	CES between the three types of labour	1.056
A	Total factor productivity	79.19

Table A2 Estimated Structural Parameters using Optimal Calibration

Appendix C: Extended Monte Carlo Simulation

The distribution of house price in Figure A1 is based on the 165,822 properties in England and Wales recorded by the Land Registry.
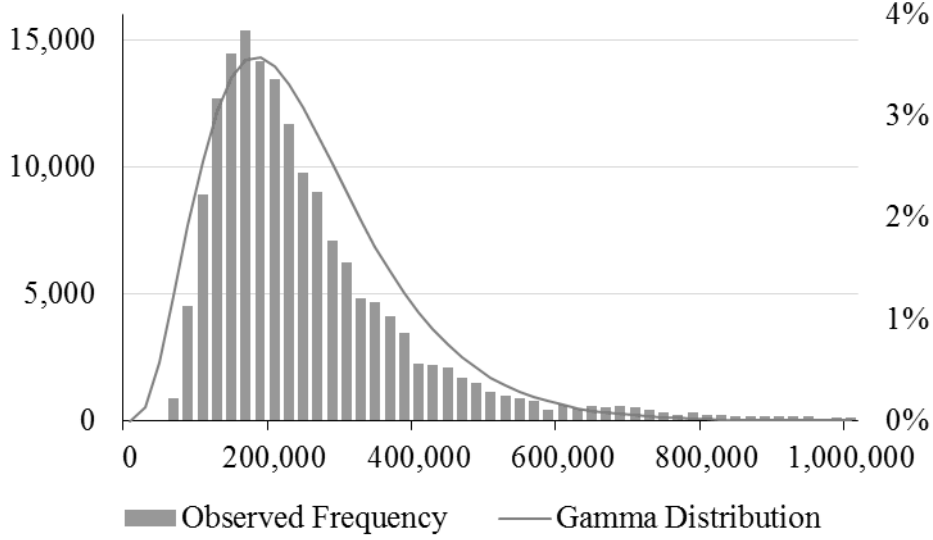
Figure A1 Distribution of House Prices in England and Wales (2010)

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.

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

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.

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

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.
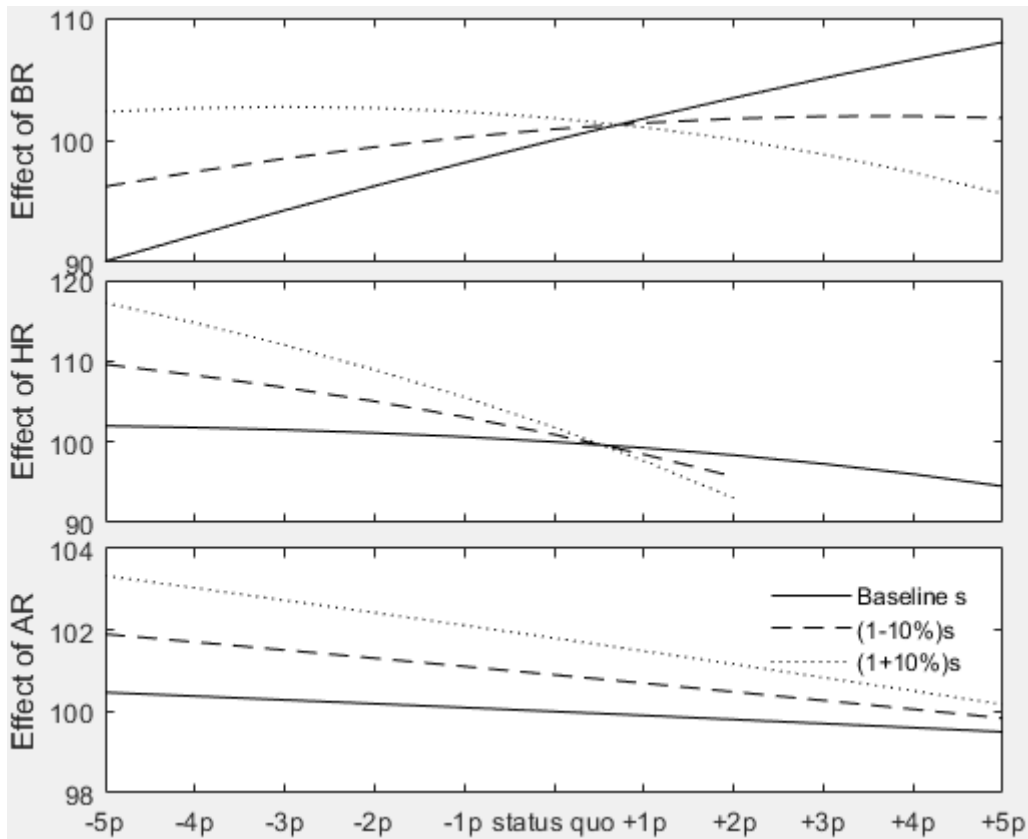
Appendix D: Robustness of Conclusions

Figure A2: Robustness Check when the Elasticity of Substitution (s) Varies

As a robustness test, we have simulated the model with 10% deviations in either direction from the best estimate of the elasticity of substitution of the utility function. In the attached for the Appendix D, although the curvature in response to different rates of income tax differs, it can be seen that the qualitative conclusions are unchanged. With the two boundary elasticities, it is not possible to get an effect for HR beyond an increase of 2p.
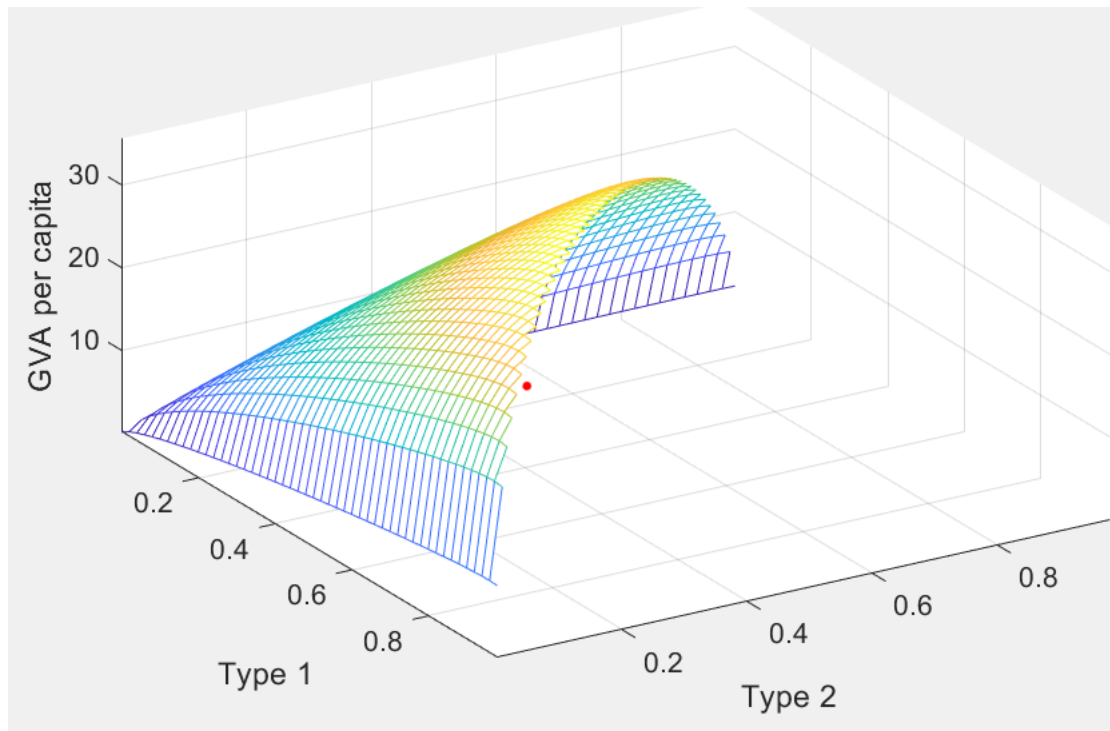
Figure A3: Visualisation of the Production Function (the red dot: status quo)

The figure represents the relation between taxpayer type shares and productivity. The horizontal axes are proportions of type 1 and type 2 and the vertical axis is the GVA per capita (in thousands). The red dot is the current position. If the share of type 2 is reduced by tax-induced migration, the average GVA will drop because of the lower productivity (wages) of type 1 taxpayers.