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CAN AN AGEING SCOTLAND AFFORD INDEPENDENCE?

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Can an Ageing Scotland Afford Independence?

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Abstract

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1. Introduction

In the light of the current Scottish independence debate, much attention is being paid to whether Scotland and the rest of the UK will be better off after the separation. Fiscal challenges are often quoted as a strong argument against independence. Demographic processes play an important role in determining future economic growth via their impact on labour market, saving behaviour and government budget. One of the arguments that have been raised during the debate is that Scotland is in a worse demographic situation than RUK, and independence will make it harder for it to provide for its ageing population. In 2012, the old-age dependency ratio[1] (OADR) in Scotland and the rest of the UK was the same at 29%. However, in the future the Scottish population is projected to age more rapidly, and by 2037 OADR in Scotland will reach 48%, while in RUK 45%[2]. However, by 2050 OADR in two regions will converge again.

This paper uses a dynamic multiregional Overlapping Generations Computable General Equilibrium (OLG-CGE) model for Scotland, the rest of the UK (RUK) and the rest of the World (ROW) to evaluate demographic scenarios for Scotland and RUK with and without independence. The model is in the Auerbach and Kotlikoff (1987) tradition and introduces age-specific mortality following Borsch-Supan et al. (2006). This modification allows precise replication of the population structure from any population projection and dramatically improves the accuracy of demographic shocks.

The model features rational optimising agents, life-cycle profiles of consumption and savings, competitive markets for goods and factors of production, perfect mobility of goods and financial capital across the three regions. Government expenditures in each region are divided into four categories: age-independent spending and expenditures on health, education, and pensions, which are sensitive to the age structure of the population.

We use the 2012-based principal population projections produced by the Office for National Statistics (ONS) as an exogenous demographic shock for Scotland and RUK. The status quo scenario assumes that Scotland stays part of the UK and all government expenditures associated with ageing population (mainly pensions and health) are funded on a UK-wide

[1] Here defined as population aged 65+ divided by population aged 20-64.
[2] According to the 2012-based ONS principal projection.

basis. In terms of modelling, this means that there is one joint government budget constraint for Scotland and RUK and all tax rates and public debt to GDP ratio are equal across the two regions. At the same time, other sectors of the economy – household and production – are differentiated between the two regions although they are linked via capital mobility and trade.

According to the status quo scenario, population ageing has a strong impact on economic development in both regions. By 2060 output per person falls in Scotland and RUK by 10% and total government spending increases by 4 percentage points of GDP. To achieve government budget balance the effective labour income tax rate has to increase from about 13.0% to 21.5%.

To show the effects of potential Scottish independence we compare results from the status quo scenario with the independence scenario. In the independence scenario, RUK and Scotland have separate government budget constraints and each of them has to pay for the growing demands of the ageing population independently. As expected, Scotland is worse off in the case of independence, although the difference with the status quo scenario is not large, especially comparing it with the overall effect of the demographic shock. The greatest difference is in 2035 and at this point the effective labour income tax rate in Scotland is 1.4 percentage points higher in the independence scenario compared with the status quo scenario. The difference is non-negligible but it is much smaller than the effect of population ageing itself. For comparison, by 2060 the effective labour income tax rate increases by 8.5 percentage points in the status quo scenario.

The rest of the paper is organised as follows. Section 2 gives a brief overview of the model and calibration strategy. Section 3 presents results and sensitivity analysis. And finally Section 4 concludes with discussion.

2. The model

The model economy is made up of three regions: Scotland, the rest of the UK (RUK) and the rest of the World (ROW), which closes the model and combines North America, Europe (EU-

15), China, India and Japan. This section briefly describes the production, household and government sectors, international trade and the market equilibrium conditions in an unspecified region. We also discuss modifications made to the model for the status quo scenario when Scotland and RUK are parts of one country. We complete the section with a brief discussion of the calibration and the demographic projections of the regions of the model. Model equations referred to in the text are presented in the Appendix. Table A1 contains model variables and parameters.

3.1 Demographic Structure

A period in the model corresponds to five years. The population is divided into 21 generations or age groups (i.e., 0-4, 5-9, 10-14, 15-19, …, 100-104). Demographic variables – fertility, mortality and net migration rates – are assumed to be exogenous. Every cohort is described by two indices. The first is t, which denotes time. The second is gg, which denotes a specific generation or age group.

The size of the cohort belonging to generation gg in any period t is given by two laws of motion (eq.1). The first implies that the number of children born at time t is equal to the size of the first adult age group at time $t-1$ multiplied by the "fertility rate" in that period. The second law of motion gives the size at time t of any age group gg beyond the first generation, as the size of this generation a year ago times the sum of the age specific conditional survival rate and the net migration rate at time $t-1$. In this model the fertility rates vary across time, while the survival and net migration rates vary across time and age. For the final generation, the conditional survival rate is zero. This means that everyone in the oldest age group in any period dies with certainty at the end of the period.

Time-variable fertility, and time/age-variable net migration and conditional survival rates are calibrated based on exogenous population projections. This permits a precise modelling of the demographic scenario of any configuration within the model.

3.1 Production sector

In each region *j*, a representative firm produces at time *t* a single good using a Cobb-Douglas technology (eq.2). The firm hires effective units of labour and rents physical capital. Both factors are region-specific. Firms are perfectly competitive and factor demands (eq.3 and 4) follow from profit maximization.

3.2 Household behaviour

Household behaviour is captured by 21 representative households that interact in an Allais-Samuelson overlapping generations structure representing each of the age groups. Children (first four generations) are assumed to be fully dependent on their parents and play no active role in the model. However, they do influence the public expenditure. All individuals within 5-year age cohorts, *gg,* are assumed to be identical. Therefore, the model portrays 21 representative individuals that characterise the behaviour of the 21 cohorts. These individuals are assumed to be forward-looking, to have perfect foresight, and to behave in a manner that maximises their lifetime utility.

An individual who begins an active economic life in region *j* at time *t* chooses a profile of consumption over their life cycle, in order to maximize a CES type inter-temporal utility function (eq.5) subject to the dynamic budget constraint (eq.6). In addition to the conventional discounting factor, future consumption is also discounted for the unconditional survival rate, which is the probability of survival up to a certain age. This means that individuals value consumption in future years less because there is a non-zero

probability that they will not survive to that time. And this probability of dying increases with age. The household is not altruistic, i.e. it does not leave intentional bequests to children. However, it leaves unintentional bequests due to uncertain life duration. The unintentional bequests are distributed through a perfect annuity market, as described theoretically by Yaari (1965) and implemented in an OLG context by Boersch-Supan et al. (2006). Differentiating utility function under the life-time budget constraint yields the first-order condition for consumption (eq.7).

Labour income is defined by eq.8 where a distinction is made between exogenous supply of physical units of labour (*LS*) and effective labour supply, which takes into account the individual's age-dependent productivity (earnings) profile ($EP_{j,gg}$). Productivity profile is defined as a quadratic function of age (eq.9).

3.3 International trade

Trade in goods is introduced in the model by assuming that each region produces one single good, which is an imperfect substitute to the good produced in any other region – the Armington (1969) assumption.

Therefore, in the intra-temporal optimisation, final demand (consumption, government spending and investment) is allocated across the three imperfectly substitutable regional final goods using CES function. Eq.10 gives the final demand of region *j* for a region *i* good. The composite price index is consistently defined as a non-linear weighted average of the regional output prices (eq.11).

3.3 Saving instruments, asset returns and investment

Household saving can be "invested" in government bonds (issued to finance public debt) and capital shares (issued to finance physical capital formation). The accumulation of each

region's capital stock is given by the usual law of motion subject to depreciation (eq.12). In this model we assume perfect substitution between domestic assets (physical assets and governments bonds), and perfect financial capital mobility across regions. The *ex ante* rate of return on physical capital (purchased at time *t*-1 and rented to firms throughout period *t*) is the real rental price of capital (expressed in terms of the price of the investment good) plus the expected capital gains, net of depreciation cost (eq.13). The *ex ante* rate of return on government bonds (issued at end of *t*-1 and held throughout period *t*) is the promised rate of return on a zero-coupon bond, plus its expected capital gains (eq.14). Perfect substitution between domestic assets implies that the expected rate of returns on physical capital and government bonds will be equalised in each region. Perfect financial capital mobility across countries implies that the expected rate of returns of all regions will be equalised *ex ante* leading to a unique world interest rate (eq.15).

3.4 Government sector

The government budget constraint is given by eq.16 with a budget balance including different categories of government spending, public pensions, debt servicing (plus the refinancing of the entire stock of one-period debt at current prices) and tax revenues from different sources.

There are three categories of government spending. Spending on health and education are assumed to be constant in real terms per person of specific age, i.e. the total amounts depend on the age structure of the population (eq, 18 and 19). The third category of government spending is assumed to be age-independent, i.e. constant in real terms per person (eq.17). Thus, population changes imply adjustments in total real government spending. The pension program is a part of the overall government budget. It is assumed

that the level of public pension is indexed to wages (eq20).The model imposes the condition that governments target a constant debt-to-GDP ratio. This requires that one of the tax rates endogenously adjusts every period. We use for that the effective labour income tax rate. Other tax rates (i.e. on capital and consumption) remain constant.

3.5 Market equilibrium and aggregation conditions

The model assumes that all markets are perfectly competitive. The equilibrium condition for the goods market is that each regional output must be equal to total demand originating from all regions as well as internal demand for health and education services provided by the government, which are assumed to be non-tradable (eq.21). Labour and physical capital are immobile across regions and a market exists for these two factors in each region (eq.22 and 23). The world financial capital market must be in equilibrium, that is, the world stock of wealth (*Lend*) accumulated at the end of period *t* must be equal to the value of the world stock of government bonds and stock of physical capital at the end of *t* (eq.24). The current account of region *j* can be derived from this model as the difference between national saving (private saving of all generations and public saving) and domestic investment (eq.25)[3].

3.6 Scotland and RUK as one country

The model presented so far was for an unspecified region in case that all of them are independent. However, in the status quo scenario when Scotland stays part of the UK the model is slightly different. The only differences are within the government sector. In this

[3] Alternatively, the current account is either given as the trade balance plus the interest revenues from net foreign asset holdings, or as the difference between nominal GNP (GDP including interest revenues on net foreign assets) and domestic absorption. All three alternative formulations have been used as an internal check.

case, Scotland and RUK have joint government budget constraint (eq. 16'). All tax rates and public debt-to-GDP ratio are equal between Scotland and RUK.

3.7 Calibration

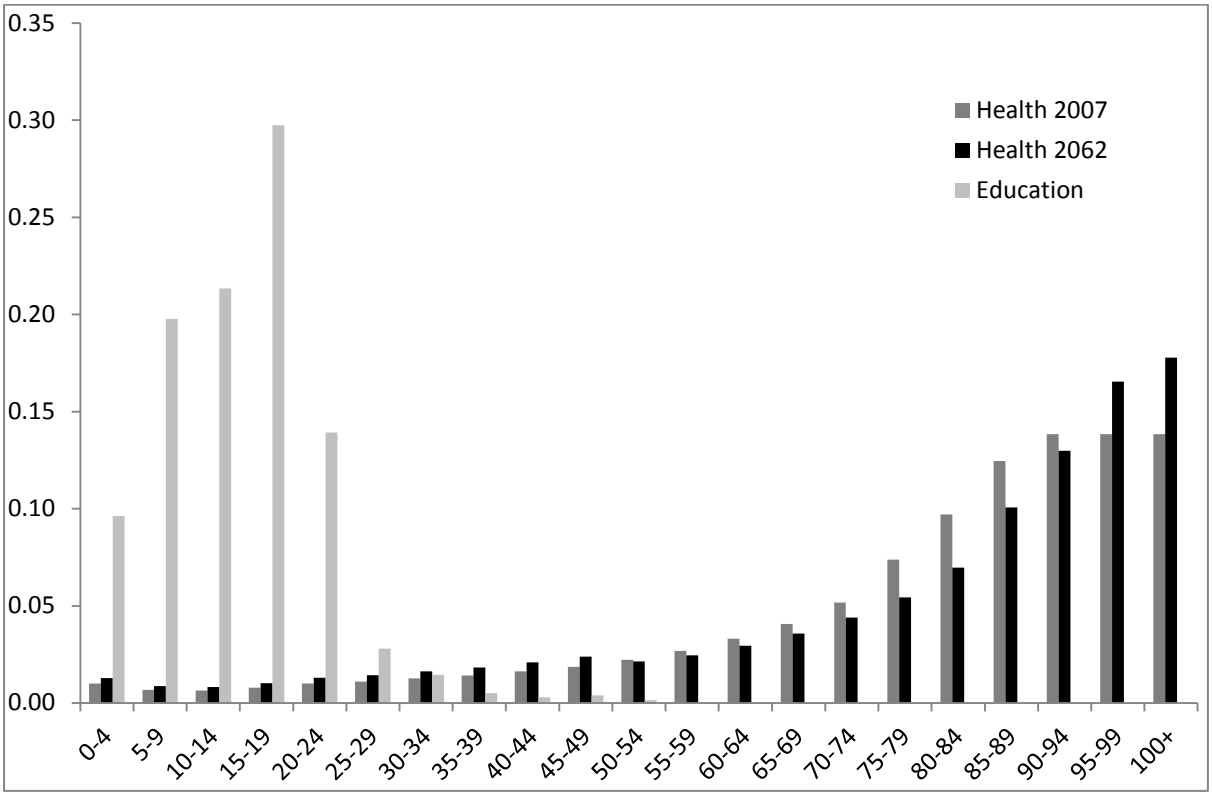
The Scotland and RUK models are calibrated using 2010 data. The calibration procedure contains four steps. In the first step we use accounting and survey data to calculate various parameters of the model. The data on public finances, GDP components and international trade are taken from the ONS, HM Treasury and Scottish Government (input-output tables and Government Expenditure and Revenues Scotland (GERS)). The effective labour income, consumption and capital tax rates are calculated from the corresponding government revenue categories and calibrated tax bases. Data on total amount of pensions are taken from the Government Actuarial Department (GAD). Based on this information, the effective pension contribution rate and the average size of pension benefits can be obtained. The average amount of pension benefits per person is obtained by dividing the total amount of pension benefits by the total number of people of pension age. For simplicity, it is assumed that both males and females start receiving pension benefits at the age of 65.

The source of the labour market data is the Labour Force Survey (LFS). Two labour market characteristics are derived from the data: age-specific employment rates and age-specific productivity profiles. The latter are estimated via the use of age-earning regressions of the Mincerian type (Mincer, 1958).

The estimates of the age structure of government spending on health and education are taken from the UK National Transfer Accounts for 2007, constructed by McCarthy and Sefton (2010). Figure 1 shows the age profiles of public spending on health (dark grey) and education (light grey) in the UK in 2007. The majority of education spending occurs between

the ages 5-9 and 20-24. Health spending grows slowly until the age of 55-59 when it starts increasing much faster, and accelerates after age 75-79.

Figure 1. Age Distribution of Health and Education Expenditure per Person, UK. 2007



Source: McCarthy and Sefton (2010), own calculations

There is a growing literature that argues that health spending depends not on age but on proximity to death (Zweifel et al, 1999; 2004; Grey, 2005). To account for increasing life expectancy, we extrapolate 2007 health spending profile for future year. The key assumption that we make is that one year increase in life expectancy corresponds to one year increase in healthy life expectancy. Starting from the age of 50, one year improvement in longevity results in shifting of health profile one year back. For example, when life expectancy increases by 1 year, the level of health spending for a 50 year old is the same as

was for a 49 year old before the improvement in longevity. ONS provides detailed mortality assumptions with its population projection up to 2062. Between 2007 and 2062 life expectancy at birth for males and females combined is projected to increase by over 9 years in Scotland and RUK. The black bars in Figure 1 show adjusted health spending profile for 2062. It is assumed that after 2062 there will be no further improvements in longevity and health spending profile will stay the same.

Calibration of the rest of the world is much less precise both because of a lack of some of the data and less importance for this application. The main source of data for ROW is the GTAP-8 database (Narayanan et al. 2012). The rest of the parameters are either omitted (e.g., public consumption is not disaggregated into categories) or calibrated to give plausible results (e.g., tax rates).

The intertemporal elasticity of substitution ($1/\gamma$) is set to 1.25 for all regions, which is within the standard range of 1–4. The (5-year) rate of time preference is solved endogenously in the calibration procedure, in order to generate realistic region specific consumption profiles and capital ownership profiles *per age group* for which no data are easily available. Armington elasticity of substitution between goods from Scotland and RUK is set equal to 3.75, and for ROW equal to 2.5. Higher trade elasticity of substitution for UK regions implies that their consumers can more easily substitute their domestic goods for foreign goods if foreign goods prices increase. It also means that with a lower Armington elasticity, ROW has more market power over its produced good than UK regions. Lower elasticities of substitution for UK regions would increase terms of trade effects (discussed below).

The *second step* of calibration consists of using the information on output, capital and labour demands with the first-order conditions of the firm problem, and steady state

condition for capital accumulation to calibrate the scaling parameter for the production function, wage, rental rates and depreciation rate.

The *third step* is the most challenging as it involves equations describing the household's optimisation problem, the equilibrium conditions in the assets and goods markets and government budget constraint to calibrate the rate of time preference, age-independent government expenditures, and the effective tax rates. In other words, the (5-year) rate of time preference is solved endogenously in order to generate realistic consumption profiles and capital ownership profiles per age group, for which no data are easily available. Note that the rate of time preference and the intertemporal elasticity of substitution together determine the slope of the consumption profiles across age groups in the calibration of the model (when the population is assumed to be stable). This is also the slope of the consumption profile of an individual across his lifetime in the simulated model in the absence of demographic shocks or economic growth. Capital ownership profiles must also satisfy the equilibrium condition on the asset market. Age-independent public expenditures are endogenously determined to close the budget constraint of the government and ensure the equilibrium on the goods market.

The *fourth and final step* uses the calibration results of the first three steps to verify that the model is able to replicate the observed data corresponding to the initial equilibrium. Only when the initial equilibrium is perfectly replicated with the calibration solution can the model be used to evaluate the consequences of exogenous shocks.

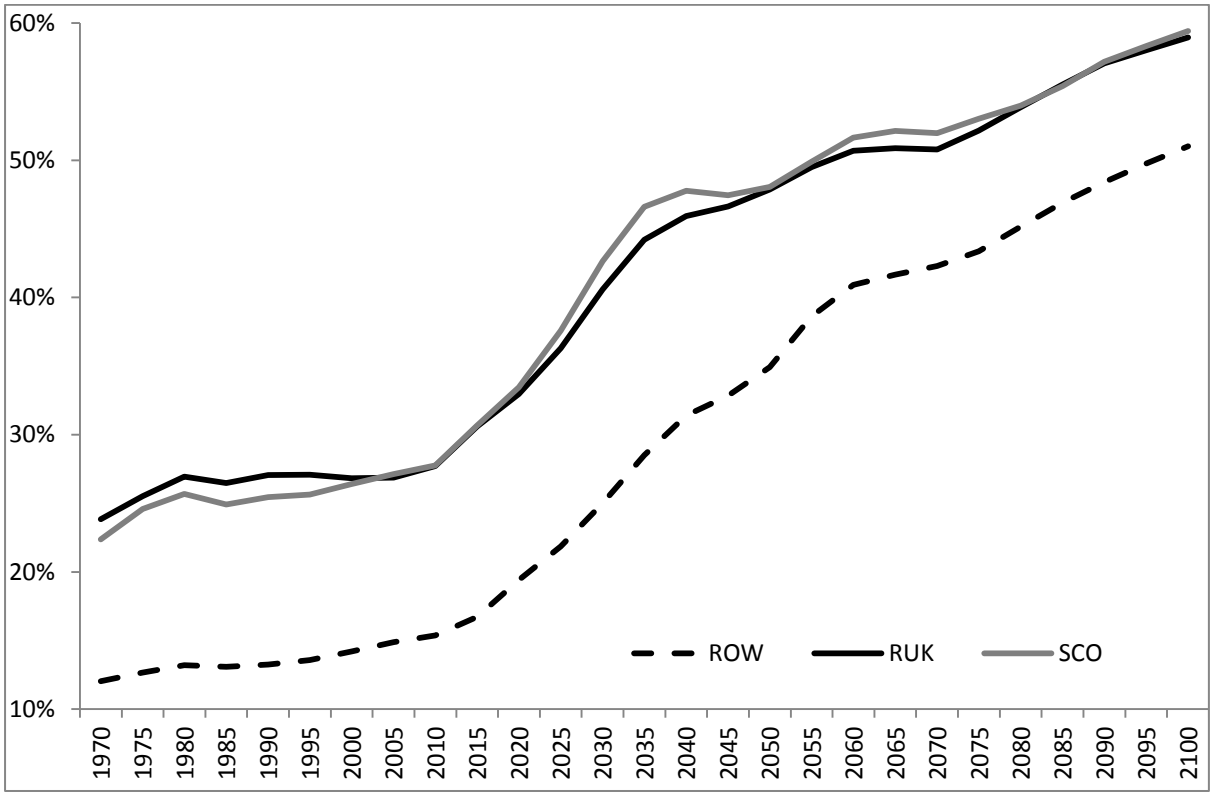
3.7 Demographic shock

Detailed demographic projections are the exogenous forcing process of the OLG simulation model described in the previous section. For Scotland and RUK we use 2012-based ONS

principal population projections. For ROW we use 2012 revision of the UN medium variant population projections (United Nations Population Division, 2013). Both sets of projections are available up to 2100.

After that we assume that population in each region reaches its stable equilibrium and calibrate fertility, survival and migration rates such that they reproduce population of the same size and structure for every consecutive year.

Figure 2. Old-age dependency ratio



Source: 2012-based principal ONS population projections, 2012 revision UN demographic projections

Figure 2 presents OADR for modelled regions. It shows that the whole world is on the verge of significant acceleration of the ageing process. Another point that attracts immediate attention is that ROW is much younger than both Scotland and RUK. In fact comparing with

ROW the difference between the two UK regions is almost negligible. However, the speed of change in population structure is faster in ROW and by the end of the century the gap between OADR in the UK and ROW is noticeably smaller: 8 percentage points compared to 13 percentage points in 2010.

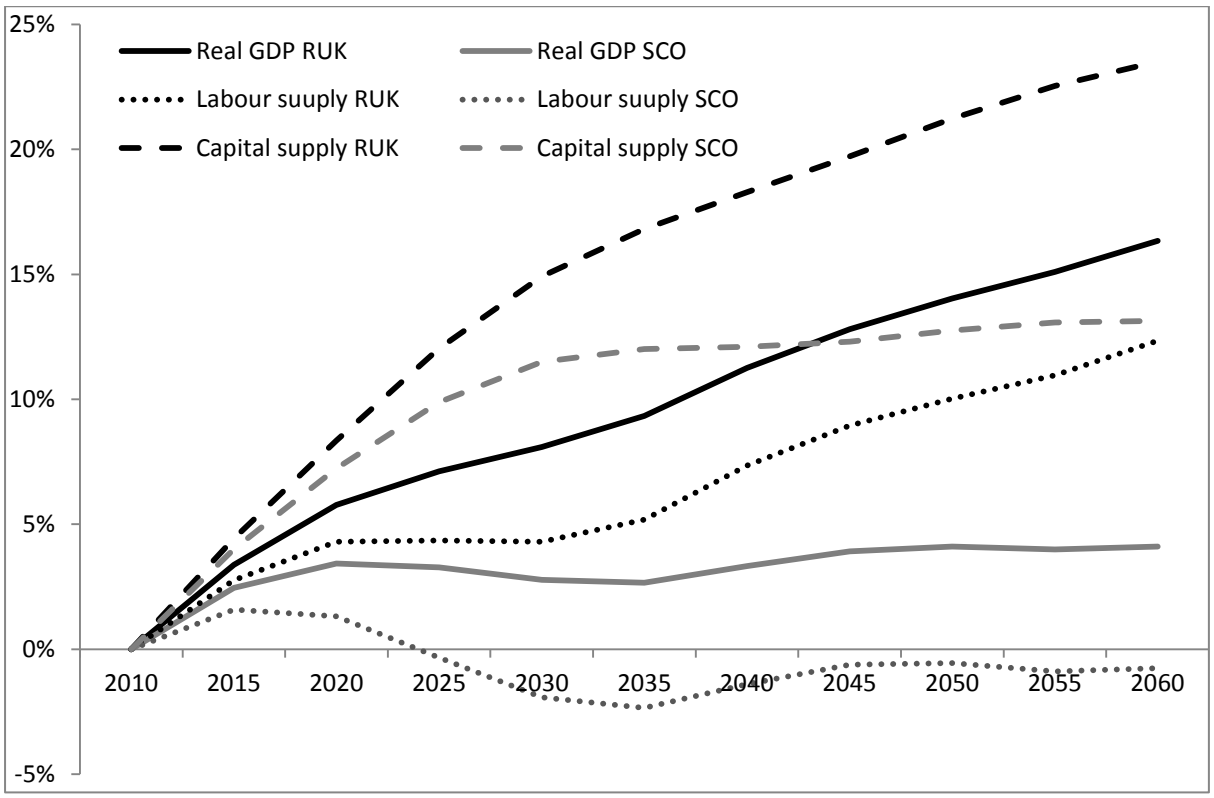
Up until the early 2000's Scotland was younger (if compared using this measure of ageing) than RUK. However, in the future Scotland will age more rapidly than RUK for several decades. But by the end of the projection period OADR in both regions converge.

3. Results

This section presents simulation results for two scenarios. We start with the status quo scenario, in which Scotland stays within the UK. In this case public spending is financed on a UK-wide basis. All results are shown as a percentage change relative to the baseline scenario without population ageing unless stated otherwise.

Figure 3 demonstrates the effect of demographic change in Scotland and RUK on supply of factors of production and the aggregate level of real GDP. Labour supply is an exogenous factor. It is measured in efficiency units and depends on population size and age structure, age-specific labour force participation rates and age-productivity profiles. Over the next 5 decades, labour supply in RUK increases by 12%, while in Scotland it is mostly flat. The difference in labour supply between RUK and Scotland is larger than what is suggested by the evolution of OADR in the two regions (see Figure 2). That is because in RUK both the 65+ age-group (numerator) and the 20-64 age-group (denominator) are increasing more rapidly than in Scotland. The difference in labour supply underpins changes in other variables as explained below.

Figure 3. Real GDP and factors of production

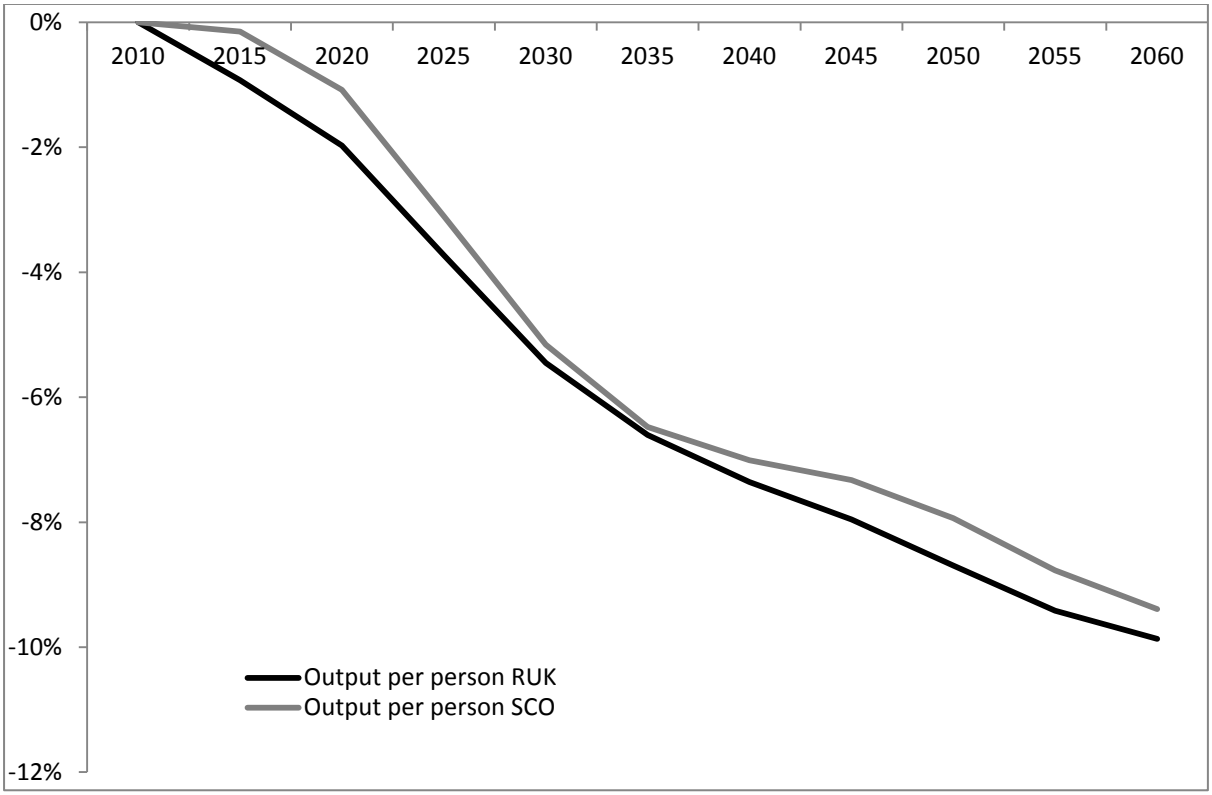


Capital supply increases faster than labour supply in both regions resulting in increase in capital labour ratio. Capital accumulation is determined by saving behaviour. In this model the only motive for saving is for provision in old age. Thus, the dynamic of capital accumulation are closely related to the age structure of the population. A more rapidly ageing population is predicted to save a larger share of its output to provide for the faster growing retired population. However, this does not mean that the overall level of saving would be higher in an ageing society as lower labour supply might result in lower level of output. In this model with free capital mobility, additional effect comes from the capital allocation across regions, which will be discussed in more detail later.

By the end of the simulation period capital supply in RUK increases by 24% and in Scotland by 13%. As a result of these changes in supply of factors of production, by 2060 the real GDP in RUK increases by 16% and in Scotland by 4%.

Population ageing is characterised by a faster growth of the retired population relative to the working age population. That is why overall growth of output does not guarantee an increase in the level of output per person. Figure 4 demonstrates that this is the case in the UK regions. Changes in the age structure of the population lead to the decrease of real GDP per person in RUK and Scotland by 10% and 9% respectively. Although Scotland is ageing more rapidly than RUK, faster growth in capital labour ratio results in marginally slower reduction in output per person.

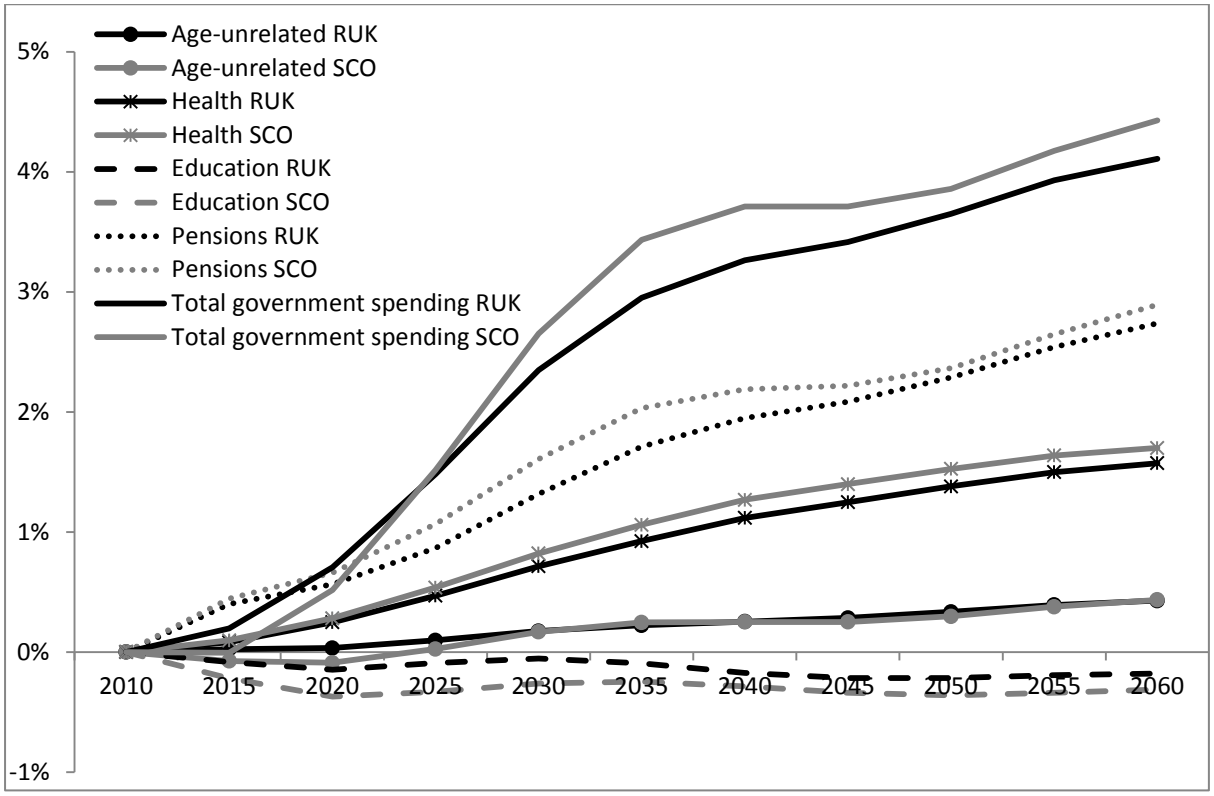
Figure 4. Real GDP per person



The dynamics of different categories of government spending expressed as a percent of GDP is presented in Figure 5. The category where growth is fastest is spending on pensions. By 2060 it increases by about 3 percentage points of GDP. The next is spending on health, which increases by about 2 percentage points of GDP. Spending on education marginally decreases. Finally, age-independent government spending increases by about 0.5 percentage points of GDP. Spending on health and pensions, which are greatly affected by older age groups, grow faster in Scotland. Spending on education, which depends mostly on young age groups, declines faster in Scotland. The overall level of public spending increases by about 4 percentage points of GDP, again slightly higher in Scotland than in RUK. The difference between the overall level of public spending and age-independent government spending demonstrates that the increases in government spending result mostly from fiscal pressure of ageing populations.

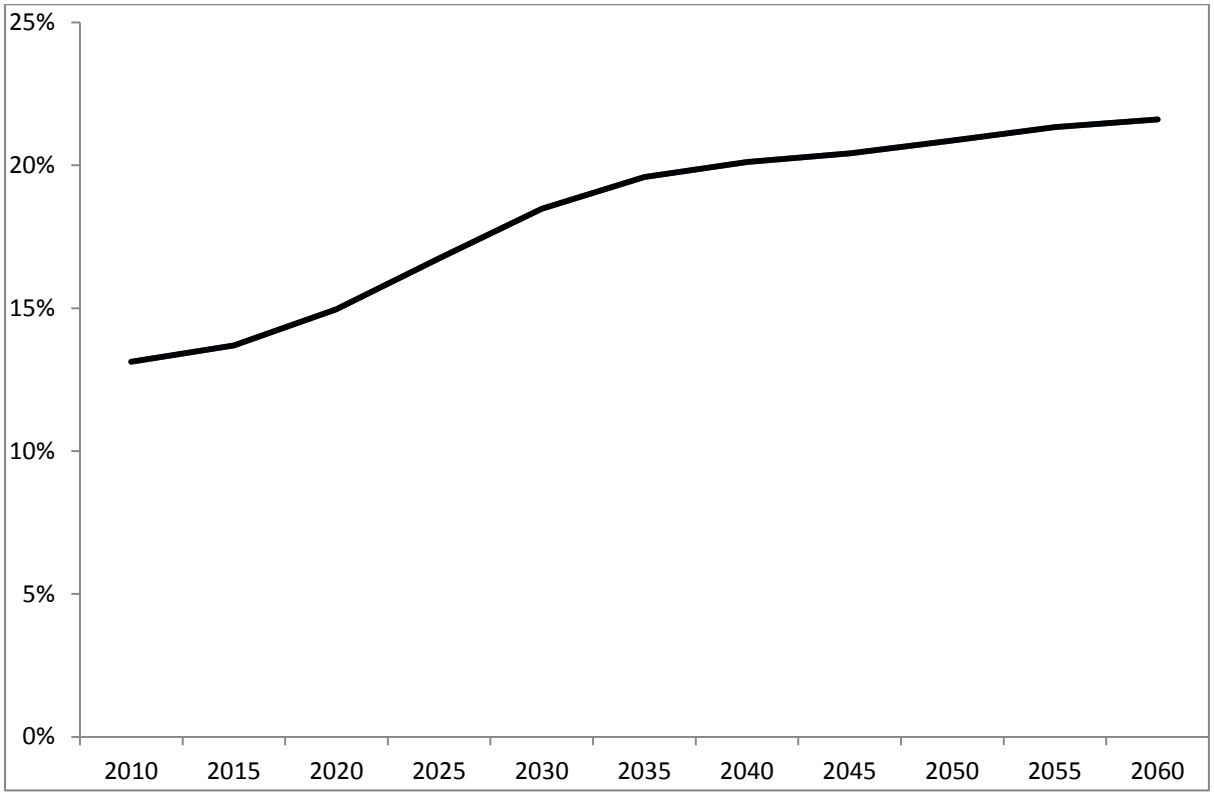
The policy instrument that allows the government sector to balance its budget in this model is the level of the effecting labour income tax rate. In this variant of the model, where labour supply in exogenous, it is a non-distortional tax. Because in the status quo scenario Scotland and RUK are parts of one country, the level of income tax rate is the same in both regions. To keep the government budget in balance, the effective rate of labour income tax increases from about 13.0% in 2010 to 21.5% in 2060. The tax toll arising from the fiscal pressure of ageing is thus equal to 8.5 percentage points, which is the necessary increase in the effective income tax rate to keep the budget in balance.

Figure 5. Government expenditures by category as a percent of GDP



There is a common argument that if the economy is growing sufficiently fast, a country should be able to increase its spending associated with an ageing population without increasing taxation. In the presented model, to avoid increasing income tax rate by 2060 total factor productivity (TFP) growth has to be about 0.6% per year. According to Harris and Moffat (2013) between 1997 and 2008 TFP growth in Great Britain was on average equal to 1.6% per year. This means that covering the public expenditures associated with ageing would require over one third of recently observed TFP growth. It has to be noted that these calculations assume no increase in quality or quantity of public services provided. A 0.6% annual growth rate would only permit to avoid a deterioration of public services.

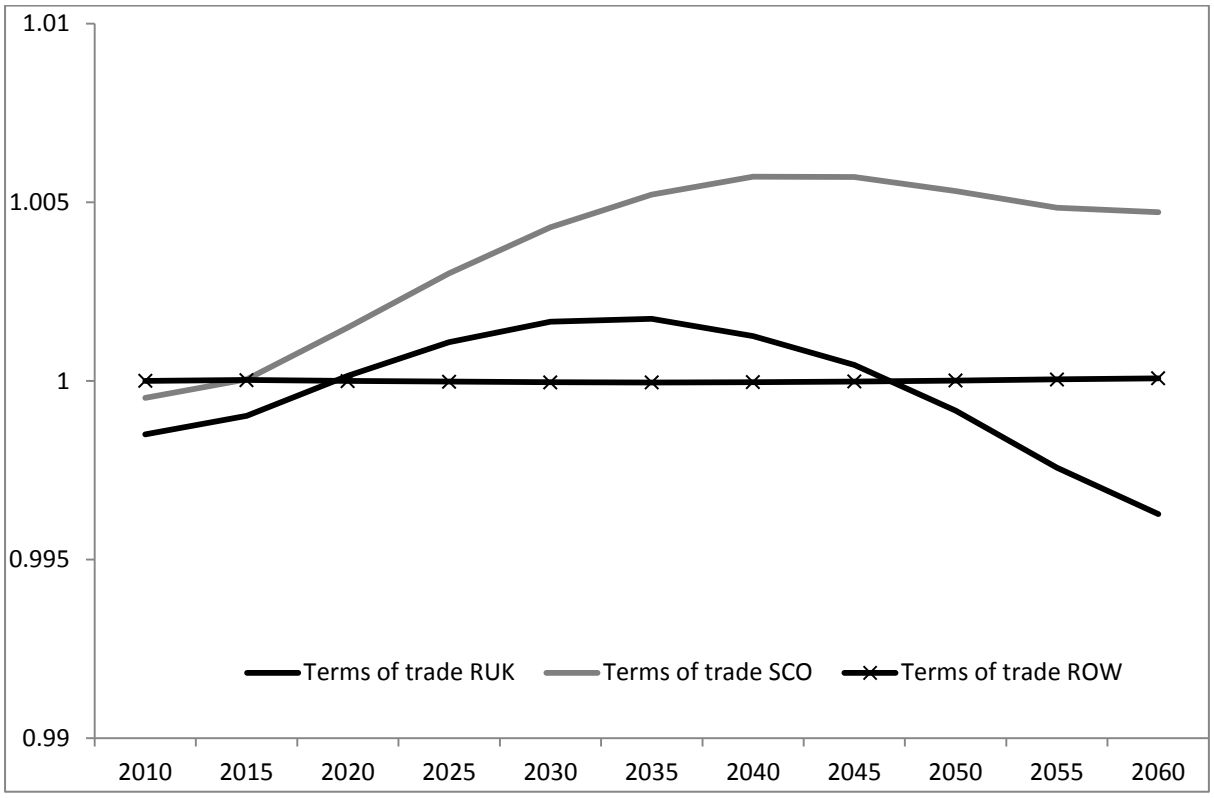
Figure 6. Effective labour income tax rate



In a closed economy, producer and consumer prices are identical. But in the presence of international trade, the price indices for produced and consumed goods do not have to be the same. The price ratio of produced and consumed goods is referred to as terms of trade. Changes over time in the terms of trade for the three regions are reported in Figure 7. With some market power given by the Armington assumption and a relative production decline due to ageing, the price of the goods produced by Scotland increases relative to the price of the goods produced in RUK and ROW. In contrast, the price index of the goods consumed by households in Scotland changes less, as consumption consists of domestic and imported

goods and the price of those goods moves in opposite direction. Consequently, Scotland's terms of trade improve over time[4].

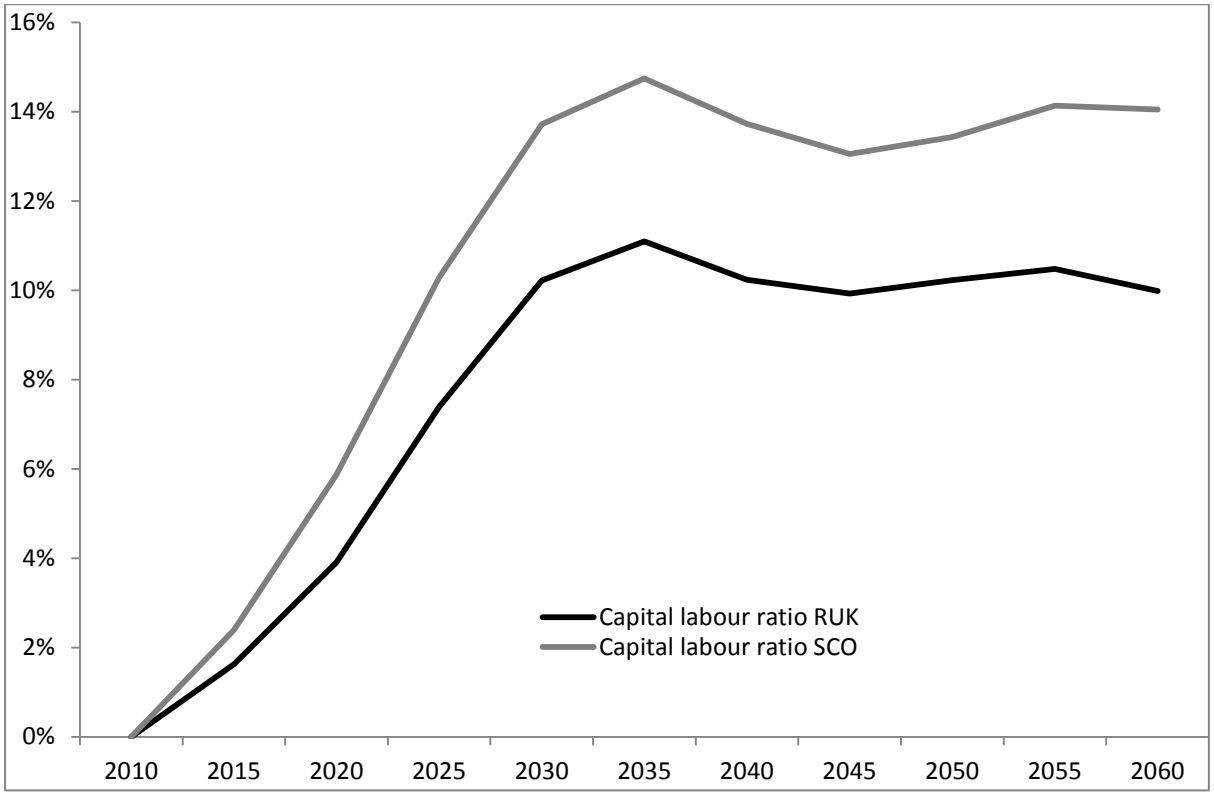
Figure 7. Terms of trade



As was mentioned above and is shown in Figure 8, capital labour ratio increases more rapidly in Scotland than in RUK. This is mainly due to the impact of population ageing on labour supply. As reported above, labour supply remains flat in Scotland between 2010 and 2060 while it increases by about 12% in RUK for the same period. By directly affecting the denominator of the capital labour ratio, a relative reduction in labour supply in Scotland contributes to making the capital labour ratio larger in Scotland than in RUK.

[4] A positive terms of trade effect was also found in Georges et al (2013) for ageing North countries in a North-South trade model.

Figure 8. Capital labour ratio

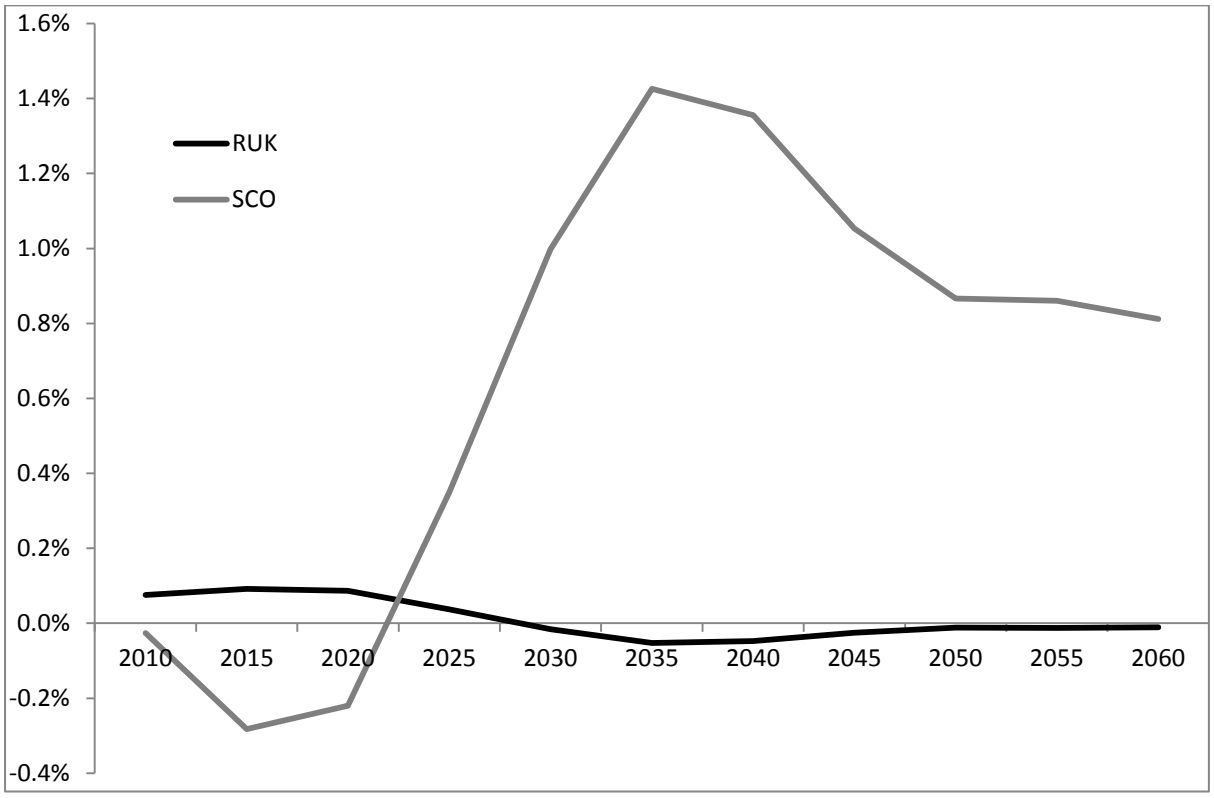


Increase in capital labour ratio puts downward pressure on returns to capital and leads to capital outflow from the more rapidly ageing region. However, improvement of the terms of trade in Scotland, discussed above, prevents large scale capital outflow from Scotland. But this is a second order effect compared with the changes in labour supply.

The results presented so far describe the effects of demographic change in the status quo scenario. However, the interesting question is what will happen if Scotland becomes independent and has to pay for ageing related expenditures itself. To show the effect of potential Scottish independence we compare the results from the status quo and independence scenarios.

Figure 9 shows the percentage point difference in the effective labour income tax rate between the two scenarios. The highest difference is in 2035 and at this point labour income tax rate in Scotland is 1.4 percentage points higher in the independence scenario. This effect is non-negligible, however, it is much smaller than the effect of population ageing discussed above. For comparison, by 2060 the effective labour income tax rate increases by 8.5 percentage points in the status quo scenario.

Figure 9. Difference in the effective labour income tax rate between two scenarios



To give a summary measure of Scotland's relative position, we calculated the difference in social welfare between the two scenarios. Social welfare takes into account welfare of every cohort alive at time *t* adjusted by its relative size in the total population. It is an equivalent

variation measure and shows by how much consumption in the independence scenario has to increase to compensate the loss of welfare relative to the status quo scenario. By 2060 the social welfare in the independence scenario is 1.2% lower relative to the status quo scenario.

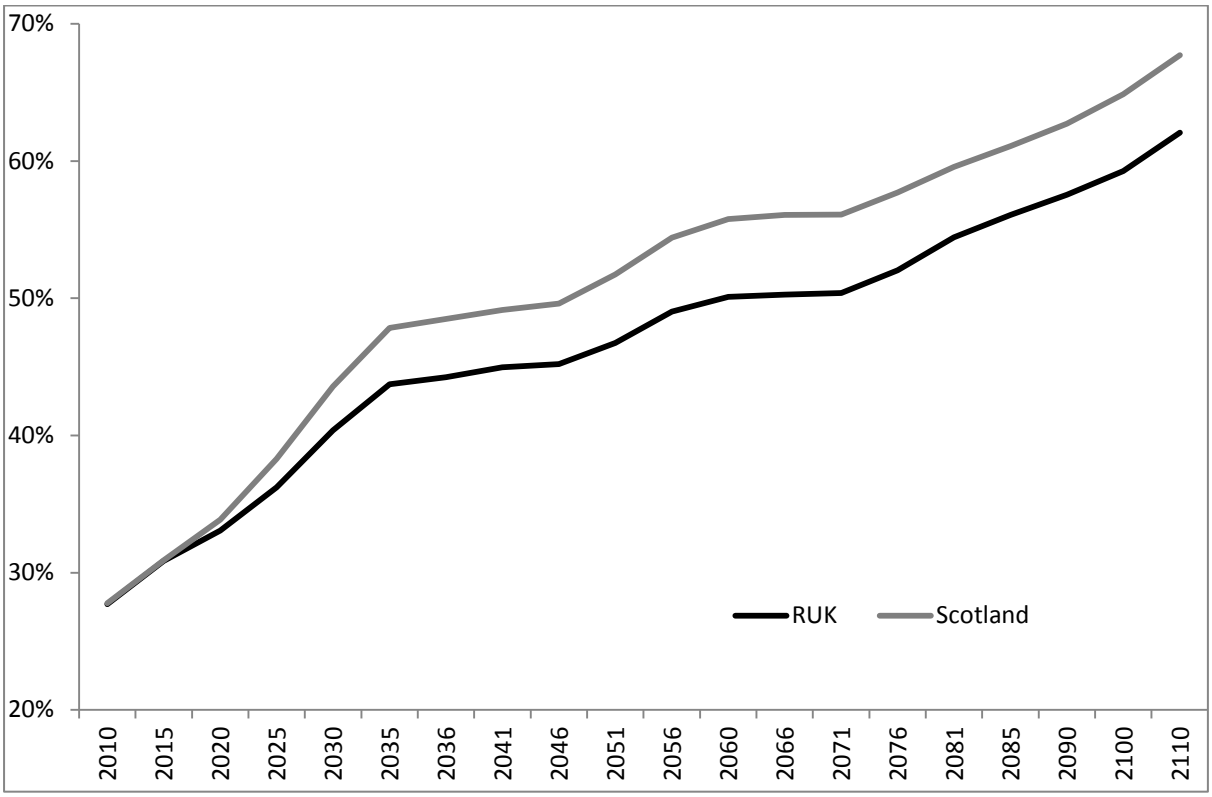
3.2 Sensitivity

The results presented in this paper rely on the population projections as a driving force behind the changes tracked by the model. As a consequence they are sensitive to the demographic assumptions. To analyse sensitivity to population projections we compare main results with a simulation based on the low migration variant of the 2010-based ONS population projections. These are the same projections that were used by the Institute for Fiscal Studies in their recent report on the fiscal sustainability of an independent Scotland (Amior et al, 2013). These projections forecast a much larger difference between the speed of ageing in Scotland and RUK. Figure 10 shows OADR for both regions for 2010-based low migration projections. Comparing this with Figure 2 reveals a very different picture. By 2060 in the 2010-based low migration projections RUK has lower OADR than in 2012-based principal projections, 50% compared with 51%. While Scotland has higher OADR, 56% compared with 52%.

The relatively better situation for RUK in the 2010-based low migration population projections makes the overall effect of ageing at the UK-wide level less severe – for the status quo scenario the effective labour income tax rate has to increase by 7 percentage points, compared with 8.5 percentage points in our main results. At the same time the difference between the two scenarios more than doubles compared to our main results – it

reaches 3 percentage points compared with 1.4 percentage points. Thus, using the population projections which are less favourable for Scotland results in the additional cost of independence being almost half as large as the costs of ageing itself. For comparison, in the case of our main simulations it only constitutes 16%.

Figure 10. Old-age dependency ratio



Source: 2010-based low migration ONS population projections

The high sensitivity of the results to the demographic projections suggests that active policy aimed at improving the demographic situation might play an important role in reducing the effects of population ageing in both regions. For example, if Scotland wants to reach the same OADR as RUK in 2060, it has to increase its net migration roughly by 50% compared with the principal ONS migration assumption. This would amount to approximately 23000

per year, which is equal to the average level of net migration that Scotland experienced between 2004 and 2011 and is below the long term net migration assumption in high migration variant by ONS (24000 per year).

4. Conclusions

Population ageing over the next 50 years will be a major demographic challenge in many regions of the world, including in the UK. To investigate the case of UK with and without independence of Scotland, we developed a multi-regional OLG-CGE model for Scotland, the rest of the UK (RUK) and the rest of the World (ROW).

To study the interaction of population ageing and potential Scottish independence, we conducted simulations under two situations: the status quo and the independence scenarios. The status quo scenario assumes that Scotland stays part of the UK and all government expenditures associated with population ageing (mainly pensions and health) are funded on a UK-wide basis. The independence scenario assumes that each region has to absorb the growing demands of its own ageing population.

According to the simulations presented in this paper, population ageing has a substantial economic impact on Scotland and RUK in both scenarios. In the status quo scenario, by 2060, output per person falls in Scotland and RUK by 9% and 10% respectively and total government spending increases by about 4 percentage points of GDP in both regions. These numbers suggest that quantity or/and quality of public services in UK are likely to decline unless productivity growth compensates for population ageing. Indeed, under the assumption that the government maintains balanced budget, the effective labour income tax rate needs to increase from 13% to 21.5%. Alternatively, to avoid increasing the level of taxation, keeping the balanced budget requires total factor productivity growth of 0.6% per year, which accounts for over a third of TFP growth observed in the recent past (Harris and Moffat, 2013).

To isolate the impact of independence in the context of population ageing, we compared the simulations results of the status quo with the independence scenarios. The comparison

suggests that Scotland is worse off in the case of independence. The effective labour income tax rate in the independence scenario has to increase further compared with the status quo scenario. The additional increase reaches its maximum in 2035 at 1.4 percentage points. The additional rise in the tax rate is non-negligible, but is much smaller than the population ageing effect (status quo scenario) which generates an increase of about 8.5 percentage points by 2060. The difference for government finances between the status quo and independence scenarios is thus relatively small.

We show, however, that the results are sensitive to the demographic projections. For instance, using the low-migration variant of 2010-based ONS population projections would more than double the cost of independence. But an independent Scotland will have power to set policy in order to tackle its demographic challenges. One such policy could be an increased level of immigration, which is not possible under the current UK migration policy target.

The aim and scope of this paper is to isolate the effects of population ageing in the context of potential Scottish independence. However, other factors may potentially make the case of independence less appealing. Medium or long run decline in the revenues from the North Sea would put additional fiscal pressure on an independent Scotland, as they would represent a much larger share of total Scottish government revenues. The level of the UK net public debt, and how it would be split between Scotland and RUK if independence occurs, will also have an important impact on fiscal balance. Fiscal rules and institutions in a newly independent Scotland would clearly have an influence on the cost of borrowing of the government and on the capacity to attract private investment.

The bottom line is that, clearly, population ageing is a major issue for Scotland and RUK, no matter the final result of the independence vote. But unless the speed and intensity of population ageing in Scotland increases rapidly relative to RUK in the years to come, demographic change is not a strong argument to influence the choice between the status quo and independence.

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Appendix: Equations, variables and parameters

A.1 Demography

(1) $$Pop_{t,gg+k} = \begin{cases} Pop_{t-1,gg+k+5}\, fr_{t-1} & for \quad k=0 \\ Pop_{t-1,gg+k-1}\left(sr_{t-1,gg+k-1} + mr_{t-1,gg+k-1}\right) & for \quad k \in [1,20] \end{cases}$$

A.2 Production sector

(2) $$Q_{j,t} = A_{j,t}\left(Kdem_{j,t}\right)^{\alpha_j}\left(Ldem_{j,t}\right)^{1-\alpha_j}, \quad 0 < \alpha_j < 1, \quad j \in J = \{\text{SCO, RUK, ROW}\}$$

(3) $$\text{Re}nt_{j,t} / PQ_{j,t} = \alpha_j A_{j,t}\left(Kdem_{j,t} / Ldem_{j,t}\right)^{\alpha_j - 1}$$

(4) $$WLdem_{j,t} / PQ_{j,t} = (1-\alpha_j) A_{j,t}\left(Kdem_{j,t} / Ldem_{j,t}\right)^{\alpha_j}$$

A.3 Household behaviour

(5) $$U_{j,t} = \frac{1}{1-\theta}\sum_{k=4}^{20}\left\{\left[\frac{1}{1+\rho}\right]^k \Pi_{m=0}^{k} sr_{t+m,g+m}\left((Con_{j,t+k,g+k})^{1-\theta}\right)\right\}, \qquad 0 < \gamma_j < 1$$

(6) $$\underbrace{Lend_{j,t+1,gg+1} - Lend_{j,t,gg}}_{\text{Asset Accumulation (during period } t)} = \frac{1}{sr_{t.g}} \times$$

$$\left[\underbrace{\left(1-\tau_{j,t}^{L} - CTR_{j,t}\right)Y_{j,t,gg}^{L}}_{\text{Net Labour Income}} + \underbrace{\left(1-\tau_{j,t}^{K}\right)ret_{j,t}Lend_{j,t,gg}}_{\text{Net Capital Income}} + \underbrace{Pens_{j,t,gg}}_{\text{Pension Benefit}} - \left(1+\tau_{j,t}^{C}\right)\underbrace{PC_{j,t}Con_{j,t,gg}}_{\text{Net Consumption Spending}}\right]$$

(7) $$Con_{j,t+1,gg+1} / Con_{j,t,gg} =$$

$$\left[\left(\left(1+\left(1-\tau_{j,t+1}^{K}\right)ret_{j,t+1}\right)/(1+\rho_j)\right)\times\left(PC_{j,t}(1+\tau_{j,t}^{C}) / PC_{j,t+1}(1+\tau_{j,t+1}^{C})\right)\right]^{\frac{1}{\theta_j}}$$

(8) $$Y_{j,t,gg}^{L} = WLdem_{j,t}EP_{j,gg}LS_{j,gg}$$

(9) $$EP_{j,gg} = \omega + (\xi)(gg) - (\phi)(gg)^2, \quad \omega, \xi, \phi \geq 0$$

A.3 International trade

(10) $$E_{i,j,t,gg} = ALCI_{i,j}^{SigC_j}\left(PC_{j,t}/PQ_{i,t}\right)^{SigC_j}(C_{j,t} + Inv_{j,t} + Gov_{j,t})$$

(11) $$PC_{j,t} = \left[\sum_i ALCI_{i,j}^{SigC_j}\left(PQ_{i,t}\right)^{(1-SigC_j)}\right]^{\frac{1}{1-SigC_j}}$$

A.3 Investment and asset returns

(12) $$Kstock_{j,t+1} = Inv_{j,t} + (1-\delta_j)Kstock_{j,t}$$

(13) $$ret_{j,t} = \underbrace{\mathrm{Re}\,nt_{j,t}/PC_{j,t-1}}_{\substack{\text{Rental Price of Capital}\\ \text{(in terms of the investment good)}}} + \underbrace{(PC_{j,t} - PC_{j,t-1})/PC_{j,t-1}}_{\text{Expected Capital Gains}} - \underbrace{\delta_j PC_{j,t}/PC_{j,t-1}}_{\text{Depreciation Cost}}$$

(14) $$ret_{j,t} = \underbrace{ri_{j,t-1}}_{\substack{\text{Promised Rate of Return}\\ \text{on Government Bonds}}} + \underbrace{(PC_{j,t} - PC_{j,t-1})/PC_{j,t-1}}_{\text{Expected Capital Gains on Bonds}}$$

(15) $$r\,\mathrm{int}_t = ret_{j,t},\ \forall\ j$$

A.4 Government sector

(16) $$\begin{aligned} &PC_{j,t}Bond_{j,t+1} - PC_{j,t-1}Bond_{j,t} = \\ &PC_{j,t}Gov_{j,t} + PQ_{j,t}(GovH_{j,t} + GovE_{j,t}) + \left(ri_{j,t-1} + (PC_{j,t} - PC_{j,t-1})/PC_{j,t-1}\right)PC_{j,t-1}Bond_{j,t} + TPens_{j,t} \\ &-\sum_{gg} POP_{j,t,gg}\left\{\tau_{j,t}^{L}\left(Y_{j,t,gg}^{L}\right) + \tau_{j,t}^{C}\left(PC_{j,t}Con_{j,t,gg}\right) + \tau_{j,t}^{K}\left(ret_{j,t}Lend_{j,t,gg}\right)\right\} \end{aligned}$$

(17) $$Gov_{j,t} = \sum_g Pop_{j,t,gg}gepc_j$$

(18) $$GovH_{j,t} = \sum_g Pop_{j,t,gg}hepc_{j,t,g}$$

(19) $$GovE_{j,t} = \sum_g Pop_{j,t,gg}eepc_{j,g}$$

(20) $$TPens_{j,t} = \sum_{gg=10}^{21} Pop_{j,t,gg}Pens_j(WLdem_{j,t}/WLdem_{j,t-1})$$

A.5 Market and aggregation conditions

(21) $$Q_{j,t} = \sum_i E_{j,i,t} + GovH_{j,t} + GovE_{j,t}$$

(22) $$Ldem_{j,t} = \sum_{gj} Pop_{j,t,gj}LS_{j,gj}EP_{j,gj}$$

(23) $$Kdem_{j,t} = Kstock_{j,t}$$

(24) $$\sum_{i}\sum_{gg} Pop_{i,t+1,gg} Lend_{i,t+1,gg} = \sum_{i} P_{i,t} Bond_{i,t+1} + \sum_{i} P_{i,t} Kstock_{i,t+1}$$

(25) $$CA_{j,t} = \underbrace{\left(\sum_{gg} Pop_{j,t+1,gg} Lend_{j,t+1,gg} - \sum_{gg} Pop_{j,t,gg} Lend_{j,t,gg}\right)}_{\text{Private Saving}} - \underbrace{\left(PC_{j,t}\, Bond_{j,t+1} - PC_{j,t-1}\, Bond_{j,t}\right)}_{\text{Public Dissaving}} - \underbrace{\left(PC_{j,t}\, Kstock_{j,t+1} - PC_{j,t-1}\, Kstock_{j,t}\right)}_{\text{Domestic Investment}}$$

Table A1. Model variables and parameters

Variables	***Description***
$Q_{j,t}$	region *j* output
$PQ_{j,t}$	region *j* output price (producer price index)
$Kdem_{j,t}$	physical capital
$Ldem_{j,t}$	effective units of labour
$Rent_{j,t}$	rental rate of capital
$WLdem_{j,t}$	wage for effective units of labour
$Con_{j,t,gg}$	consumption demand of household of generation *gg* at time *t*
$C_{j,t}$	aggregate consumption in region *j* at time *t* $=\Sigma ggPOP_{j,t,gg,}\ Con_{j,t,gg}$
$PC_{j,t}$	price index of a composite good
$Lend_{j,t,gg}$	stock of wealth accumulated by household-*gg* at the end of period *t*-1
$Kstock_{j,t}$	region *j* capital stock
$Inv_{j,t}$	investment in region *j*
$ret_{j,t}$	expected rate of return on physical capital purchased at the end of *t*-1 and rented throughout *t*
$ri_{j,t-1}$	promised coupon rate of interest on region-*j* government bonds issued at the end of *t*-1
$rint_t$	world interest rate, expected as of the end of period *t*-1 for period *t*
$Gov_{j,t}$	region *j* real public expenditures
$E_{j,i,t}$	real bilateral export of region *j* to region *i*
$CA_{j,t}$	region *j* current account
$TPens_{j,t,gm}$	total level of pension spending
$Y^{L}_{j,t,gg}$	labour income of household-*gg*
$LS_{j,gg}$	supply of physical units of labour by household-*gg* (exogenous)
$EP_{j,gg}$	household age-dependent productivity (earnings) profile
$Pop_{j,t,gi}$	population size of working-age cohorts *gi*
$Pop_{j,t,gm}$	population size of retired cohorts *gm*
Parameters	***Description***
$fr_{j,t}$	fertility rate
$mr_{j,t,gg}$	net migration rate

$sr_{j,t,gg}$	conditional survival rate
ρ_j	pure rate of time preference
θ_j	inverse of the constant inter-temporal elasticity of substitution
$A_{j,t}$	scaling factor of Cobb-Douglas production function (TFP)
α_j	share of physical capital in Cobb-Douglas production function
$\tau^L_{j,t}$	effective tax rate on labour income (endogenous)
$\tau^K_{j,t}$	effective tax rate on capital income
$\tau^C_{j,t}$	consumption tax rate
$CTR_{j,t}$	contribution to the public pension system (endogenous)
$Pens_j$	public pension level of per retiree
δ_j	depreciation rate of capital
$ALCI_{i,j}$	region-*i* share of region-*j* final demand
$SigC_j$	Armington substitution elasticity
$gepc_j$	age-unrelated government expenditures per person
$hepc_{j,t,gg}$	government health expenditures per person of a specific age
$eepc_{j,gg}$	government education expenditures per person of a specific age