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Asset Accounting, Fiscal Policy and the UK's Oil and Gas Resources, Past and Future

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***Abstract**: The UK has been an exception to the trend of channelling revenues arising from the depletion of subsoil assets into a resource fund. In this paper, we construct an asset account for the UK's oil and gas resources to evaluate the cost of this exceptionalism and, looking forward, the implications of establishing a fund now. We show that had a decision been made to establish a resource fund in 1975, this fund could now be substantial in size (about GBP 280 billion in 2010). A significant contributor to this result is the historical efficiency of the UK fiscal regime in capturing oil and gas rents, as we demonstrate. A further benefit of the resource fund would have been a reduction in volatility of resource revenues flowing to the Treasury. An ex post cost-benefit analysis of the simulated fund suggests it could have been a sound public investment. However, our simulation of a future resource fund based on (possible) shale gas and oil revenues shows that it could reach a size similar to the 1975-2010 fund only under optimistic assumptions about prices, revenues and economic reserves.*

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1. Introduction

The recent evidence that the UK may possess sizable resources of shale gas and oil has prompted reflection about whether the UK 'wasted' its North Sea petroleum resource, and whether some form of sovereign wealth fund (SWF) would now be a more effective way to use tax revenues from shale gas and oil exploitation. A meaningful answer to the question of 'wasted' assets seems out of reach, not least because of the difficulty of building a plausible counterfactual. But it is worth revisiting the historical data on North Sea petroleum to consider a number of questions concerning the contribution of the sector to the development of the UK economy.

Hamilton and Ley (2011) list 12 countries or jurisdictions where resource funds and/or fiscal rules for resource revenues have been implemented.[1] Given that North Sea revenues reached 9.9% of fiscal revenues and 3.7% of GDP in 1984, with revenues exceeding 1% of GDP from 1979 to 1987, it is fair to ask whether the UK was an outlier in not establishing some form of SWF (for a historical analysis of the UK oil and gas industry see, e.g. Kemp, 2011a,b; Harvie, 1994; Stewart, 2013).

Exhaustible resources and the revenues they generate present two broad problems for macroeconomic management: gross production and tax revenues tend to be large and highly volatile, and the stream of revenues is finite, ending when the resource deposit ceases to be economic. Large flows of resource tax revenues lead to the distinct risk that fiscal policy will be pro-cyclical and hence a source of macroeconomic instability. And the finite nature of the resource revenue stream raises important questions about the sustainability of the macroeconomy – will wellbeing fall as the resource is exhausted? The contribution of this paper is to demonstrate how asset accounting can throw light on this debate in a number of ways.

We construct natural resource asset accounts for the UK covering the period 1975 to 2010 in order to examine several key aspects of the North Sea experience (for a general discussion see UN, 2013; Hamilton and Hartwick, 2014, Obst and Vardon, 2014). Building resource asset accounts requires the estimation of resource rents, and these rents provide a useful benchmark for the effectiveness of revenue capture from petroleum production through the tax regime (henceforth, in this paper, 'resource revenues'). This is because the rent is, in effect, the payment owed to the owner of the natural resource, e.g. the government (for a broader discussion of resource taxation, see Keen and MacPherson, 2010). The resource asset accounts also yield a measure of the value of resource depletion (Hamilton, 2014), another useful benchmark for resource revenue generation. Finally, we integrate the resource asset account with national accounts data to calculate a fundamental sustainability indicator, 'adjusted' net savings, and related indicators of net wealth creation.

As Ossowski *et al*. (2008) argue, some combination of a natural resource fund and fiscal rules on the use of resource revenues can reduce pro-cyclical tendencies and provide investments and savings to support future wellbeing in extractive economies. Recent interest has focused in particular on how resource revenues could be channelled into a financial asset such as a

[1] Some of these funds combine saving and stability objectives (e.g. Kuwait and Norway) while other countries have funds for one objective only (e.g. savings in Alaska and Alberta and stability in Papua New Guinea and Venezuela) or separate funds to serve distinct objectives (e.g. Oman).

sovereign wealth fund (SWF) (see also, for example: Davis *et al*. 2003; van der Ploeg, 2014, Hassler *et al*. 2015; Clark *et al*. 2013).[2]

We simulate a simplified version of the Norwegian Government Pension Fund for the UK by assuming that all resource revenues from the North Sea were invested in a global portfolio of financial assets, and that the fund paid out a fixed percentage of assets, 3.9%, to the Treasury from 1975 to 2010.[3] The simulation answers four questions. First, how large a sacrifice, in terms of reduced current revenues, would this have entailed? Secondly, in what year would fund payouts have exceeded current resource revenues? Thirdly, how much would the fund have reduced the volatility of resource revenues flowing into the Treasury? Finally, how large would the fund and the payout have been in 2010?

Looking forward, we also simulate a SWF for the UK that begins operation in 2015. The fund accumulates revenues from the declining North Sea reserves and, starting as early as 2025, accumulates (potential) revenues from shale gas and oil as well. Under the most favourable projections for recoverable resources, extraction, prices and rents, by 2040 this fund could grow as large as the fund we simulate for 1975 to 2010. Yet for less favourable projections, this potential fund is smaller, possibly significantly so and underlining further perhaps past opportunities missed.

Our conclusions on the effectiveness of resource taxation in the UK are positive: on average 65% of resource rent and 80% of resource depletion values were captured by taxes and royalties over 1975-2010. The conclusions on the sustainability of the economy are less encouraging – if we deduct the value of resource depletion from published estimates of net national saving for the UK, in most years this measure is less than 4% of GNI and it approaches 0 in some years.

The simulated SWF for 1975 to 2010 shows that sacrifices in terms of foregone current revenues to the Treasury would have been large, 10-20 billion constant 2010 GBP, over the years 1979 to 1987. By 1988, however, payouts from the SWF would have exceeded resource revenues and the value of the fund would have doubled the size of the government balance sheet by 2010. The volatility of payouts from the fund would also have been much lower than the volatility of resource revenues from 1985 to 2010.

It is important to note that our simulation of a SWF is a partial analysis rather than a full counterfactual scenario for government finances in the presence of a SWF. Since there is little economic logic to simultaneously increasing debt and paying resource revenues into a SWF, the implication is that a counterfactual would have to include reductions in public expenditures and/or increases in non-petroleum revenue.[4] The numbers are large enough that macroeconomic consequences could be expected. However, our judgment is that a full counterfactual would be arbitrary in many ways.

[2] An alternative model for a fund is an earmarked pot with which to finance projects identified ‘now’ as being productive investments (van den Ploeg, 2014). For example, this investment might be in domestic produced, human capital or even natural capital.

[3] Our analysis therefore builds on Hawksworth (2008) which calculates that the UK could have had a fund of some GBP 450 billion (an amount greater than the tax revenues collected over the period of that study). Scottish Government (2009) also simulate the establishment of a (hypothetical) past fund by assuming different (but relatively modest) percentages of tax revenues being invested as well as different rates of return.

[4] There is an element of endogeneity at work here as well, since the availability of resource revenues may have led government to reduce or restrain taxation of the non-petroleum economy.

Rather than constructing a counterfactual for government income and expenditure, we carry out an ex post cost-benefit analysis of introducing a SWF for two different starting points, 1975 and 1990. The costs of the SWF are the petroleum tax revenues paid into it, rather than into general revenues; the benefits are the payouts from the fund to the Treasury. Because the fund can, in principle, provide revenues in perpetuity after the depletion of the resource, the result is that benefits exceed costs by 10% to 100% depending on the start year and the social discount rate. A SWF would have been a sound public investment.

The rest of this paper is organized as follows. Section 2 presents an account for oil and gas assets in the UK over the period 1975-2010 and derives alternative measures of net saving over this period. This section also reviews resource revenues generated and benchmarks them against total resource rents and the value of resource depletion. Section 3 then models the size of a hypothetical SWF based on historical resource revenues and provides projections to 2040 based upon potential revenues from conventional and non-conventional petroleum resources – these are the "two windfalls" of the title of the paper. Section 4 discusses this costs and benefits of establishing a UK SWF including an ex post CBA. Section 5 concludes.

2. Accounting for UK Oil and Gas

2.1 The UK Petroleum Asset Account

The petroleum asset account constructed here is based on standard resource accounting principles as laid out in the United Nations System of Environmental and Economic Accounts (UN SEEA) (UN 2013). The starting point is an estimate of resource rents, which are measured as the difference between resource revenues and the economic cost of extraction, which includes current extraction costs, depreciation and the opportunity cost of fixed capital.

A complication in asset accounting for the UK is that there are no separate extraction cost estimates available for natural gas. We therefore use the oil extraction costs in estimating resource rents, and treat gas as a co-product of oil extraction. Resource revenues in the rent calculation are therefore the sum of revenues from oil and gas extraction. For purposes of measuring unit resource rents, gas is measured in tonnes of oil equivalent so that it can be added to quantities of crude oil.

Table 1: Assumptions and Parameter Choices for Petroleum Asset Accounts

Assumption or parameter	Value
Resource lifetime	Capped at 25 years at current production rates
Path of resource rents	Fixed at the current year and held constant up to the point of exhaustion
Co-production	For accounting purposes gas is treated as a co-product of oil extraction
Opportunity cost of fixed capital (assumed rate of return on assets)	4.3%
Discount rate	3.5%

Resource asset values are calculated as the present value of resource rents up to the point of exhaustion. Physical reserves are measured as the sum of proven and probable resources. We assume a cap on reserves equal to 25 times current production. While oil reserve estimates for the UK exceeded 25 years up to 1980, extrapolating resource rents more than 25 years into the future seems dubious, particularly given the volatility of resource prices. For purposes of the present value calculation, resource rents are fixed at the current year and held constant up to the point of exhaustion. This is how resource asset values are typically estimated, although in some instances governments use specific forecasts of prices, costs and quantities extracted (see, for example, ONS, 2014 and Kahn *et al*. 2013). The key assumptions and parameters used in estimating petroleum asset values are shown in Table 1.

The rate of return used to establish the opportunity cost of fixed capital is equal to the 10 year moving average of interest rates on government bonds as measured in 2013, while the discount rate is the recommended rate from the UK Green Book for cost-benefit analyses covering periods of 30 years or less (HM Treasury, 2003). For simplicity we assume these rates to be fixed from 1975 to 2010, which may lead to minor differences between our asset estimates and any values published by the UK Office for National Statistics (ONS).

As stipulated in the SEEA, the value of depletion of petroleum is measured as the unit value of depletion times the quantity extracted (where, again, gas is measured in tonnes of oil equivalent). The unit value of depletion is equal to the current resource asset value divided by the current physical stock (capped at 25 years lifetime). Note that this methodology implicitly accounts for resource discoveries if the resource lifetime is less than the cap. As shown in Hamilton and Atkinson (2013), as long as resource rents are assumed to be constant over the resource lifetime, the unit value of depletion declines when there is an increase in the physical stock owing to discoveries. Other things being equal then, a depletion-adjusted measure of Net National Income rises when new resources are discovered. The resulting resource asset account estimates can be found in Annex 1 to this paper.

2.2 The Linkage between Resource Asset Accounting and Policy

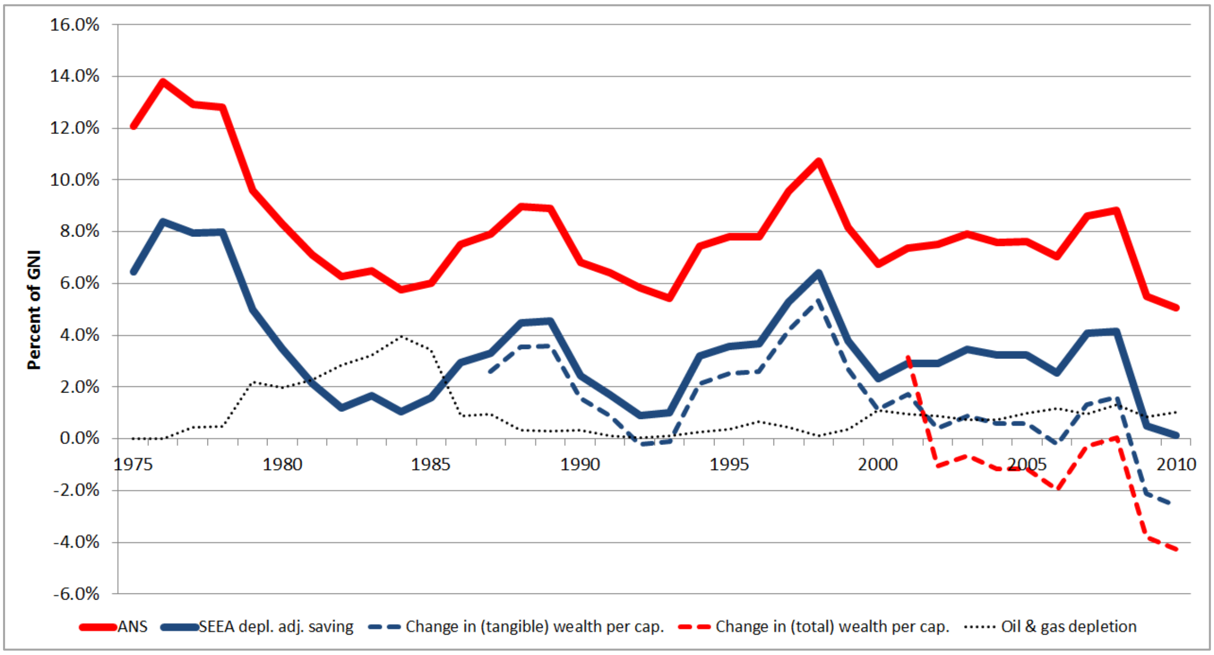
Measuring the value of resource depletion is an essential input into policies for sustainable development in extractive economies. The Hartwick Rule (Hartwick 1977) shows that future consumption can be sustained when exhaustible resources are extracted if other investments offset the value of resource depletion. Hamilton and Clemens (1999) show that wellbeing cannot be sustained if 'genuine' saving, including the value of resource depletion, is negative. This forward-looking strategy for saving has parallels too with the permanent income hypothesis (PIH) (see, for example, van der Ploeg, 2014).

The practical link between changes in total wealth and sustainability was first explored by Pearce and Atkinson (1993). Subsequent growth theoretic literature, including Hamilton and Clemens (1999), Dasgupta and Mäler (2000) and Asheim and Weitzman (2001), has elaborated the theoretical foundations for this approach to measuring sustainability. The SEEA enshrines these findings in its definition of two extended national accounting aggregates – depletion-adjusted saving and depletion-adjusted national income. Similarly, the World Bank publishes figures on Adjusted Net Saving (ANS) going back to 1970 for over 150 countries in the *World Development Indicators* – this extended measure of the change in real wealth includes not only resource depletion but also investments in human capital and damages from pollution exposure.

In Figure 1, we combine these indicators with the findings from our resource asset account to comment on asset accumulation and wealth more generally for the UK. Except for the early 1980s, the value of resource depletion is a relatively small share of Gross National Income

(GNI). ANS is fairly low but positive, with education expenditure playing a big role in keeping it above zero. The new SEEA statistical standard – which excludes this education expenditure – shows 'depletion-adjusted net saving' to be just above 0 for at least some of the historical period. Notably, this is the case for the early 1980s when the value of resource depletion was at its highest (relative to GNI), in the early 1990s, and more recently at the end of the historical series.

Figure 1: Change in Real Wealth in the UK (% of GNI)



Note: Per capita (wealth) measures as expressed as percentage of per capita GNI.

From 2001-2010 UK population growth was moderate at 0.5% per year on average. Yet relatively low rates of ANS suggest that it is useful also to look at the change in per capita wealth. This measures the extent to which total assets are shared over a changing population. This is reflected in an extra "wealth dilution" term which must be subtracted from the measure of net saving (Hamilton, 2003).[5] Figure 1 includes two measures of the change in per capita wealth.

The first is the change in the tangible wealth per capita, where both produced assets and oil and gas resources are taken into account. This estimate goes back to 1987 when UK balance sheets for produced assets commence. The change in this tangible wealth (net of wealth dilution) stays positive until 2008 after which it is negative. The disparity between depletion adjusted saving and this measure is also notable after 2000.

The second measure is the change in tangible assets plus human capital in per capita terms. This corresponds roughly to ANS which, by including education investment, reflects how *total* assets are changing over time. This estimate begins only in 2001, the earliest year for

[5] To be precise, the wealth dilution term is measured as the total wealth per capita times the population growth rate.

which ONS data (in Jones and Fender, 2011; Fender and Carver, 2013) on UK human capital are available. This wealth change was negative for most of that decade.[6]

2.3 Accounting for Government Resource Revenues

The picture about the sustainability of the economy, in the previous section, while mixed is far from encouraging. These highly aggregated insights take us only so far. Relating this asset accounting to the public finances is also important given that a critical pathway for boosting savings from resource depletion originates from appropriating these benefits through the tax regime. This tax regime, established in the Oil Taxation Act of 1975, has evolved substantially over subsequent years. Broadly speaking, these changes have had two objectives: (a) securing a larger take of the value of resource production (particularly when resource prices were high); and latterly, (b) a simplification of the layers of tax imposed on resource producers (HMRC, 2008; Kemp, 2011a,b).[7]

The initial regime consisted of three different tax streams starting with a 'Royalty' amounting to a charge of 12.5% of the gross value of oil and gas produced within a licensed area (less allowable deductions). Two further (field-based) charges applied to the net profits[8] of producers: Petroleum Revenue Tax (PRT) and Corporation Tax (CT).[9] Two subsequent charges (both established in 1981) were Supplementary Petroleum Duty (SPD) and a Gas Levy (on otherwise tax exempt gas). The SPD was short-lived and abolished after two calendar years while the Gas Levy was phased out after the late 1990s. The Royalty applies to fields licenced before 1982 only and was discontinued altogether by 2002. PRT now does not apply to fields developed after March 1993.

The tax rates for both PRT and CT have also undergone a number of revisions. In the past, PRT rates have been 45% (until 1978), 60% in 1978, 70% from 1979 before reaching a peak of 75% level in 1983. From 1993, this was reduced to 50% and this rate still applies currently for those fields subject to the PRT. While CT for resource producers has tracked the standard corporation tax, from 2002, this was complemented by a further supplementary charge introduced at 10% but increased from the beginning of 2006 to 20% and to 32% in 2011. This was accompanied by a pledge to reduce this rate if oil prices decline below a certain level (Frank and Webber, 2012; Pope and Roantree, 2014).

Figure 2 indicates the various government receipts (henceforth, resource revenues) that this regime has generated from 1975 to 2010. The key messages are twofold. First, there is the relative importance of PRT in the late 1970s and much of the 1980s (and the Royalty and SPD too but to a far lesser extent and temporarily in the case of the latter). Secondly, within the last ten years of the period considered, the relative importance of CT clearly increased substantially. Indeed, the CT becomes the principal instrument used to collect resource

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[6] To the extent that population change reflects net migration, the impact of this on human capital should be reflected in the stock estimates since they are based on current labour force data.

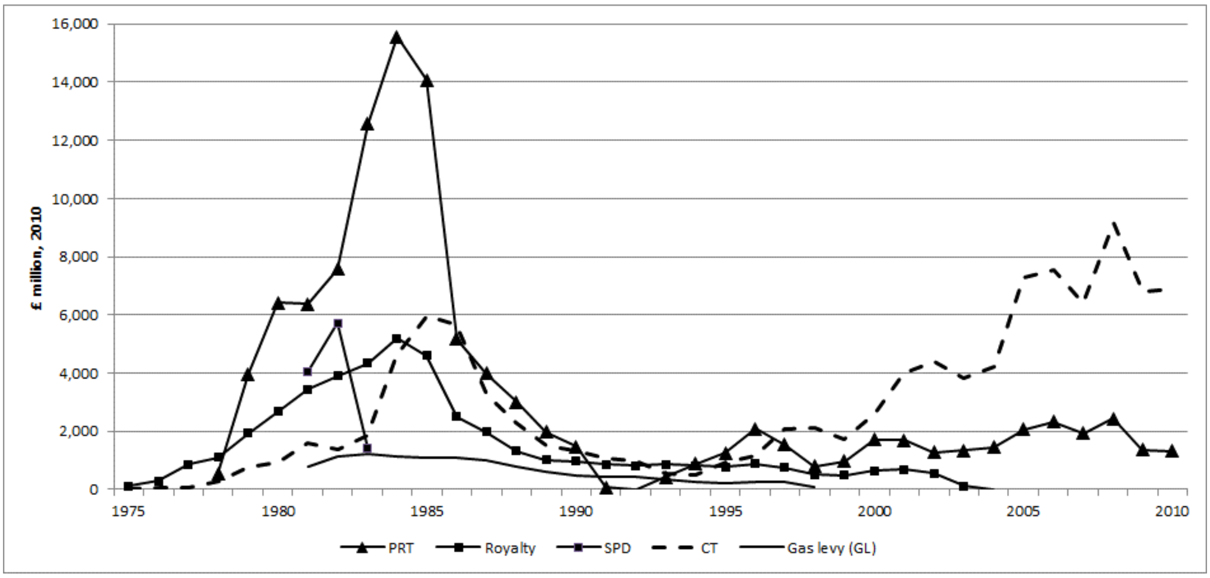
[7] See, HM Treasury (2013) for a discussion of the possible extension of this tax regime to shale gas resources in the UK

[8] Defined as the value of production net of allowable capital and operating expenditures.

[9] Note that PRT is a being a deductible item in terms of calculating what CT is due. This CT is the same as for any economic sector in the UK but with one key difference. In the oil and gas production sector, much of this CT is ring-fenced; that is, chargeable on profits from resource depletion (rather than other areas of a producer's operations) (HMRC, 2008).

revenues in the oil and gas sector. On average, these resource revenues in total[10] contributed 2.5% of total government revenues over the period 1975 to 2010. Clearly this average is skewed by the tax proceeds accruing in the 1980s where these amounted to 5.7% of total revenues on average (and 8.4% on average from 1981 to 1985).

Figure 2: UK Resource Revenues to Exchequer, 1975-2010 (GBP million, 2010)



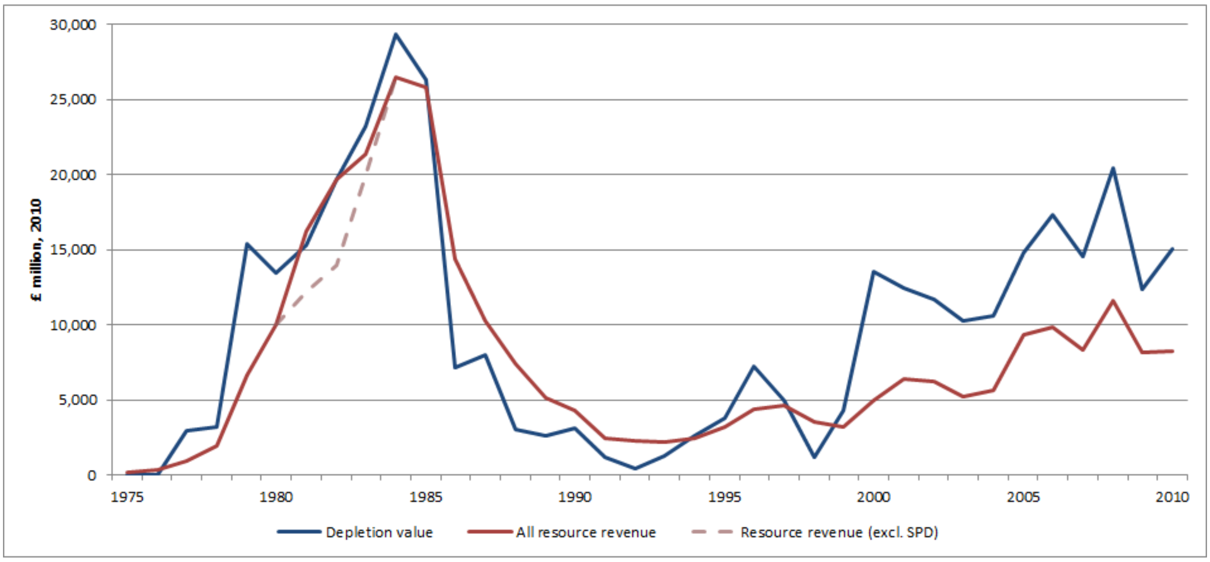
Source: adapted from data in HMRC (2013)

Figure 3 shows the extent to which these resource revenues have succeeded in capturing resource rents. We compare revenues with depletion values since, according to the theory outlined in Section 3.1 of this paper, this is the portion of total resource rents which must be invested in other assets if sustainability is to be achieved. What is interesting is that the two series track one another reasonably closely. On average, this amount captured through taxation corresponds to 80.6% of depletion values over the period 1975-2010 (which, in turn, corresponds to 65.2% of resource rents over the same period).

This is a striking result. While this tax regime has been critiqued on the grounds of being dominated by short-term macroeconomic policy and creating uncertainty for resource exploration and development (Kemp, 2011a, Nakhle, 2008, Staerck, 2002),[11] it has been effective in capturing resource rents. Figure 3 further illustrates this for the case of the SPD widely criticized as a short-term expedient (e.g. Kemp, 2011a) but which according to the figure enabled a greater proportion of depletion value to accrue to HM Government rather than producers during its brief duration from 1981 to 1983.

[10] We include here the Gas Levy. The fact that the tax was not production-based has led, for example, Scottish Government (2009) not to include its value under its assessment of oil and gas tax revenues. However, the charge is levied on resources not otherwise subject to tax presenting a case for including it as part of the benefits of depletion appropriated by central government.
[11] More broadly, Boadway and Keen (2010) identify a stable and predictable regime as well as the taxation of rents on endowments as the key elements of a theoretically defensible regime. Daniel *et al*. (2010) provide a thorough overview of both the theory and practice of resource taxation.

Figure 3: Resource Revenues in Comparison to Depletion Values (GBP million, 2010)



Of course, what this asset accounting misses is whether these depletion values were optimal (which would require that marginal resource rents rise at the rate of interest – the Hotelling Rule). And while the average performance of the tax regime is important, so is its variability. Over the 1980s and 1990s, resource revenues exceeded depletion values on average: that is, the tax regime over-performed in respect of this criterion. By contrast, from 2000 onwards there was substantial divergence, with tax revenues falling short of depletion values.

3. Simulating a Sovereign Wealth Fund for the UK

3.1 Looking Back on 1975 to 2010

To understand the potential benefits of a SWF for the UK, we simulate a fund established in 1975 and track its size and payout up to 2010. This provides estimates of the sacrifices entailed by the fund (years when resource revenues exceeded fund payouts), the long-run potential payout from 2010 onwards, and the reduction in volatility of revenues into the Treasury when comparing fund payouts to current resource revenues.

The technique we use to simulate a UK SWF is based on the 'bird-in-hand' approach employed by the Norwegian Government Pension Fund. The fund operates on the basis of three principles: all petroleum revenues are paid into the fund, revenues are invested in financial assets, and payouts from the fund to the Treasury are at a fixed rate each year. The fixed payout rate we use is based upon aggregate long-run real rates of returns on assets in major economies from 1900 to 2010 (Credit Suisse 2011). We assume that the fund is fully invested in a global portfolio of 60% equities and 40% bonds, which yields a mean real rate of return of 3.9%.

The simulation of the fund is straightforward. The net value of the fund at the end of the preceding period is equal to the gross value minus the payout on the gross value. The gross value of the fund at the end of the current period is therefore equal to current resource revenues, plus the net value of the fund at the end of the preceding period times 1 plus the nominal rate of return on assets in the current period.

A complication in the simulation is that only long run averages are reported in Credit Suisse (2011), while the underlying (Dimson-Marsh-Staunton) data on real returns by country by year are proprietary. We are therefore forced to construct a synthetic annual nominal rate of return for the UK SWF as the sum of the long-run aggregate real return on assets, 3.9%, plus the rate of inflation in the UK economy as measured by the GDP deflator. The synthetic nominal returns can differ considerably from actual returns in any given year because the assumed constant real rate of return on assets introduces an element of smoothing in the calculation. Over the long run, however, the value of the smoothed fund should be close to that of the fund based on nominal returns.

Based on this smoothed accounting, the simulated value of the fund totals GBP 284 billion in 2010 (nominal). While this hypothetical fund value amounts to only 4% of total produced assets in the UK, it would represent a rough doubling of the value of assets in the central government balance sheet.

Figure 3: Resource Revenues and Returns from a (Hypothetical) SWF

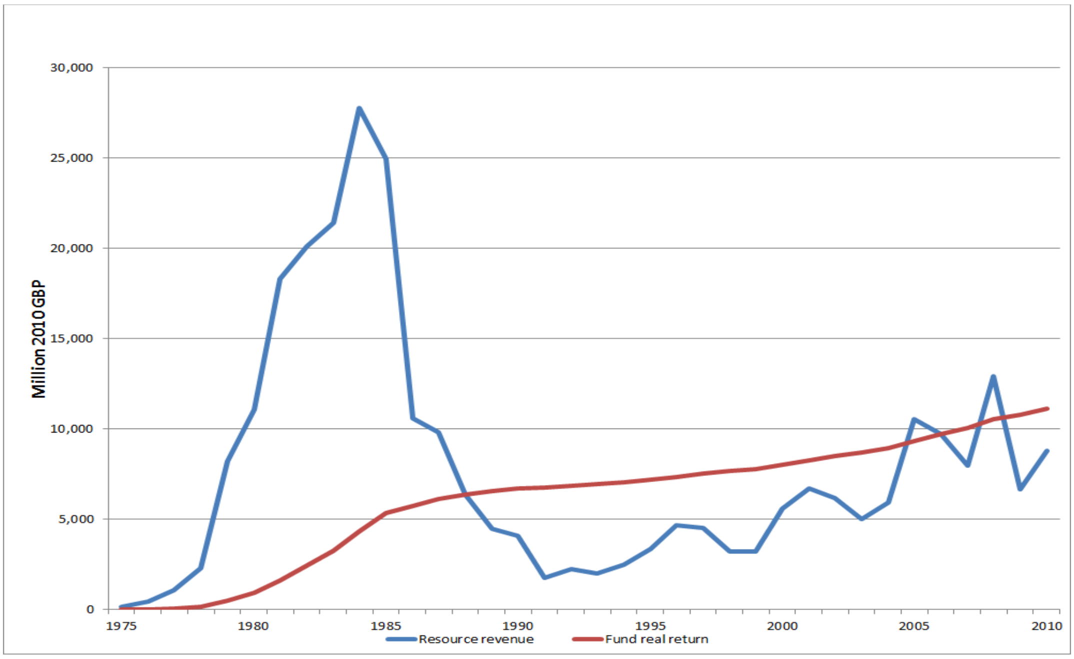


Figure 3 plots the evolution of resource revenues and the value of the payout from the simulated fund from 1975 to 2010. Two key conclusions follow: the payouts from the SWF are less volatile than annual resource revenues, and payouts exceed resource revenues from 1988 onward (with two minor exceptions). However, the figure also shows that resource revenues were much larger than the payout from the fund from 1979 to 1986, the period following the second oil crisis. While a slow buildup of payouts is a natural property of a 'bird-in-hand' fund, this result indicates the considerable short-run sacrifices that government would have had to make in implementing the fund. The compensation for this sacrifice would be a fund that continues to make annual payouts of tens of billions of pounds to the Treasury long after the North Sea petroleum deposits have ceased to be in production. We turn to this question of sacrifices in Section 4, where we carry out an ex post cost-benefit analysis of the simulated fund.

The low volatility of fund payouts seen in Figure 3 is to some extent an artefact of the smoothing introduced by our synthetic calculation of nominal returns. In Annex 2 we simulate a UK SWF that invests all of its revenues in US stocks and bonds, building upon historical data on nominal returns on US financial assets (Damodaran, 2014). This fund is compared with a SWF that also invests in US financial assets but uses a synthetic nominal return as constructed for the SWF underlying Figure 3. The fund based on observed nominal returns has a higher value in 2010 and exhibits more volatility than the smoothed fund simulated using synthetic nominal returns. From 1985 to 2010 the standard deviation of year to year changes in flows equals 35% for resource revenues, 13% for the fund simulated using nominal rates of return, and nearly 6% for the fund using synthetic estimates of nominal returns.

The simulation in Annex 2 based upon historical nominal returns shows that the resource fund buffers revenues and thereby reduces the volatility of flows to the Treasury. Yet there is a partially offsetting source of volatility in the form of year to year variation in the nominal returns on investment in the portfolio of the SWF. The Annex also indicates this broad conclusion holds for a fund based on a global portfolio of financial assets, but the data available are limited.

3.2 Looking Forward

The preceding historical simulation of a SWF has intrinsic interest. But our framework has implications for the future as well. OBR (2013) provides forecasts of predicted revenues from future oil and gas production up to around 2040. These data – while contingent on forecasts[12] – indicate that the stream of future resource revenues is likely to be declining in real terms. There is an obvious implication here. A decision to start a fund ‘now’ – based on *conventional* oil and gas resources – will be limited in terms of the size of the returns that it generates. This begs a further question. Given the on-going debate about *unconventional* gas and oil resources, what might be the revenue implications of this possible windfall?

These unconventional resources refer most notably to natural gas and, to a lesser extent, oil resources trapped in shale beds – formed of sedimentary rocks. These resources can be freed by hydraulic fracturing (or ‘fracking‘) entailing injection of fluids, including water, at high pressure into rocks (Royal Society/ Royal Academy of Engineers, 2012; DECC, 2013a). Significant attention has centred on shale gas production in the US using this technology, its transformative effect on the gas market, as well as the institutional reasons for this boom (see, for example: Rogers, 2011; Wang and Krupnick, 2013). Debate has also focused on the range of negative externalities that this extraction technology could give rise to (see, for example, Krupnick *et al*. 2013; Royal Society/ Royal Academy of Engineers, 2012; Mason *et al*. 2015).

Within the UK, two regions have been identified as having considerable potential (EIA, 2013, BGS/ DECC, (2013a, 2013b): (a) the North UK Carboniferous Shale Region: geological basins and troughs across northern England and southern Scotland; and, (b) the South UK Jurassic Shale Region: basins in Southern England and offshore into the English Channel. In what follows, we construct an asset account based on recent tentative estimates of the extent

[12] These are estimates of resource revenues (forecast to be raised from the North Sea oil and gas fiscal regime) predicted by the Office for Budgetary Responsibility (OBR). OBR published a range for these values (for high/ low resource prices and high/ low production). The data used here (currently) are the mid-range forecasts that the OBR publishes. The OBR also publishes low and high predictions based on assumptions about (respectively) less steep and steeper price paths.

of shale gas and oil in the UK. We do so, however, in the acknowledgement that there is considerable uncertainty about the extent of these resources as well as their technical and economic recoverability. To quote POST (2013, p1), an estimate of "… UK reserves could be anywhere from zero to substantial."

Table 2 summarises a handful of studies that assess availability. These refer to gas-in-place (GIP) or oil-in-place (OIP), the quantities reckoned to be physically contained in source rock (EIA, 2013). DECC (2010) estimates that shale gas reserves potential could be about 135 mtoe. However, subsequent studies by US EIA (2013)[13] and DECC (2013a, 2013b, 2014) have been more optimistic.

The substantial variation across studies partly reflects differences in scope and methodology as well as evolving knowledge about novel geological areas. Notably, the BGS/ DECC studies provide a more detailed assessment of particular basins including an assessment of the extent in place with different probability levels. The US EIA study is arguably somewhat more conservative in some of its assumptions. There is greater consistency, however, between these BGS/ DECC and US EIA estimates if the latter can be interpreted as 90% probability estimates of potential resources.

None of these estimates in Table 2 refer to the ultimate recoverability of resources. US EIA (2013) also assesses geological and technical factors influencing the likelihood of production. This results in estimates for the UK of *recoverable* shale gas of 728 mtoe and for shale oil of 94 mtoe.[14] Assuming, very optimistically, that all of these resources were economically recoverable over the longer-term, this would have the effect of doubling current UK reserves of oil and gas.

Table 2: Estimates of Potential Shale Resources (mtoe)

Publication	Area of assessment	Shale Gas	Shale Oil	Total
DECC (2010)	Whole of UK	135		135
EIA (2013)	Whole of UK	17,444	7,366	24,810
BGS/ DECC (2013a,b, 2014)	Midland Valley, Scotland	1,235 (*p90*) 2,008 (*p50*) 3,365 (*p10*)	436 (*p90*) 818 (*p50*) 1,528 (*p10*)	1671 (*p90*) 2,826 (*p50*) 4,893 (*p90*)
	Bowland, N. England	20,550 (*p10*) 33,225 (*p50*) 57,025 (*p90*)		20,550 (*p90*) 33,225 (*p50*) 57,025 (*p10*)
	Weald Basin, S. England		293 (*p90*) 591 (*p50*) 1,143 (*p10*)	293 (*p90*) 591 (*p50*) 1,143 (*p10*)

Notes: *p(90)* refers to 90% probability of estimated resources being in place; *p(50)* refers to 50% probability of estimated resources being in place; *p(10)* refers 10% probability of estimated resources being in place;

To construct a preliminary asset account for shale gas and oil resources, we use as our starting point the data for resources-in-place from BGS/ DECC (2013a,b, 2014). Regarding recoverability, POST (2013) relates the US experience that reserves have tended to

[13] This is an increase on an earlier initial study described in US EIA (2011).
[14] BGS/ DECC (2013a,b, 2014), however, baulks at estimating recovery factors such as this on the basis of current uncertainty.

correspond to 8% to 20% of this measure of resource extent. This seems a generous assumption given the findings of US EIA (2013) which stresses the likely geological complexity of the UK compared to the US experience. Hence, we assume – in broad line with EIA (2013) – recoverability of 4% (but also test for sensitivity to more and less conservative assumptions). It is important to note this further (implicitly) assumes technically recoverability equates to economic recoverability (e.g. proven plus possible reserves). Moreover, we are unable here to consider the environmental and regulatory hurdles that will also determine actual recoverability (KPMG, 2011) and, therefore, the value of these resources as economic assets.

For accounting purposes, further assumptions are needed on a range of parameters. This includes resource prices, the timing and magnitude of depletion as well as the proportion of the value of this production appropriated by Government through a future fiscal regime. Table A3.1 in Annex 3 provides details of these assumed values and lower and upper bounds assumed to test sensitivity. We note here though significant uncertainties do exist regarding, for example, development and production costs in the UK and Europe generally (see Rogers, 2011; Stevens, 2013 although some estimates of possible costs are presented in IEA, 2012, 2013).

Table 3 illustrates some initial assessments of the implied magnitudes of a simulated fund for our base-case. What is clear is that this fund could match our estimate for conventional oil and gas over 1975-2010 only if relatively high levels of both resource availability and recovery rates can be assumed. Yet the suggestion in the BGS/ DECC (2013, 2014a,b) studies as well as US EIA (2013) is that resource availability is far more likely to correspond to the medium or perhaps even the lower bound of the estimates that we use. For this lower bound amount, a recovery rate of about 4% could produce a fund roughly equivalent in size to that achieved by investing resource revenues from conventional oil and gas over the same period. A further Table in Annex 3 looks at the sensitivity of these findings to alternative assumptions about other important parameters.

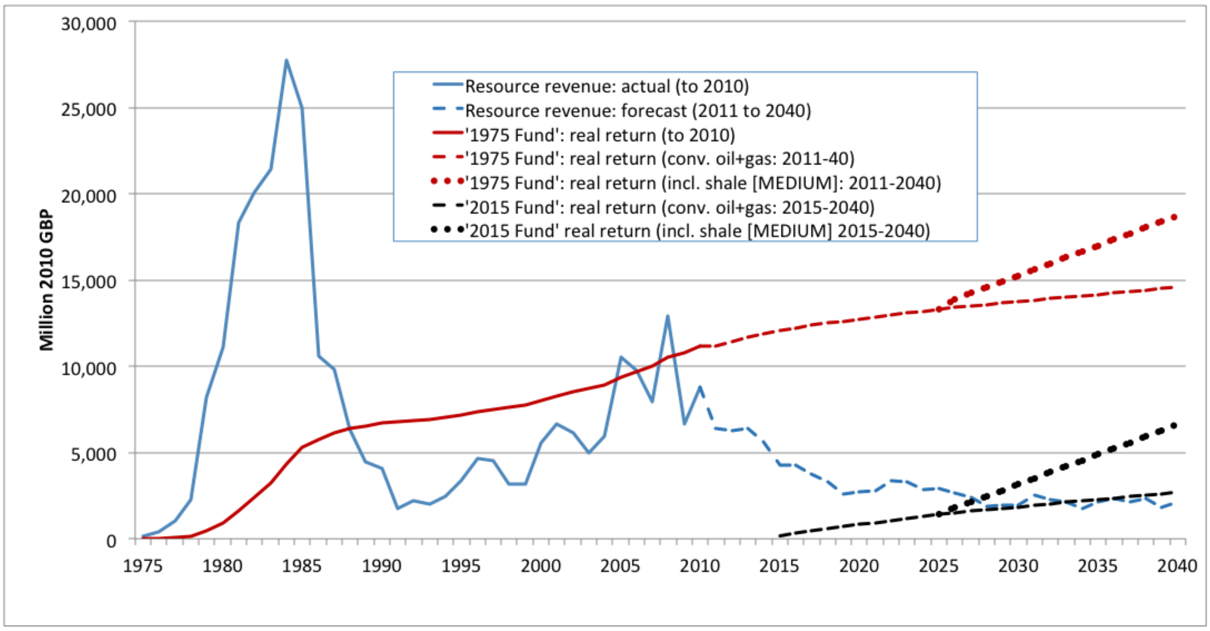
Table 3: Hypothetical values of a SWF for UK Shale Resources (2010, GBP millions)

Estimated Resources	**Assumed recovery rate**		
	4 per cent	2 per cent	6 per cent
Low	62,679	31,339	94,018
Medium	100,286	50,143	150,429
High	175,500	87,850	263,250

Notes: See Table A3.1 in Annex 3 for details of assumed values used to estimate these magnitudes

Finally, Figure 4 places this in the context of our earlier analysis in Section 3.1 of revenues and (hypothetical) fund returns. The series of unbroken lines repeat those earlier findings (i.e. Figure 3) whereas the series of broken line continue this story from 2011 to 2040. Resource revenues from conventional oil and gas (blue line) are forecast to decline over this period, from GBP 5 to 6 billion annually over the period 2011-2020 to around GBP 2 billion annually from 2031-2040). If a fund for conventional oil and gas were established from 2015, then only by the end of the period would its potential returns exceed the forecast revenues.

Figure 4: Resource Revenues and Returns to 2040



Source: authors' calculations

Of course, all such assessments of future resource values are contingent on oil prices. Annex Table A1.1 shows the effect of the large oil price drop in 1986 on resource asset values. The 2014/2015 fall in oil prices is of a similar magnitude. The current debate surrounding the externalities that could result from exploration and exploitation of shale gas (Royal Society/ Royal Academy of Engineering, 2012, Mason *et al*. 2015) is also relevant here, since this could reduce the expected social value of shale-based sub-soil assets.[15]

This point notwithstanding, if shale oil and gas revenues were included in such a fund, then depending on the size of the resources (low, medium or high corresponding to Table 3) clearly this will boost fund payouts significantly (the higher broken black line in Figure 4). Exactly how much will depend on the timing of significant shale resource production. The (higher) broken red lines illustrate the missed opportunity of not starting a fund using resource revenues in 1975. While conventional oil and gas add a further one-third to this fund by 2040 (about GBP 90 billion, GBP 2010), shale resources add between 22% and 62% (with a best guess of 35%) with a corresponding increase in (hypothetical) returns by 2040.

4. Discussion: Cost and Benefits of Establishing a SWF

Given the current prevalence of SWFs in a growing number of resource abundant countries, it is worth asking why the UK chose not to establish a fund. Kemp (2011a,b) provides a thorough review of the relevant official historical documents (including British Cabinet minutes and papers) providing formal records of this decision, crucially in the late 1970s. His account indicates a wide ranging debate about: the appropriate scale of a fund (e.g. would it be a repository for all resource revenues or just some smaller proportion); the expenditure it could facilitate (i.e. discrete investment projects or reducing external debt burdens) and

[15] However, Mason *et al*. (2015) also cite beneficial externalities on, for example, (national) energy security and displacement of the use of coal for energy production.

whether this hypothecation of tax revenues would misallocate resources by possibly divorcing these spending decisions from normal fiscal processes.

Importantly, Kemp identifies the apparent absence in explicit debate – up to the political decision in 1979 not to establish a fund – of intergenerational equity, as a guiding principle for managing this UK resource windfall. Such discussion came more to the fore, however, when in the early- to mid-1980s concerns resurfaced about the use of resource revenues (perhaps in part as a result of the by-then apparent magnitudes of resource revenues). In particular, a series of contributions by the Bank of England (BoE 1980, 1982 and, later, 1986) explicitly recognises that these revenues were generated by a 'wasting asset' and as such "… would require investment of sufficient of the revenues to main the real value of the capital." (BoE, 1982, p56).[16]

Common to those later papers was discussion of principles and, broadly speaking, an investment strategy rather than a more detailed plan based on revisiting the idea of establishing a fund. Moreover, in the 1970s, Kemp (2011a) makes clear that was discussed was a very particular type of fund, construed as an investment account (using the typology in van der Ploeg, 2014, discussed earlier) with which to fund identified 'projects' in the same fiscal year as resource revenues were paid in. So what was debated then was not a SWF in the sense commonly understood now (or, for that matter, as would have been observable in examples from Alaska and Alberta in the late 1970s).

Stewart (2013) further cites the difficult economic context, particularly in the early 1980s, as a practical obstacle to a positive decision to establish a fund.[17] Kemp (2011a) notes a significant element of the economic strategy of the in-coming Conservative administration in 1979 was to use resource revenues to support its macroeconomic policy and reduce public borrowing. HM Government Budgets from 1979 reduced both basic and higher rates of income tax, while the tax rate on corporations was considerably reduced from 1984. Resource tax rates meanwhile rose, with the PRT rate levied on oil and gas was increasing in 1979, 1980 and 1982. As a result, resource revenues increased from 3.5% of central government tax receipts in 1979 to peak at 10.1% in 1984.

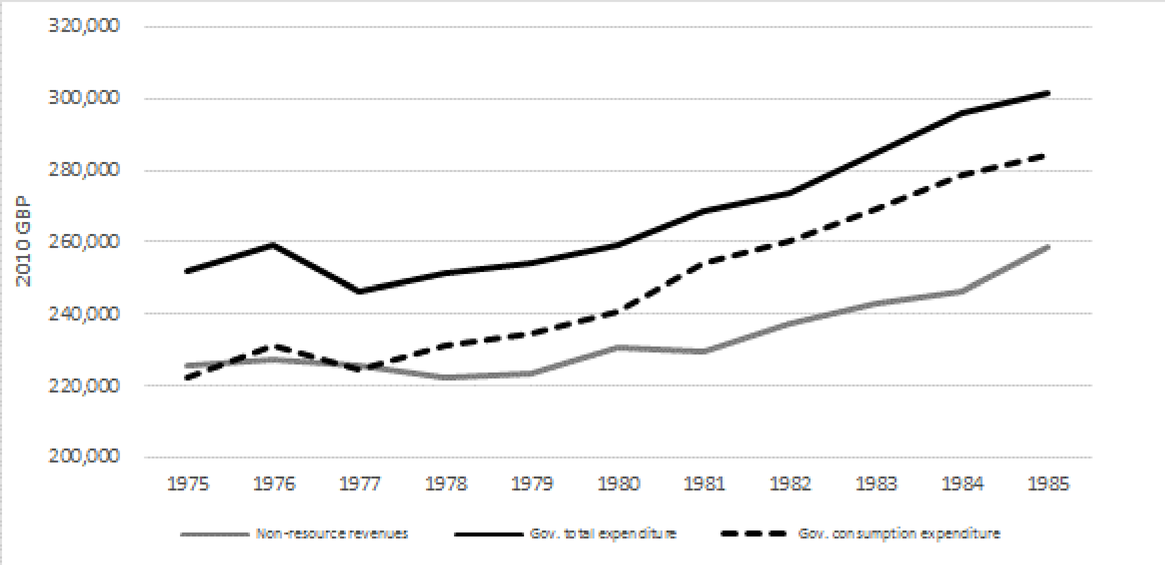
The fiscal consequences of instead investing these resource revenues in a SWF in the early 1980s presumably would have been large. To illustrate this, Figure 5 focuses on the first decade of oil production. Both government consumption and total expenditure grew strongly from 1977 to 1985. There was a flattening of non-resource revenue from 1975 to 1979, and it grew more slowly than total and consumption expenditure afterwards. Because money is fungible there is no unambiguous way to determine how resource revenues affected the main fiscal aggregates historically. One message, however, from the figure is that it appears possible that resources revenues contributed significantly to filling the gap between (non-resource) revenue and expenditure.[18]

[16] Odling-Smee and Riley (1985) examines this same issue from the perspective of the UK Treasury and the role of resource revenues in improving public finances.

[17] There was some debate about whether increases in oil and gas production was itself responsible for some of these problems through, for example, appreciation in the exchange rate and decline of the manufacturing sector (see, for example, Atkinson *et al*. 1982). Bean (1987), however, concludes that while some impact cannot be ruled out, a more significant factor appears to have been macroeconomic policy during this period.

[18] Of course, some portion of what officially comprises government consumption may actually have an investment component, particularly expenditure on education. Data published in ONS (2014) indicate that from 1979 to 1985 education expenditures increased by 0.3% in real terms over this 6 year period. This is

Figure 5: Non-resource Tax Revenues and Government Expenditure from 1975 to 1985



Source: ONS (2014)

To explore the likely sacrifice from the establishment of a sovereign wealth fund in 1975, we choose not to simulate a counterfactual path for the fiscal revenues and expenditures that could result from. This would be essentially arbitrary. The alternative we examine is to carry out an *ex post* cost-benefit analysis of the SWF as a public investment. Resource revenues transferred to the fund become costs from the Treasury viewpoint, while fund payouts to the Treasury are benefits. For simplicity we assume that the petroleum resource is depleted by 2010. Costs of investing in the SWF cease at this point. The fund, however, is assumed to continue paying out an amount equal to its 2010 value (the real return on the portfolio) in perpetuity. Table 4 shows the present value of costs and benefits of investing in the SWF, normalized per capita, for different time horizons and discount rate assumptions.

To isolate the effects of the oil price bubble and other economic circumstances in the early 1980s, we simulate costs and benefits for two assumptions about the year that investment in the fund commenced, 1975 and 1990. Starting in 1975 yields a larger present value of benefits from the fund, but it also yields a high present value of costs because these costs (payments into the fund) are front-end loaded. This front-end loading is much diminished for the fund simulated to commence in 1990.

The first discount rate assumed, fixed 3.5%, is equal to the *Green Book 2003* social discount rate for projects where costs and benefits span 30 years or less. The second discounting scenario uses a discount rate of 3.5% that declines beyond 30 years. This is the *Green Book 2003* social discount rate assumption for assessing policies affecting the long term[19] – which is precisely what a SWF is designed to do.

considerably lower than the average annual increase (1.8%) for 1975-2010 (see also Crawford *et al*. 2009). By contrast, non-education government consumption increased by 3.4% over 1979-1985.

[19] The schedule of the declining discount rate is 3.5% for the first 30 years, 3.0% for the next 45, 2.5% for the next 50, 2.0% for the next 75, 1.5% for the next 100, and 1.0% beyond this point.

Table 4. Costs and Benefits of Establishing a SWF, 2010 GBP / capita

	Fund established 1975		Fund established 1990	
	Total resource revenue (cost)	SWF returns (benefit)	Total resource revenue (cost)	SWF returns (benefit)
Fixed 3.5% discount rate				
Present value	2,897	3,182	1,251	1,394
Levelized costs and benefits	145	159	88	98
Ratio of benefits to costs	1.10		1.11	
Declining 3.5% discount rate				
Present value	3,000	5,068	1,251	2,510
Levelized costs and benefits	143	240	88	176
Ratio of benefits to costs	1.69		2.00	

Source: Authors' calculation. The discount rates are derived from *Green Book 2003*. Levelized costs and benefits are calculated over 1975-2010 or 1990-2010 as appropriate.

As shown in Table 4, the present value of benefits from the SWF exceeds costs by 10% to 69% for the fund starting in 1975; for the fund starting in 1990 the corresponding figures are 11% and 100%. In terms of levelized *net* annual benefits, these vary from GBP 14 to 10 per capita for the fixed discount rate, and GBP 97 to 88 for the declining discount rate – in each case the 1990 scenario yields the lower net benefit figures.

The fixed discount rate results are of course sensitive to the choice of discount rate, with a discount rate of 3.92% (the assumed constant real rate of return of the SWF) yielding 0 net benefits for either start year. This is an artifact of the synthetic nominal SWF return that we simulate.

This ex post analysis suggests that if a SWF had been established per *Green Book 2003* standards, the net benefits per capita would be positive and moderately large for the assumption of declining discount rates. This assumes, of course, 20/20 hindsight and requires the use of a discounting standard that did not exist in 1975 or 1990.

5. Conclusions

We have simulated a potential fund based on investing resource revenues. Specifically, had the UK established such a fund along the lines of the Norwegian example, starting in 1975, its value would amount to about GBP 284 billion in 2010. We show that this would have provided a number of further benefits. First, there would be much lower volatility of payouts from the fund compared with the volatility of resource revenues; this would have consequences for fiscal stability. Second, owing to the early 1980's bubble in oil prices, the fund would have fairly rapidly produced annual income greater than annual resource revenues.[20] Lastly, the UK government would today enjoy a rough doubling of the public sector balance sheet, and the balance sheet would be more diversified.

Such benefits are not without sacrifice of course. Resource revenues would flow into the SWF, with only the returns on the fund being paid into general government revenues. On the presumption that it makes little sense to pay into a SWF and simultaneously increase public debt,[21] then in the absence of more borrowing, non-oil fiscal revenues and so public expenditures would have to adjust to preserve the gross operating balance of central government after the SWF is established. While we have not sought to evaluate an arbitrary counterfactual to the historical government policy, we do show that from a cost-benefit perspective, the net benefits per capita would be positive and reasonably large.

Of course, this cost-benefit case relies on a number of assumptions including SWF returns being enjoyed in perpetuity. This potential for sustained payouts is clearly a virtue. Indeed, from this standpoint, the UK decision in 1979 (and implicitly subsequently) against establishment might be viewed as a failure of a basic (but early) test of government commitment to sustainability. Having said that, the need for a formal fund has been questioned more recently by Hughes (2014) in large, diverse economies where resource rents are a relatively small percentage of activity; e.g. the UK over the past 40 years or so. Reinvesting these rents is important, he continues, but the degree of reinvestment can be assessed by using an indicator such as depletion-adjusted saving. Our finding, however, is that depletion-adjusted saving has been relatively low in the UK since 1975, pointing to insufficient investment of resource revenues.

Had it established a fund in 1975 as we have simulated here, the UK would have been in the experimental vanguard. What is perhaps surprising is that the policy debate about establishing a fund appears not to have been seriously revisited until recently. The current debate appears to hinge on the use of revenues from shale-based depletion only. [22,23] Our analysis of shale oil and gas shows that a fund of similar size is only likely to be realized for relatively optimistic assessments of shale gas and oil resource availability and high recovery rates. While more conservative assumptions could result in a fund that is still considerable in magnitude, these findings emphasise the size of the missed opportunity in the past. And paradoxically, while we show that – in the past – resource revenues have tracked depletion values reasonably closely, there is more recent evidence of divergence between these series.

Doubts about the size of future resource revenues do not negate the case for a resource fund. Resource prices are volatile and large increases have been experienced in the early 1970s and 80s, as well as the mid-2000s. Having a fund in place would position the UK, and any country with similar or larger resources, to benefit from any such windfall. And, as we have shown, comprehensive resource asset accounts can be a complementary tool to support the establishment of a fund, assess the effectiveness of resource taxation, and track progress toward sustainability.

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[20] This bubble, of course, could not have been foreseen by decision-makers in 1975.

[21] This assumes that rates of return on international investments are not significantly higher than domestic borrowing costs.

[22] See, for example: http://www.bbc.com/news/uk-england-29968603 (accessed 04/08/2015).

[23] But see Hughes (2014) for a discussion in the context of Scottish independence.

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Annex 1

Table A1.1: Monetary Asset Account for UK Oil and Gas, 1975-2010 (2010, million GBP unless otherwise indicated)

	Asset value	Production value	Resource rent	Depletion value (% of resource rent)	
1975	0	1,540	0	0	
1976	0	4,252	0	0	
1977	74,029	10,476	4,340	2,961	(68.2%)
1978	80,766	12,539	4,735	3,231	(68.2%)
1979	384,820	31,541	22,559	15,393	(68.2%)
1980	336,844	29,477	19,747	13,474	(68.2%)
1981	366,939	32,923	22,078	15,289	(69.3%)
1982	393,723	38,692	26,766	19,686	(73.5%)
1983	394,298	42,845	30,113	23,194	(77.0%)
1984	410,378	49,858	36,308	29,313	(80.7%)
1985	342,530	47,055	32,122	26,348	(82.0%)
1986	85,913	23,335	8,590	7,159	(83.3%)
1987	95,437	23,846	9,542	7,953	(83.3%)
1988	36,736	17,333	3,673	3,061	(83.3%)
1989	33,479	16,811	3,140	2,575	(82.0%)
1990	40,480	18,109	3,796	3,114	(82.0%)
1991	16,341	16,363	1,446	1,167	(80.7%)
1992	6,021	15,848	505	401	(79.5%)
1993	17,171	17,614	1,519	1,227	(80.7%)
1994	31,732	19,466	3,173	2,644	(83.3%)
1995	41,431	20,454	4,447	3,766	(84.7%)
1996	72,129	24,240	8,380	7,213	(86.1%)
1997	54,871	21,780	5,890	4,988	(84.7%)
1998	12,053	17,142	1,400	1,205	(86.1%)
1999	34,100	20,320	4,793	4,262	(88.9%)
2000	108,503	30,318	15,251	13,563	(88.9%)
2001	99,294	28,400	13,956	12,412	(88.9%)
2002	93,276	27,413	13,111	11,660	(88.9%)
2003	82,240	25,296	11,559	10,280	(88.9%)
2004	95,237	25,562	12,095	10,582	(87.5%)
2005	147,638	30,736	17,152	14,764	(86.1%)
2006	172,820	34,029	20,077	17,282	(86.1%)
2007	145,187	31,304	16,867	14,519	(86.1%)
2008	224,469	39,534	24,093	20,406	(84.7%)
2009	136,137	30,070	14,612	12,376	(84.7%)
2010	181,022	33,504	18,099	15,085	(83.3%)

Annex 2

In this annex we simulate a SWF for the UK that invests only in US financial assets, yielding results that are in some respects more realistic than those calculated in the main body of the paper. The analysis builds upon historical data on nominal returns on US financial assets going back to 1928 (reported in Damodaran 2014), as well as historical inflation data from the US Bureau of Labor Statistics.

The simulations of the US asset fund employ two alternative assumptions. The first assumption is that returns on the resource fund are calculated at historical nominal rates for the US. Under the second assumption, a synthetic nominal return is calculated as the sum of the inflation rate and the long run real rate of return on US financial assets (this is the approach used in the main body of the paper). UK resource revenues are converted to US dollars at annual average exchange rates.

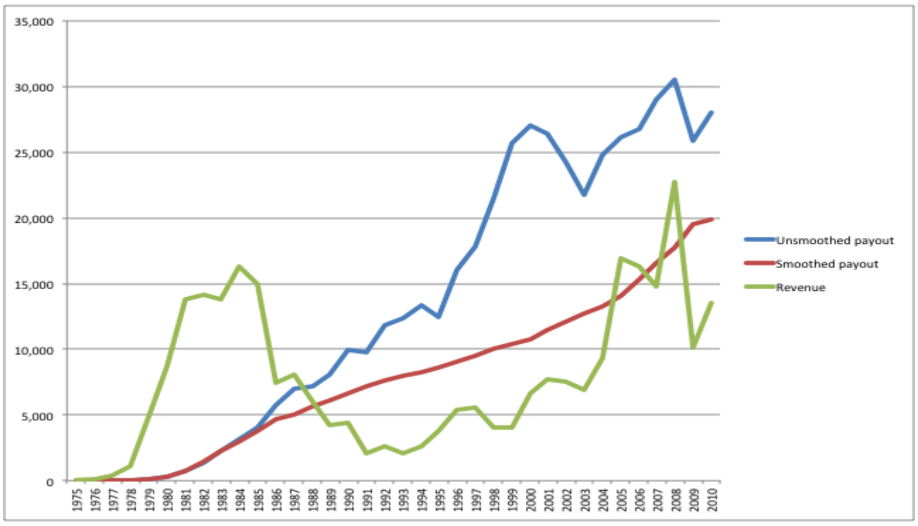
The basic variables for the simulation are gross fund value $A^G(t)$, net fund value $A^N(t)$, long-run real rate of return on financial assets r^r (constant), nominal rate of return $r^n(t)$, annual inflation $i(t)$ and resource revenues $R(t)$. For fund payout $r^r * A^G(t-1)$ the basic accounting is as follows:

$$A^N(t-1) = A^G(t-1) * (1 - r^r)$$

$$A^G(t) = R(t) + A^N(t-1) * \left(1 + r^n(t)\right)$$

Given an initial endowment of the fund $A^G(0)$, these two equations permit simulation of the growth of the fund and the payouts from the fund as resource revenues are captured. In the 'unsmoothed' simulation nominal returns $r^n(t)$ are measured at historical values; in the 'smoothed' simulation nominal returns are calculated as $r^n(t) = i(t) + r^r$. According to data from Damodaran (2014), a fund invested 60% in the S&P 500 and 40% in 10 year bonds would have a long-run (1928-2013) real rate of return r^r of 4.6%.

Figure A2.1 UK SWF Invested in US Financial Assets, Smoothed and Unsmoothed, $mn (nominal), 1975-2010



Source: authors' calculations

Figure A2.1 plots resource revenues and payouts from the unsmoothed and smoothed funds in nominal dollars from 1975 to 2010. As expected, the curves for resource revenues and the smoothed fund bear a family resemblance to the equivalent curves in Figure 3, with the key difference being nominal dollars vs. constant 2010 GBP. By 2010 the unsmoothed fund using historical nominal returns is nearly 50% larger than the smoothed fund (reflecting high returns on financial assets in the US during the 1980s and 1990s), and its payouts are much more volatile.

Table A2.1: Standard Deviation of Year on Year Changes in Revenues and Fund Payouts

	US[1]	UK[2]	World[3]
	1985-2010	1985-2010	1997-2010
Resource revenues	35.2%	36.5%	35.8%
Unsmoothed payouts	13.1%	17.3%	16.4%
Smoothed payouts	5.8%	5.1%	10.3%

Source: authors' calculations
Notes – Based on data on returns in: [1] Damadoran (2014); [2] Barclays; (2013); [3] Dimson *et al*. (2002)

By measuring year-on-year changes in revenues and the two measures of fund returns, we calculate the volatility of these changes as seen in Table A2.1. The first column of the table shows that even unsmoothed payouts, based on historical nominal returns on financial assets, reduce the volatility of flows into the Treasury considerably compared to the alternative of simply paying the proceeds of resource taxation into general revenues.

By way of comparison, the second column looks at the volatility of a fund based on the return on UK equities over the same period. The final column measures the volatility of a global portfolio over 1997-2010 (based on data on global returns in Dimson *et al*. 2002). The rankings of the different measures of the volatility of revenues and fund payouts are the same across the three columns, while the UK and World portfolios exhibit higher levels of volatility compared to the US.

Annex 3

Table A3.1 below describes the data used to calculate the size of a fund based on shale (gas and oil) resources. The initial parameter values refer to a broad measure of prospective shale oil and gas (Section 4). These 'resources-in-place' might be "low", "medium" or "high" in extent. This, in turn, is based approximately on the totals implied by BGS/ DECC (2013a,b, 2014) in its assessments across Scotland (Midland Valley), North England (Bowland) and South England (Weald Basin) (see Table 2). Immediately below in Table A3.1 is an assumption about what percentage of these (low, medium or high levels of) resources in place are actually recoverable. For example, a recovery rate of 4% on the medium estimate of 'resources-in-place' implies 'reserves' of about 1,440 mtoe; a recovery rate of 6% on the high estimate of resources in place implies reserves of about 3,780 mtoe, and so on.

The remaining values in the Table reflect choices about parameters needed to transform this assumed estimate of physical reserves into a monetary flow of depleted resources and the accumulation of a potential fund. Specifically: (a) the unit values for tonne of oil equivalent resource is based roughly on OBR (2014); (b) we assume that production is zero until a given date (e.g. production begins in 2020, 2025 or 2030) and is constant thereafter (until the resource is exhausted); and, (c) in terms of accumulation of a fund, we further assume that resource revenues accrue from the outset of production with an arbitrary cut-off, for purposes of illustration, of 2040.

Table A3.1: Assumptions and Parameter Choices for SWF Based on (Future) Revenues from Shale Resources

		Base-case	Sensitivity	
Total resources in place (mtoe)	Low	22,500		
	Medium	36,000		
	High	63,000		
Percentage of resources recoverable		2,%, 4%, 6%		
Start of production: years from 2010		15	10	20
Depletion path/ lifetimes		35	25	45
Price: GBP per toe (GBP, 2010)		500	400	600
Total rent: as % of production value		50%	35%	65%
Resource revenues: as % of total rent		65%	50%	80%

Table A3.2 describes the value of a *hypothetical SWF* that could be built, by 2040, from depleting these assumed shale resources. The initial three rows of results indicate the size of the fund given: (a) three distinct potential sizes of 'resources-in-place'; (b) three distinct probabilities of these resources being recovered; plus (c) a range of additional (base-case) assumptions. The following four rows indicates the sensitivity of findings – for low and medium resources-in-place only – to a different assumption about when production begins: i.e. a shorter or longer time horizon for resource revenues to accumulate in a fund by 2040 (and where all other parameter values remain the same). The final four rows assume production begins in 2025 – again, for low and medium resources-in-place – but otherwise look at relatively 'optimistic' and 'pessimistic' scenarios. In the former, the oil price is high as is the proportion of rent (to production value) and in addition the capture of resource revenues is high too. In the latter, all of these parameters are assumed to take low values. (See Table A3.1 for details.)

Table A3.2: Sensitivity of a Hypothetical SWF in 2040 to Alternative Assumptions (million GBP, 2010)

Estimated Resources	Assumed recovery rate			Other assumptions
	4 per cent	2 per cent	6 per cent	
Low	62,679	31,339	94,018	*See base-case assumptions in Table 3*
Medium	100,286	50,143	150,429	
High	175,500	87,850	263,250	
Low	83,571	41,786	125,357	*Production begins in 2020 + rest of base-case assumptions*
Medium	133,714	66,857	200,571	
Low	41,786	20,893	62,679	*Production begins in 2030 + rest of base-case assumptions*
Medium	66,857	33,429	100,286	
Low	120,343	60,171	180,514	*Price/ rent/ resource revenues high + rest of base-case*
Medium	201,080	100,540	301,619	
Low	27,000	13,500	40,500	*Price/ rent/ resource revenues low + rest of base case*
Medium	43,200	21,600	64,800	

Recall that our fund for 1975-2010 was GBP 284,106 million (GBP, 2010) by 2010. The above Table indicates that a shale-based fund only approaches this magnitude in the presence of a high amount of resources-in-place and a 6% recovery of those resources (i.e. GBP 263,250 million, GBP 2010) or either earlier production and/ or optimistic assumptions about other parameter values. The possible fund sizes for more conservative estimates remains significant in many cases, although not so with more pessimistic (but still plausible) assumptions. Linking this back to our discussion of Figure 4, Table A3.3 illustrates the magnitude, and implied pay-out, in 2040 of two hypothetical SWFs; one beginning in 1975 and the other beginning in 2015 (based on e.g. medium levels of resources-in-place and an assumed 4% recovery rate).

Table A.3.3: Summary of Size and Payment from Hypothetical SWF in 2040 (million GBP, 2010)

		Size of hypothetical fund	Implied fund payout
1975 Fund	**Total**	477,679	18,725
	Contribution from:		
	Conventional resource revenues: 1975-2010	284,106	11,137
	Conventional resource revenues: 2011-2040	93,287	3,657
	Shale resource revenues: 2015-2040	100,286	3,931
2015 Fund	**Total**	168,910	6,621
	Contribution from:		
	Conventional resource revenues: 2015-2040	68,624	2,690
	Shale resource revenues: 2015-2040	100,286	3,931