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Guidelines for Exploiting Natural Resource Wealth

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GUIDELINES FOR EXPLOITING NATURAL RESOURCE WEALTH

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Abstract

The principles of how best to manage the various components of national wealth are outlined, where the permanent income hypothesis, the Hotelling rule and the Hartwick rule play a prominent role. As far as managing natural resource wealth is concerned, a case is made to use an intergenerational sovereign wealth fund to smooth consumption across generations, a liquidity fund for the precautionary buffers to deal with commodity price volatility, and an investment fund to park part of the windfall until the country is ready to absorb extra spending on domestic investment. Capital scarcity implies that a positive part of the windfall should be spent on domestic investment. The conclusions highlight the political economy problems that will have to be tackled with these normative proposals for managing wealth.

Keywords: permanent income, Hotelling rule, Hartwick rule, precaution, capital scarcity, absorption constraints, Dutch disease, investing to invest, political economy

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I. Introduction

What is the wealth of a nation? One way of looking at it is that it consists of the total assets owned by citizens, businesses and government of a particular country minus all the liabilities of these parties.[1] The net financial claims such as shares, bonds, commodities owned by the nation are certainly part of a nation's net wealth, provided one is careful to net out government bonds owned by own citizens. From an accounting point of view, the year-to-year change in net financial claims must correspond to the current account of the nation.[2] Hence, if the nation produces more than it consumes or exports more than it imports and earns interest income from abroad, its current account will be positive and the nation will be getting richer in terms of the net financial claims held on the rest of the world. We will refer to this as the net financial wealth held overseas.

But this is not all what determines the wealth of the nation. The wealth of the nation also consists of physical capital, natural capital, human capital, and its creative wealth. Physical capital consists of factories including machineries and transport vehicles, but also the physical infrastructure (irrespective of whether it is provided publically or privately) of a country. Human capital is defined as the earning power of the working population of a nation and corresponds to the present discounted value of all future wage income that can be earned in future years by the working population (Hamilton and Liu, this issue). Income before taxes should be used because the present discounted value of taxes to be paid by the working population is netted out by the corresponding future claims of the government. Of course, this is difficult to assess since one has to make an assessment of the expected future productivity growth and earnings of the nation as well as of the number of unemployed, disabled persons and pensioners in the future as well as the expected lifetimes of the working population. Natural capital (see Obst and Vardon, this issue, and Helm, this issue) consists of the value of all under-the-ground resources such as oil, gas, diamonds, minerals and water but also of the value of the various types of land including waste lands, forests, agricultural land, wetlands, and land to build on and of the value of the fish in territorial waters. As shown by the detailed endeavours of the World Bank (2006) to create a cross-country database, these require heroic assumptions about matters such as how to price natural assets, what interest rates to use, what extraction or harvesting costs to employ and what to assume about sustainable harvesting of forests and fisheries (e.g., van der Ploeg and Poelhekke, 2010). Nevertheless, an impressive database has been developed which can be used to better understand what constitutes the wealth of a nation and how to best manage it.

[1] A good overview of the issues is given in Cameron and Hamilton, this issue.

[2] Of course, one has to make appropriate adjustment to allow for revaluations of assets and liabilities due to changes in asset prices and/or exchange rates.

The World Bank supposes that the present value of consumption corresponds to total wealth. In that case, the residual between this and the sum of financial wealth held abroad, physical capital, human wealth, and natural resource wealth is the unmeasured portion of total wealth which includes institutional, social and other forms of intangible capital. Hamilton and Liu (this issue) refer to this as in intangible capital.[3] It is the stock equivalent of the Solow residual in growth accounting and shows how much additional intangible capital is created by making efficient use of the other more tangible components of national wealth. The World Bank data suggest that the rich OECD countries have actually in absolute terms more natural resources that are exploited than poorer sub-Saharan countries, but natural resource wealth for the latter countries is often a much greater share of the nation's wealth. The reason is that the rich countries have a huge share of intangible wealth in the nations' wealth (as well as more physical capital).

The genuine change in net wealth of the nation can be split up in the following seven components:

(1) the current account,

(2) the investment in net capital (both private capital and infrastructure) after providing for depreciation,

(3) the changes in human capital (approximated by the total amount spent on education, less losses to human capital from death and depreciation),

(4) the change in intangible capital (partially approximated by spending on R&D)[4],

(5) the depletion of exhaustible natural resources such as oil, gas and minerals,

(6) the depletion of renewable resources such as fisheries and forests which is unsustainable, and

(7) the deterioration of the quality of the natural environment,

(8) the revaluation of assets and liabilities.

This change in net wealth is often referred to as *genuine saving* of a nation. Component (4) of genuine saving often gets less attention than it should. However, it has a similar interpretation as the Solow residual in growth accounting in as far as it measures what we don't know. The World Bank painstakingly

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[3] Mankiw, Romer and Weil (1992) show how augmenting the Solow model of neoclassical growth to allow for the accumulation of human capital as well as physical capital leads to a much better description of cross-country differences in income per capita and of conditional convergence. This is the flow equivalent of what we call human capital and should be distinguished from intangible capital, which included all other determinants of growth and prosperity like institutional capital, legal structure and how efficient a country employs its factors of production. Being able to empirically distinguish between intangible and human capital requires strong assumptions about the aggregate production function.

[4] More recently, the methodology and database have been extended to allow for human capital as well tangible wealth so as to create a better estimate of the intangible capital residual as a kind of stock equivalent of total factor productivity or the Solow residual (Hamilton and Liu, 2013).

makes adjustments to allow for the depletion of natural resources, viz. components (5) and (6). The World Bank also allows for a negative impact of the deterioration of the quality of the natural environment as can be seen from component (7), which is conceptually similar to the depreciation of assets mentioned under (8) as it is a loss value of the environment when environment is considered as an asset. Hence, the social cost associates with the emissions of greenhouse gases resulting from burning fossil fuel and the social cost of fine particles are factored in and subtracted from genuine saving. Of course, this requires an assessment of what the present value of the marginal damages associated with emitting another unit of fossil fuel or of fine particles and depends very much on the social rate of discount. More generally, component (8) consists of the total of revaluations of assets and liabilities due to changes in asset prices, commodity prices and the exchange rate. For example, a depreciation of the currency would boost the value of assets denominated in foreign currency. An expected increase in future commodity prices would boost the value of natural resource wealth.

If the measures of genuine wealth and genuine saving thus constructed provide a full and accurate picture, a country becomes richer if genuine saving is positive and poorer if genuine saving is negative (e.g., Arrow et al., 2003). Under the assumptions that population growth is constant, consumption per citizen is independent of the size of the population and production displays constant returns to scale, it can be shown that net saving per citizen equals the change in social welfare per citizen (Dasgupta, 2001). If the more conventional components of wealth creation, components (1)-(4), show a surplus, this thus does not necessarily mean that the nation is getting richer as seen from a broader and more comprehensive perspective. For example, if the natural resources are depleted from the crust of the earth in an unsustainable manner and pollution of the natural environment is big, then components (5)-(7) show a deficit which may be large enough to offset the surplus on the more conventional components (1)-(4).

In a country with a rapidly growing population one might want to steer towards zero genuine saving per head of the population in order to smooth consumption per head of current and future cohorts. This requires a surplus in genuine saving corresponding to the product of the rate of population growth and the nation's genuine wealth, but a proper welfare-founded analysis is more complicated. In contrast, a country who is expected to have rapid productivity growth may wish to have some genuine dissaving since current poorer cohorts should be expected to make less of a sacrifice than future richer cohorts who will be richer as they benefit from much higher state of technical progress than the current cohorts.

The objective of this paper is to take the above discussion further and show how the various components of a nation's wealth are best managed. The resulting proposals are based on a mixture of the well-known permanent income hypothesis, the Hotelling rule for efficient natural resource depletion (Hotelling, 1931) and the celebrated Hartwick rule for the speed at which to transform assets under the ground into assets above the ground (Hartwick, 1977; Hamilton and Hartwick, 2005; Hamilton and Hartwick, this issue). We will introduce capital scarcity, absorption constraints and volatility of commodity and asset prices and on the basis of the resulting analysis argue for three types of fund: an *intergenerational* fund to smooth consumption across generations, a *liquidity* (or stabilization) fund to collect precautionary buffers to hedge against residual, non-diversifiable risk, and an *investment* fund to park funds until the economy is ready to absorb the new spending on investment projects (cf. van der Ploeg and Venables (2012)). We unashamedly take a normative rather than a positive approach, but will discuss at the end some political pitfalls.

Section II discusses how to much to save and accumulate and how much to consume and offers some guidelines on how to manage national wealth paying particular attention on the role of intergenerational sovereign wealth funds in managing natural resource wealth. Section III extends the framework of section II to allow for the notorious stochastic volatility of commodity prices and makes the case for a separate liquidity or stabilization fund next to an intergenerational fund as hedging is for most countries either impractical or politically inadvisable. This section also discusses how to take account of asset price volatility and how hedging should take place in countries where the biggest assets is the hidden national resource wealth hidden in the crust of the earth. It also argues that one may want to go short in those assets that are negatively correlated with the return on natural resource wealth that is in the crust of the earth, so that as a hedge one borrows to buy assets that are negatively correlated with the return on natural resources. Section IV extends the framework to allow for capital scarcity and absorption constraints and makes the case for a separate investment fund next to the intergenerational and liquidity funds. This section highlights the inefficiencies associated with adjustment costs incurred when rapidly ramping up investment in infrastructure. It also highlights the notion of home-grown infrastructure, which cannot be purchased on international markets, and how this leads to temporary Dutch disease phenomena. Section V concludes with a summary of the normative policy proposals and briefly discusses some political caveats.

II. Managing the various components of national wealth

We start with offering a basic stylized framework on how to manage the various components of a nation's wealth.[5] To keep it simple, we abstract from renewable resources, the deterioration of the quality of the environment and revaluations of assets and liabilities so that we leave out components (6)-(8) in the change in wealth discussed above. We thus suppose that the wealth of a nation consists of net foreign assets *F*, capital consisting of production capital *K* and infrastructure *S*, human capital *H*, intangible

[5] For related studies on how to manage resource wealth keeping, however, the rate of extraction of natural resources constant, see Collier et al. (2010) and Segal (2012).

capital A, and natural resources, R which corresponds to the flows mentioned under components (1)-(5) of the change in the nation's wealth. Human capital can be interpreted to include health capital as well as educational capital. Infrastructure includes private and public infrastructure and might consist of legal infrastructure as well as bridges, roads and railways.

To gain some initial insight in how to manage the various components of a nation's wealth, we first focus at a small open economy with perfect access to international capital market which can freely lend and borrow at a given world rate of interest r. This economy is small in that it takes world prices for its produced goods as given, bur large in that it can exercise some monopoly power in the export markets for the sale of its natural resources. Labour supply L is exogenous and grows at the rate n. The production factors of production necessary to produce final goods are physical capital K, infrastructure S, and labour L. Aggregate production is given by $AY(K,S,HL)$, where $Y(K,S,HL)$ is a concave production function with constant returns to scale, H is human wealth of a representative household with one unit supply of labour, and A is total factor productivity which grows at the exogenous rate g. We suppose that the nation does not use natural resources to produce final goods, but does extract and sell natural resources N each year on world markets. It can extract natural resources at zero cost, but the initial stock of natural resources R_0 is finite. For sake of argument, the country faces isoelastic foreign demand for its natural resources with constant price elasticity equal to $\varepsilon > 1$. The inverse demand function for natural resources is denoted by $p = p(N)$. Although the country is small, we are assuming that it has some market power on the world market for the specific natural resource in which it is endowed. What matters is that the instantaneous profit function is concave, which can be obtained alternatively with a convex extraction cost function. However, we suppose that the cost of extracting one unit of natural resources is equal to the constant Ψ.

Society has utilitarian preferences, so simply adds the utilities across all citizens at a given point of time. The utility of the representative citizen is the present discounted value of a stream of current and future felicities, where the felicity at any point of time increases and marginal felicity falls as consumption increases (i.e., $U(C/L)$ with $U' > 0$ and $U'' < 0$ with C denoting aggregate consumption and C/L consumption per capita). For simplicity, we suppose that there is a constant elasticity of intertemporal substitution σ, which corresponds to constant relative risk aversion $1/\sigma$ (i.e., $-CU''/U' = 1/\sigma$). We will also refer to $1/\sigma$ as the coefficient of relative intergenerational inequality aversion. We refer to ρ as the social rate of discount. It is the rate which is used to discount welfare units and is therefore the utility rather than the consumption) rate of discount. The country has to decide how much to invest in production capital, infrastructure, and human capital, how much to consume, and how much of national saving to allocate across the different assets. It does this by maximizing a discounted utilitarian social welfare function subject to the constraints describing the development of net foreign asset holdings from the current account[6], dynamics of investment in physical capital, infrastructure and human capital, and the depletion of the reserves of natural resources. The optimality conditions (see appendix I) can be summarized as follows.

First, the growth rate in per-capita consumption must be proportional to the gap between the world interest rate and the discount rate with the factor of proportionality being equal to the inverse of intergenerational inequality aversion (see equation (A5)). This is the celebrated Keynes-Ramsey rule. Hence, the more society cares about intergenerational inequality, the less it is prepared to depress consumption today in order to save and have more consumption in the future.

Second, efficiency requires that the marginal value of net foreign assets, physical capital, infrastructure and human capital should be equalized, so we can speak of the marginal value of wealth for short. It follows that the marginal products of physical capital, infrastructure and human capital should all equal the same user cost consisting of the rental plus depreciation charges.

Third, the marginal revenue of natural resources sold on world markets should equal the sum of their marginal extraction cost Ψ and their Hotelling rent. The Hotelling rent itself should grow at the market rate of interest in order for society to be indifferent between keeping an extra unit in the soil and taking it out of the soil. This is the celebrated Hotelling rule. It implies that the rate of change in the commodity price equals the rate of interest minus the monopoly mark-up on the marginal extraction cost. The rate of change in the resource extraction rate falls at a rate which is the product of the rate of change in the commodity price and the price elasticity of commodity demand. With isoelastic demand and if we were to assume zero extraction cost of natural resources, then the price of natural resources would have to grow at the rate of interest r and demand fall at a rate equal to the product of the interest rate r and the price elasticity of commodity demand ε. This approximation for the Hotelling rule is reasonable for relatively scarce natural resources such as oil and gas for which the extraction cost is a relatively small proportion of marginal revenue, but it is not a good assumption for coal which can be quite costly to extract.

Fourth, natural resource wealth is defined as the present value of natural resource revenue. Given the Hotelling rule, this can be shown to equal the present value of current oil revenue divided by the elasticity of commodity demand. Natural resource wealth thus simply equals the price of the commodity times the stock of natural resource reserves. In general, the more inelastic demand for natural resources (the lower ε), the bigger the monopoly power on the world market for natural resources, and the larger natural resource wealth.

[6] If the sum of interest income from abroad and sales revenues from production and natural resource rents exceeds the sum of demand for consumption and investment goods, then the nation's holding of foreign assets increases.

Fifth, total wealth of the nation V is defined as the sum of net foreign assets, physical capital, infrastructure, human capital and natural resource wealth. It follows that the change in the total wealth of the nation must equal the interest on the wealth of the nation minus aggregate consumption of the nation. Using the Keynes-Ramsey rule and ruling out Ponzi games, the corresponding present-value budget constraint states that the present value of aggregate consumption cannot exceed total wealth of the nation. At an optimum aggregate consumption C thus equals a constant proportion of total wealth V; to be precise, $C = \left[(1-\sigma)r + \sigma\rho - n\right]V.$ If the intertemporal substitution effect exactly offsets the income effect (i.e., if the elasticity of intertemporal substitution σ equals one), this marginal propensity to consume simplifies to $(\rho - n),$ where ρ is the social rate of discount and n is the population growth rate. If the intertemporal substitution effect does not fully offset the income effect (i.e., $\sigma < 1$), it is clear that the marginal propensity to consume out of total wealth increases in the interest rate. Otherwise, the substitution effect dominates and the marginal propensity to consume decreases in the interest rate as the main impact is now substitution of current for future consumption as saving becomes more attractive. As consumption per capita (C/L) grows at the rate $\sigma(r-\rho),$ wealth per capita (V/L) also grows at this rate.

In case the discount rate equals the world interest rate, $\rho = r$, it follows that consumption per capita and total wealth per capita are fully smoothed. This implies that falls in natural resource wealth per capita must be exactly compensated for by increases in non-resource wealth per capita. For example, if the nation has less oil wealth per capita, this must be fully compensated for by higher net foreign assets, physical capital, infrastructure or human capital per capita. This echoes the celebrated Hartwick rule (1977), which says that under-the-ground assets must be fully converted into above-the-ground assets in such a way that total wealth is unchanged.

It helps to consider the dynamics of non-resource wealth in efficiency units (i.e., corrected for both population growth and productivity growth) for the case $\rho = r$ (see equation (A11) in appendix I). This shows that a high value of natural resource reserves leads to accumulation of non-resource assets, especially if the demand for natural resources is more elastic and the trend rate of growth of the economy is large. Hence, if the depletion of natural reserves occurs more rapidly, the nation needs to save more in other non-resource assets to keep consumption and total wealth per citizen constant over time. A higher trend rate of growth implies that natural resource income (in efficiency units) declines more rapidly and thus also necessitates more saving per capita in order to smooth consumption across generations.

Natural resource prices, in practice, do not follow Hotelling paths very closely. Hence, we also consider the case where the time path of natural extraction follows an exogenous, possibly ad hoc path, where V^R denotes the present value of natural resource revenues corresponding to this ad hoc extraction path and

$(r-n)V^R$ indicates the permanent value of natural resource revenues (i.e., the annuity value of natural resource wealth). The temporary component of natural resource revenues then equals actual revenue minus the permanent value of revenues. We thus obtain the following guidelines.

Guidelines 1: *National wealth should be managed according to the following six guidelines:*

(a) Net saving of non-resource assets by the nation, whether it is accumulation of net foreign assets, capital, infrastructure or human capital, should react to the temporary component of natural resource revenue.

(b) Consumption should be a fixed proportion of the nation's total wealth. Specifically, this means that consumption should react to the equivalent permanent value of natural resource income (i.e., the annuity provided by the natural resource wealth) and not to current natural resource revenue. This proportion should equal the growth-corrected interest corrected for population growth if this equals the corresponding social rate of discount.

(c) The quicker the depletion of natural resources and fall in natural resource revenue, the bigger the gap between current and permanent natural resource revenue and thus the country should save a bigger proportion of its natural resource windfall.[7]

(d) With $\rho = r$ any running down of natural resource wealth must exactly be compensated for by increasing in net foreign assets or net investment in physical capital, infrastructure or human capital, so that total wealth per capita stays constant.

(e) If the country can borrow on international markets for net investment in capital, infrastructure and human capital and run current account deficits for that purpose, then the size of such investments should be independent of the size of the natural resource windfall.

Guidelines (a), (b) and (c) are in accordance with the permanent income hypothesis, since they ensure that consumption is optimally smoothed across different generations. In societies where the incumbent politicians are primarily motivated by securing re-election, the social rate of discount can be much higher ($\rho > r$). In that case, the propensity to consume out of wealth is higher and the nation saves less and will be getting poorer with the passage of time, especially if politicians have a high willingness to substitute present for future consumption as indicated by a low elasticity of intergenerational inequality aversion.[8]

[7] With isoelastic demand this occurs for higher price elastiticities of natural resource demand. The country then has less monopoly power on the word market for natural resources and thus does not hold back depletion of natural resources.

[8] Some deduce intergenerational inequality aversion from household saving studies (with a typical estimate being 1.5), but politicians who have to make a judgment about welfare of different generations will have a completely different value. A utilitarian politician will have zero inequality aversion when considering the welfare of different generations whilst a Rawlsian politician will have infinite inequality aversion when applying the max-min criterion.

Guideline (d) corresponds to the celebrated Hartwick rule (Hartwick, 1977; Hamilton and Hartwick, 2005; Hamilton and Hartwick, this issue). Guideline (e) follows from the condition that the return on the various types of assets should be equalized and thus that with perfect access to international capital markets all types of investment can be financed with international borrowing and be independent of the size of the natural resource windfall. Of course, as we already know from the empirical evidence regarding the Feldstein-Horioka puzzle, this guideline will not be observed if countries face capital scarcity. We will explore this in section IV.

To illustrate Guidelines 1, consider an exponentially declining windfall of natural resource revenues $\Omega \exp(-\omega t)$, which declines exponentially at the exogenous rate $\omega > 0$. Let us refer to it as an oil windfall for short. Clearly, this formulation can also be used to model oil rents after extraction costs. It can then be shown that the permanent value of this windfall equals $\left(\frac{r-n}{\omega+r-n}\right)\Omega \exp(-\omega t)$ and thus the transient component is $\left(\frac{\omega}{\omega+r-n}\right)\Omega \exp(-\omega t)$. The fraction of the current oil windfall that should be saved should, according to Guideline 1(c), equal $\left(\frac{\omega}{\omega+r-n}\right)$. We thus see that in line with the permanent income hypothesis a bigger proportion of the windfall is saved if the windfall is rapidly declining (high value of ω). For the extreme case of a permanent windfall ($\omega = 0$), none of the windfall must be saved. At the other extreme, as the duration of a windfall goes to zero ($\omega \to \infty$), all of the windfall should be saved.

These guidelines can also be used to indicate how a *temporary* and *anticipated* oil windfall corresponding to zero windfall revenue from time T onwards should be managed. This permits us to highlight the case for sovereign wealth funds, which is usually made for the case where $\rho = r$. To achieve smoothing of consumption across different generations a temporary and anticipated windfall with oil revenue ceasing after time T necessitates borrowing ahead of the windfall, repaying debt and interest followed by building up assets during the oil windfall, and consuming the income from accumulated assets after the windfall. Such a policy fully smoothes consumption and thus fully smoothes national wealth, hence it implies that any fall in under-the-ground oil wealth must be compensated with a matching increase in above-the-ground financial wealth. For example, in the run up to the windfall the borrowing must exactly be matched by the increase in the oil wealth (i.e., the present discounted value of the windfall) as a result of it becoming closer and thus being subject to less severe discounting. During the windfall the paying off of debt and building up of financial assets is exactly matched by the reduction in under-the-ground oil wealth resulting from depletion. After the windfall under-the-ground oil wealth is zero and thus above-the-ground financial wealth must be constant and exactly equal to initial oil wealth.

If the economy is enjoying trend productivity growth at the rate g, it seems reasonable to choose the social rate of discount in such a way that consumption per capita increases at this rate. This requires one to set $\rho = r - g/\sigma$, so that the discount rate is depressed somewhat to ensure that there is more saving now in order to have higher consumption in the future. This adjustment can be smaller if intertemporal substitution is easier. See section III.1 for an application of this idea.

Guidelines 2: *With the social discount rate chosen to ensure smoothing of consumption per capita and a windfall which is both anticipated and temporary we have the following policy guidelines for managing a sovereign wealth fund and smoothing consumption across generations:*

1. *In anticipation of a certain natural resource windfall the country should borrow on international financial markets.*
2. *During the extraction of the natural resource, the country should first repay the accumulated debt plus interest and then continue to build a sovereign wealth fund.*
3. *Once the windfall has ceased the country withdraws a fixed annuity each year from the fund, which remains constant from that time onwards.*
4. *If the social discount rate is chosen to ensure that consumption per capita grows at the rate of productivity growth, the fund and the annuity will grow at this rate too.*

III. Volatile commodity and asset prices, diversification and precautionary buffers

To cope with volatile commodity prices, one could in principle use options to hedge the risk. Such options provide an insurance policy against the risk of future commodity price volatility. However, in a world with frictionless markets, infinite horizons and no capital scarcity or asymmetric information, to protect against volatile commodity prices hedging and using a stabilization or liquidity fund can deliver the same result – they are precisely equivalent in an ideal world. Of course, the world is not ideal in which case these two methods for dealing with volatility are not equivalent. Indeed, in practice, futures markets are too thin and costly for this to really work or simply do not exist and it is better to rely on fund to cope with commodity price volatility. Although barrier options such as a knockout option[9] are cheaper than plain-vanilla put options, they are also riskier. Furthermore, if the fund is relatively big, then one might open to the charge of market manipulation. Finally, hedging is politically very risky. Citizens will be hard to convince that money spent on a hedge to protect against falling commodity prices is well spent if oil

[9] A knockout option is an option where the upside for the buyer is limited, and is hence cheaper to buy. For instance, a call option on $100 oil might have a strike price of $110 and a knock out price of $120. The option holder can profit up to $120, after which the option expires worthless, limiting the potential loss for the option writer, and hence the cost of writing the option.

prices consequently do not fall, since especially in poorer countries the money might be better spent on education, housing or health of poor people. Many developing countries thus have to live with a large amount of non-diversifiable commodity price risk. The best way to deal with this risk is to accumulate precautionary buffers in a liquidity fund, so that when there is a positive shock to commodity prices extra revenue is channelled towards the fund and with a negative shock the fund helps to mitigate the fall in consumption.

Flexible labour and good markets and avoiding irreversible commitments help to be better prepared for commodity price volatility. The government could also relate debt payments to the commodity prices it is vulnerable to, so that in the event of a crash in commodity prices the debt burden falls as well and diversify the economy into sectors whose fortunes are negatively correlated with the commodity sector.

We first extend the framework of section II to allow for the volatility of commodity prices and discuss how this leads to the need for a liquidity or stabilization fund next to an intergenerational fund. We then discuss how the optimal management of the various components of natural resources is affected by the volatility of asset prices. To simplify the exposition, we will consider exogenous extraction paths of natural resources and abstract from physical capital, infrastructure and human wealth. We thus focus on resource wealth V^R and non-resource financial wealth held abroad in a fund F, so that total wealth simply equals $V = V^R + F$. Resource wealth is the expected present value of future resource rents and A can be viewed as the size of the sovereign wealth fund.

III.1. Commodity price volatility and the rationale for a liquidity fund

As shown by Kimball (1990), prudence occurs if the third derivative of the utility function is positive. The coefficient of relative prudence is defined as $CRP = -CU'''(C)/U''(C) = 1 + 1/\sigma$ and thus moves up and down with the coefficient of relative risk aversion and the degree of intergenerational inequality aversion. Policy makers face uncertainty about commodity prices, natural resource reserves, investment returns, asset returns and general economic outcomes, notably growth prospects. We focus, for the time being, on the most important form of uncertainty for resource-rich economies, namely commodity price volatility. We use a mean-reversion model for commodity prices, which corresponds to a homoskedastic AR(1) process for the log of commodity prices. For simplicity, we focus on net foreign assets (as indicated by component (1) in the introduction) so that the government maximizes the expected value of the utilitarian social welfare function subject to the constraint $\dot{F} = rF + \left[P(N) - \Psi\right]N - C$ whilst taking the time path of natural resource rents, $(P - \Psi)N$, as exogenous, where F indicates net foreign assets held by the country and Ψ indicates marginal natural resource extraction costs as before. The optimization conditions yield a stochastic Euler equation or Keynes-Ramsey rule to allow for prudence (see appendix II). This implies that, even if the world interest rate equals the social rate of discount ($r = \rho$), the expected growth in consumption is positive, which implies that the country is saving precautionary buffers initially by running current account surpluses. The extent of this precautionary saving and the resulting magnitude of the precautionary buffers that are being accumulated are bigger if prudence and relative volatility of commodity prices are substantial. Furthermore, the expected growth in consumption and the resulting degree of precautionary saving are higher if commodity price shocks are less transient because the permanent income hypothesis suggests that a greater part of the revenue resulting from more permanent shocks is saved if these shocks are more permanent. Hence, if shocks are permanent, all expected future prices increase by the same amount as the initial shock and the precautionary buffers will be large. If shocks are purely transient, they have no effect on future expected commodity prices and there will be no precautionary saving. In general, with mean reversion the effect of current commodity price shocks on expected values of future price shocks is positive but less than one and the effect on precautionary saving is smaller. Finally, there is less need for precautionary saving if productivity growth makes a country richer in the future and is hence better able to deal with future income shocks.

To illustrate the effects of precautionary saving, we present in Table 1 some calculations for the optimal sizes of the required intergenerational and liquidity funds and the resulting permanent consumption increments that these can support for two oil/gas-rich countries, namely Norway and Iraq (for more details see van den Bremer and van der Ploeg (2013). [10] Our calibration supposes that Iraq oil is cheaper to extract in Iraq (10 US $/barrel) than in Norway (15 US $/barrel o.e.). Furthermore, population growth n in Iraq (2.3% per annum) is much rapid than in Norway (0.5%). The rate of technical progress g is 1.8% per annum in Iraq and 1% in Norway, so that total trend growth rates for these two countries are 4.1% and 1.5% per annum, respectively. The real risk-free interest rate is 6% per annum in Iraq and 3.4% in Norway.

We assume that the social rates of discount in Iraq and Norway are chosen so that consumption is smoothed in efficiency units, not consumption or consumption per capita, so that the annuity per capita will grow at the rate of technical progress like everything else in the economy. In a growing economy this requires that the discount rate is set lower than that would be required to smooth consumption per capita.[11] This seems not unreasonable given that recipients of the natural resource 'dividend' would like

[10] Oil-rich countries will have larger current account surpluses in the face of more volatile oil price volatility (Ghosh and Ostry, 1997; Bems and Carvalho Filho, 2011). Furthermore, oil price volatility can be seen to lead to more aggressive oil extraction rates (e.g., Pindyck, 1980, 1981; van der Ploeg, 2011).

[11] Smoothing consumption per capita requires that the discount rate is set to the interest rate, $\rho = r$. However, smoothing consumption in efficiency units requires that $\rho = r - g/\sigma < r$ if $g > 0$ where σ indicates the elasticity of intertemporal substitution.

to see their dividend in line with the growth in wages and profits. Furthermore, there is no incentive to borrow using future growth as collateral.[12] As a result, the reported consumption increments that can be financed by the accumulated funds will grow at the trend rate of growth. Using this choice of social discount rates requires one to set ρ equal to 6% and 3.4% in Iraq and Norway, respectively, so that the growth-corrected social discount (measured in utility units) and real interest rates in both countries are both 1.9% per annum. We set the coefficient of relative prudence equal to 3.

For the stochastic process (13) we set $\upsilon_P = 0$. For crude oil we estimate $\hat{m}_P^* \hat{\eta}_P = 0.27$ (t-ratio = 1.33) and $\hat{\eta}_P = 0.066$ (t-ratio = 1.16) and $\hat{\sigma}_P^* = 0.29$ for the period 1960-2011, which corresponds to a mean price of $\exp(\hat{m}_P) = 110$ US$ per barrel and a volatility of $\hat{\sigma}_P = 0.26$. For the gas price we obtain $\hat{m}_P^* \hat{\eta}_P^* = 0.21$ (t-ratio = 1.70) and $\hat{\eta}_P^* = 0.066$ (t-ratio = 1.54), which corresponds to a mean price of $\exp(\hat{m}_P) = 32$ US$ per barrel of oil equivalent, $\hat{\eta}_P = 0.064$ and a volatility of $\hat{\sigma}_P = 0.20$.

Norway

The Norwegian oil and gas industry constitutes about a quarter of GDP and half of exports. The peak of oil production was at around the turn of the millennium. The Norwegian government puts the revenue in the Government Pension Fund Global, which functions both as an intergenerational and a liquidity fund. Production from proven oil and gas reserves will fall substantially during the next twenty five years, even allowing for improved recovery, discoveries of new fields and undiscovered resources. Projected net oil and gas cash flows to the government decline up to 2060 and are sensitive to the projected oil price. Average extraction costs were 9 US$/b.o.e. during 1990-2000, 6 US$/b.o.e. for 2000-2005 and 14 US$/b.o.e. for 2005-2010. For the future we adopt constant extraction costs of 15 US$/b.o.e. Reserves at the end of 2011 are 24.5 billion b.o.e. of gas and 22.0 billion b.o.e. of liquids (mainly oil and henceforth denominated as oil). We use official forecasts for the extraction scenario. Using this assumption for extraction cost and the 2012 price of oil and the 2012 production of oil and gas, annual resource rents are calculated to be 92 billion US$ in 2012 or 28% of non-resource GDP and taper off to 15% of non-resource GDP in 2030 under the official production forecast and our estimated process for the oil price.

To determine the size of the optimal intergenerational buffer, we calculate the optimal savings responses when oil price volatility is set to zero. This results in a gradual increase in sovereign wealth accumulation, from initially 1.8 to eventually 6.8 times non-resource GDP. This saving response ensures a permanent

[12] Of course, one has to incorporate credit constraints that prevent borrowing on the basis of future growth and thus prevent efficient smoothing of consumption explicitly into a more general analysis. With the chosen parameter values such credit constraints do not bite, but they might if a less farsighted (conservative) view is taken.

increase in consumption of 12.9% of non-resource GDP or an annual annuity of 8,537 US$ in efficiency units for each Norwegian citizen in 2012. This annuity for each citizen will grow at the productivity growth rate of 1% per annum. To obtain an estimate of the magnitude of the optimal size of the liquidity fund, we calculate the optimal savings response with oil price volatility described by (13). Norway should thus accumulate a mere additional 3% of non-resource GDP in its liquidity fund. Still, it amounts to an additional fund of 1966 US$ per citizen in 2012 growing at a rate of 1% per year. The prudent saving response implies less consumption today (–0.3% of non-resource GDP) and more consumption in the long run (0.06%). The temporary nature of Norway's windfall implies that the prudence effect also falls with time and the upward tilt of the path for the consumption increment reduces with time accordingly. A lower economic growth rate boosts oil production in efficiency units and thus boosts the marginal propensity to consume out of an oil price shock and induces a bigger liquidity buffer. A bigger prudence effect is also obtained if we use estimates for a random walk process as shocks now persist forever; the optimal size of the liquidity fund is 3.5 times bigger.

Table 1: Optimal sizes of intergenerational and liquidity funds

			Norway	Iraq
Intergenerational fund	Final fund size	[% non-resource GDP] [USD per citizen]	677 $449{,}292\times1.01^t$	17,214 $80{,}429\times1.018^t$
	Permanent consumption annuity	[% non-resource GDP] [USD per citizen]	12.9 $8{,}537\times1.01^t$	327 $1{,}528\times1.018^t$
Liquidity fund	Additional final fund size	[% non-resource GDP] [USD per citizen]	3 1966×1.01^t	1179 5510×1.018^t
	Precautionary saving 2012	[% non-resource GDP] [USD per citizen]	0.3 202×1.01^t	72 338×1.018^t
	Additional permanent consumption annuity	[% non-resource GDP] [USD per citizen]	0.06 37×1.01^t	22 105×1.018^t

Key: The variable *t* indicates the number of years that has lapsed since the beginning of the plan.

Iraq

Iraq has made significant economic progress since the Transitional Government was established in 2005. Annual headline inflation has fallen from over 60% to single digits, and the dinar has remained stable against the US dollar. Debt sustainability has improved. Domestic fuel subsidies have been ended. The reduction in conflict and ensuing economic progress has led to large increases in oil extraction. Oil reserves at the end of 2011 were 143 billion barrels of oil and we suppose that production will grow linearly and reach 2 billion barrels per year in 2030, up from 1 billion barrels in 2011. With estimated extraction costs of 10US$ per barrel and oil prices at 110 US$/barrel in 2011, oil rents are 87% of total GDP or 650% of non-resource GDP. Oil rents are then projected to rise to 200 billion US$ in 2030.

Ignoring oil price volatility, Iraq should accumulate sovereign wealth amounting to a gigantic 172 times non-resource GDP reflecting both the huge size of its windfall and its low level of non-resource GDP. This gives rise to a sustained annual consumption increment of 3.3 times non-resource GDP. The corresponding intergenerational fund grows to 80,429 US$ per capita and amounts to an initial annual annuity of 1,528 US$ for each citizen, both of which will grow at 1.8% per year. Iraq's initial annuity for each citizen is smaller than for Norway (8537 US$), but grows at a faster rate. Since the Iraqi windfall is large and lasts long, the marginal propensity to consume out of oil wealth will be large so that Iraq is vulnerable to oil price volatility and needs to build up a relatively large volatility buffer or stabilization fund compared to its generational fund. The prudent gradual accumulation of financial assets over eight decades leads taking account of oil price volatility to a volatility buffer of 12 times non-resource GDP (5,510 US$ per Iraqi, again growing at 1.8% per annum), which amounts to 7% of the intergenerational fund. This brings the total sovereign wealth fund up to 184 times non-resource GDP or 85,839 US$ per Iraqi citizen, which again grows at the rate of 1.8% per year. To achieve this, consumption has to fall compared with the no-prudence outcome, so that it rises by 255% instead of 327% of non-resource GDP initially (i.e., by 338 US$ per citizen less, growing at the rate 1.8% per year) and then rises to 349% of non-resource GDP in the long run. More disappointing growth prospects do not affect the final size of the intergenerational fund (as consumption in efficiency units is smoothed across generations), but does lead to a bigger permanent consumption increment and to a significantly larger liquidity fund underlining the reducing effect of productivity growth on the need for precautionary saving. Using a random walk for oil prices instead of an AR(1) process does not affect the size of the optimal intergenerational fund, but does lead to liquidity fund which is a factor 8 bigger. Hence, the effects of mean reversion on the size of the liquidity fund are substantial.

We summarize what we have learned from managing natural resource wealth under commodity price volatility in the following policy recommendation.

Guideline 3: *Besides an intergenerational sovereign wealth fund a resource-rich country should have a liquidity fund to channel the precautionary buffers necessary to cover for commodity price uncertainty. This liquidity fund will be relatively large if commodity prices are more volatile and shocks to commodity prices are more persistent, if growth prospects are more bleak, and if policy makers are more prudent and have less intergenerational inequality aversion. A more temporary natural resource windfall necessitates less precautionary buffers, but more intergenerational buffers.*

III.2. What assets should the intergenerational and liquidity funds invest in?

By careful choice of the sovereign wealth portfolio a resource-rich country can hedge the risks associated with commodity price volatility. The key question is whether one should choose equity holdings in companies who lose when the oil price rises, in companies who benefit from increases in the oil price. Examples of the former are intensive energy users such as aluminium smelters or steel producers, whilst examples of the latter are companies that offer substitutes for fossil fuels or produce energy efficient cars. Net asset holders that invest in companies whose share prices vary inversely with the price of oil need to hold less precautionary buffers. The continuous-time theory of capital asset pricing (e.g., Merton, 1990) with the standard theory of prudential saving (e.g., Kimball, 1990) has been integrated to generate policy recommendations on how to manage under-the-ground resource assets and above-the-ground financial assets in an optimal manner (Bremer, van der Ploeg and Wills, 2013).[13]

The capital asset pricing model states that the problem of portfolio management can be separated into two parts (Tobin, 1958). First, the size of the risky portfolio relative to the total portfolio is inversely related to the coefficient of relative risk aversion and proportional to the average excess return of the market. The share of the risky portfolio can exceed one in which case the size of the risky portfolio exceeds the total portfolio and the fund is taking a short position by borrowing in the risk-free asset. If it is less, it is taking a long position by saving in the risk-free asset. Second, completely independent of the degree of risk aversion, the portfolio share of each risky asset depends on the expected own excess return and the covariance with the excess returns of the other assets. Once the portfolio allocation is determined, consumption adjusts to the risk in the portfolio through precautionary saving and follows from a similar stochastic Euler equation as (15) with the prudence term now equal to $0.5CRPw^2\sigma^2$ with *w* the share of risky assets and σ^2 the residual volatility of the portfolio. Hence, precautionary buffer stocks are built up to cope with the residual, non-diversifiable risk of the portfolio. Consumption is a constant proportion of the size of the portfolio with the constant being smaller than in the case without asset price volatility to reflect the additional precautionary saving response.

The Norwegian Fund, which is probably the best managed and most transparent fund in the world, follows the standard capital asset pricing theory quite closely: the mix of equity versus bonds is mandated by the government at 60-40 percent, the FTSE All Cap Index has to be tracked for the allocation of the risky assets, and each year a 4 percent of the Fund is supposed to be withdrawn for the general budget but in practice it is often more than 4 percent. However, Norway like most other funds in oil-rich countries does not take account of oil and gas reserves. Even though reserves are currently about as large as the size

[13] An earlier study integrates oil price volatility in the intertemporal asset pricing model where investment in capital is the risky portfolio instead of a portfolio of risky financial assets (Gaudet and Khadr, 1991).

of the Fund, Norway does not make an effort to diversify its assets above the ground away from those under the ground.[14]

Extending the capital asset pricing theory to allow for commodity price as well as asset return volatility gives the following insights. First, more is invested in all risky assets. Second, a short position is taken in risk-free assets and more is invested in risky assets that are negatively correlated with the returns on natural resources in order to hedge the risk of commodity price volatility. For example, oil-rich countries might invest relatively high proportions in plastics, aluminium and steel which are energy-intensive and whose returns are negatively correlated with oil. Conversely, such countries might invest less in industries producing renewable energy as their returns are positively correlated with oil. Third, as natural resource reserves are depleted, this short position is unwound.[15] Fourth, precautionary saving is required to cope with the residual, non-diversifiable commodity price risk which is especially large when markets are incomplete. Fifth, total wealth and consumption rise steadily over time in view of the precautionary saving buffers that are accumulated. Finally, if commodity prices are pro-cyclical, the rates of natural resource extraction should be slowed down because then there more reserves are left if commodity prices and asset returns are high.

We summarize our discussion in the following policy message.

Guideline 4: *Sovereign wealth fund managers of resource-rich countries should hold bigger shares of risky assets, go short in risk-free assets and invest more in assets that are negatively or not correlated with returns on natural resources and gradually undo this position as resources are depleted, and accumulate precautionary saving buffers to deal with residual non-diversifiable risk. As a hedge these countries should extract natural resources more slowly, especially if commodity prices are pro-cyclical.*

IV. Capital scarcity, absorption constraints and investing to invest

Many resource-rich economies are characterized by various issues such as Dutch disease, absorption constraints and capital scarcity that are not captured by the frameworks discussed in sections II and III. Here we briefly discuss some of these complications to do with these issues.

First, Dutch disease problems typically occur as the extra demand from the revenue of selling natural resources on world markets pushes the production of non-tradable goods and services to the limit and thus

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[14] In 2008 the Norwegian Ministry of Finance did consider to exclude oil and gas stocks whose returns were seen to be too closely correlated with the returns on oil and gas reserves, but did not do this as the benefits were seen to be too small.

[15] This is not unlike the insight from personal finance that young people with a lot of human capital should go short in risk-free assets and invest more in risky assets than older people with less human capital.

puts upward pressure on the price of non-tradables (e.g., Corden and Neary, 1982; Corden, 1984). To the extent that there is mobility of production factors so that labour and capital can move freely from the tradable to the non-tradable sector, the increase in the price of non-tradables and the corresponding appreciation of the real exchange rate will be mitigated, though not eliminated. The implied decline in production of non-resource tradables, however, will be exacerbated by more factor mobility. Due to the decline in the production of non-resource tradables, the extra demand for them is satisfied by imports paid for by selling natural resources on the world market. The use of intergenerational funds to smooth consumption, especially if households have less good access to financial markets than the government, will lead to smoothing of the effect on the real exchange rate.

Second, as production needs infrastructure (e.g., roads, railroads, ports, hospitals, schools but also nurses, teachers and a good legal system) and one needs infrastructure to build more infrastructure, an economy experiences absorption problems when faced with an additional windfall-induced demand for non-tradables (van der Ploeg and Venables, 2013). The key feature is that infrastructure cannot be readily imported from abroad but must be 'home-grown' and this may take years. Resource-rich countries may use part of their windfalls to expand their extraction capacity. Given that most of this is undertaken by foreign multinationals, capital scarcity should not be an issue for extraction investments if fields are profitable. However, this is not the case for infrastructure. As investment in infrastructure occurs, the productive capacity of the non-tradable sector expands and the symptoms of Dutch disease such as the appreciation of the real exchange rate fade away provided infrastructure is home produced and cannot be bought on the world market.[16] This is the central idea about investing to invest. One needs infrastructure (including nurses, teachers, etc.) to make it possible to have more infrastructure and this can take years for this process to occur due all kinds of absorption constraints. It thus makes sense to have an *investment fund* in addition to the intergenerational and liquidity funds already discussed to temporarily park natural resource revenue until the economy has built enough structures and is ready to absorb the extra windfall-induced demand for non-tradable goods and services.

In fact, public investment is notoriously hard to deliver. As the output elasticity with respect to infrastructure is about 15% (Bom and Ligthart, 2010), it is crucial for boosting the productive capacity of a country and promoting economic development. For many developing countries only about 40% of

[16] In the traditional three-sector analysis of Dutch disease with capital added to the non-traded sector Dutch disease is not eliminated (e.g., Corden and Neary, 1982). The point is that production in non-tradables only goes up if the price goes up, because otherwise factors would not have an incentive to move. Hence, the real exchange rate has to rise. Dutch disease, meaning both a rise in the real exchange rate and a shift of production from non-resource tradables to non-tradables, is an equilibrium (and efficient) phenomenon, not a feature of adjustment. However, in the dynamic analysis of absorption constraints the appreciation of the real exchange rate is reversed in the long run when the stock of infrastructure has fully reached its new higher steady-state level and all absorption problems have disappeared (van der Ploeg and Venables, 2013).

spending on investment actually materializes due to all kinds of delays in planning and implementation, absorption problems and various types of rent seeking (Dabla-Norris et al., 2011). This corresponds effectively to sizeable intertemporal costs of adjusting infrastructure (also sometimes referred to as 'structures' to reflect that it is not only physical infrastructure but also education, health and legal infrastructure that matters). As a result the windfall of a natural resource is best managed with an immediate increase in consumption as future generations are richer as the economy will be more developed and with a slow build-up of infrastructure (van der Ploeg, 2012). The temporary shortages in the non-tradable sector and appreciations of the real exchange rate will fade away as the economy accumulates infrastructure as has been shown by van der Ploeg and Venables (20130 for the case that infrastructure is intensive in non-tradables.In fact, this is the key ingredient of an investing-to-invest strategy. A rentier economy with a relative small population such as Kuwait can import all its infrastructure (including nurses, teachers, etc.), but a large resource-rich economy with a big population has to invest in its infrastructure at home: nurses are needed to train more nurses, teachers are needed to produce more teachers, and roads are necessary before one can build other roads. Overcoming these fundamental absorption issues takes many years and is the reason why Dutch disease can last for a prolonged period.

Third, as long as a country has perfect access to international capital markets, it faces a given world rate of interest which is unaffected by a windfall of natural resource revenues. In that case, the optimal level of private capital and public capital is pinned down by technology and the world interest rate so that none of the windfall should be spent on physical capital or infrastructure: they should already be at their optimal levels. Any financing need is supplied by international capital markets. However, many countries face capital scarcity and have to pay an interest premium on top of the world interest rate which increases in the level of public and publically guaranteed debt of a country. Econometric cross-country evidence on the determinants of the interest spread suggests that a 10%-point increase in the debt-GDP ratio raises the interest differential by 6.9%-points if the economy has an initial debt-GDP ratio of 100 percent (van der Ploeg and Venables, 2011). It is thus optimal to spend a part of a natural resource windfall on physical capital and infrastructure as otherwise their levels would be sub-optimally low (e.g., van der Ploeg and Venables, 2012). The reason is that the social cost of borrowing corresponds to the world interest rate plus the interest premium plus a term to internalize the interest-spread externality. If there is capital scarcity, it is thus optimal to pay off debt and reduce the risk premium and the interest burden which biases away from future towards present consumption. This effect is especially strong if intergenerational inequality aversion is not so large and capital scarcity is substantial. The need to build a precautionary saving buffer tilts consumption also towards the present. Furthermore, the windfall allows a more rapid buildup of public investment and a speeding up of the process of economic development. This inevitably leads to a temporary deterioration of the efficiency of public investment.

Guideline 5: *Building an intergenerational fund to smooth consumption also helps to smooth the real exchange rate and smooth Dutch disease effects. Rather than having lots of deindustrialization all at once which reverses when the natural resource windfall and spending stops, there will be a smaller amount of deindustrialization over a longer time. With perfect capital markets none of the natural resource windfall should be spent to increase physical capital or infrastructure. With capital scarcity a natural resource windfall must be used to tilt consumption from the future to the present, to pay off foreign liabilities and fund an investing-to-invest strategy. To relieve absorption problems one must build up structures before the demand for non-tradable goods and services can be met. It is wise to park some of the windfall in an investment until the economy is ready to absorb this extra demand.*

V. Concluding remarks

A key challenge for many resource-rich countries is to convert their natural resource assets into long-lasting assets above the ground such as physical capital, human capital and financial wealth held abroad. If they do this well and are able to keep genuine saving per capita, i.e., national saving per capita suitably corrected for the depletion of natural resources and deterioration of the natural environment, zero or positive then social welfare per citizen will stay stable or increase over time provided consumption per head is independent of the population size and population growth is constant. Countries that squander their natural resources have negative genuine saving, become poorer over time. It thus boils down to what the best way to manage national resource wealth is.

Natural resource windfalls last for a limited period, are often known some years in advance, and are highly volatile and unpredictable. Since markets for financial derivatives are too thin and poorly developed, three types of funds can play a role in managing these features of resource windfalls. An *intergenerational fund* is needed to smooth the benefits of a temporary windfall over current and future generations abstracting from uncertainty about future commodity prices. During the windfall when natural resources are extracted, produced and sold, the revenue is put into the intergenerational fund. Once the windfall has ceased, the returns on this fund are used to finance the general deficit. If the resource windfall is expected to fade out in the future, the country must save to achieve the same level of consumption per capita in all time periods. If the windfall is known for certain to be arriving some years ahead, the permanent income hypothesis suggests that the country borrows with the future windfall as security so that the permanent increase in the primary deficit extends to the announcement period. An intergenerational fund also helps to mitigate some of the sharp appreciations of the real exchange rate associated with Dutch disease, which are particularly severe when factor mobility between the tradable and non-tradable sectors and international migration of labour is small. A *liquidity fund* is needed to collect additional precautionary buffers as a prudent response to commodity price volatility. This fund is designed to self-insure against periods when commodity prices are low. This fund is larger if commodity prices are more volatile, commodity price shocks are more permanent, policy makers more prudent, and the windfall lasts for a longer period. Finally, an *investment fund* is needed to temporarily park funds until domestic investment projects are ready to be undertaken. This is necessary if countries are not well integrated in global capital markets. In countries with perfect access to world capital markets none of the windfall should be spent on domestic investment projects simply because such countries are assumed to already have the optimal amount of domestic capital: the windfall should feed the intergenerational and liquidity fund and curb the general deficit, but not feed an investment fund. However, many developing countries suffer from capital scarcity and pay a premium when borrowing to fund investment projects. It is then optimal to spend part of the oil windfall on domestic investment to alleviate capital scarcity. Domestic investment projects may face all kinds of absorption, planning and legal constraints in which case it makes sense to temporarily park part of the oil windfall until it is feasible to undertake the project.

The management of these three types of sovereign wealth funds should take account of the remaining natural resource reserves that are still in the crust of the earth or the seas. With commodity price volatility one should hold bigger shares of risky assets than one would do otherwise. It is also wise to go short in assets that are negatively or not correlated with returns on natural resources and gradually undo this position as natural resources are depleted. It is also wise to engage in precautionary saving to deal with residual non-diversifiable risk. These countries should extract natural resources more slowly, especially if commodity prices are pro-cyclical, because this allows them to hedge their above-the-ground portfolios.

Our analysis has been entirely normative, but managing natural resource windfalls is fraught with political dangers. The most acute one is the danger of sovereign wealth funds being raided by political rivals. This encourages incumbents to shy away from establishing sovereign wealth funds and instead to use the natural resource revenues to invest in partisan, illiquid assets, especially when their chances of being kicked out of office are large. There is thus a bias towards more debt and away from growth-promoting investment projects (cf., Persson and Tabellini 2000; Aquiar and Amador, 2011). One reason politicians build a bridge, school or hospitals for their political clientele may be that the tax system cannot be used in a discriminatory manner to channel funds to your own clientele but not the rest of the country, especially in countries with a cohesive tax system (Besley and Persson, 2011). These distortions can be mitigated if the political system becomes more inclusive. Another political concern is that in fractionalized societies fighting for control of natural resources natural resources are extracted excessively fast and this can ruin growth prospects (Tornell and Lane, 1999; Hodler, 2006; van der Ploeg, 2010). Rapacious depletion of natural resource can lead to a negative genuine saving if this is associated with erosion of institutional capabilities and deadweight losses, but note that anticipation of better times (e.g., an expected sustained rise in commodity prices) can give a normative rationale for negative genuine saving (van der Ploeg, 2010). Resource-rich countries also often have large net financial asset positions yet their trade balances exceed their current accounts. This might suggest the presence of substantial remittances, but can also indicate siphoning off of windfall revenue.

If the fiscal authorities fail to manage natural resource windfalls properly by channeling revenue towards intergenerational, liquidity and parking funds, the real exchange will be much more volatile and Dutch disease symptoms will be much more severe with large, temporary appreciations, especially as such windfalls are typically anticipated several years in advance. Furthermore, if prices and wages do not adjust instantaneously, there will be unemployment during the announcement period as the real exchange will already show substantial appreciation during this period. Investment may also fall during this period as the long interest will rise in response to anticipated hikes in the future short interest rate. The best response for the monetary authorities is then to expand monetary policy during this period in order to fight this temporary unemployment (e.g., Wills, 2013). In fact, the central bank could build up reserves to avoid the appreciation of the real exchange rate which would be a fund of some sort.[17]

Sometimes resource windfalls are harnessed for growth and development, but all too often this fails especially if legal and financial institutions are bad, the country is landlocked and ethnically fractionalized (for a survey, see van der Ploeg, 2011). It is thus a challenge to transform subsoil wealth into productive growth-enhancing physical and human capital and not to squander it. Even countries that follow all the guidelines laid out in this paper can still squander their natural resources if their investment of their natural resource revenues is directed towards ‘white elephants’ with no discernible effect on growth and development and no rate of return other than those engaged in rent seeking. It can help to counter such political failures in managing natural resource wealth if the amount extracted and where the revenue go are published in an open and transparent manners along the principles of the Earned Income Transparency Initiative and the Natural Resource Charter. If it is not feasible to do that, it may be better to keep natural resources unexploited until fairer and more democratic political times emerge.

[17] A similar argument has been made by Bachetta and Benhima (2013) for an initial depreciation of the currency combined with an accumulation of central bank reserves to explain the Chinese experience. This done in an context where there is limited financial development and insufficient saving instruments for the private sector.

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Appendix I: Analytics of the intergenerational fund

The felicity of the representative citizen is given by the concave utility function $U(C/L)$, $U' > 0$, $U'' < 0$, where C stands for aggregate consumption. For simplicity, the utility function displays constant coefficient of relative risk aversion or, equivalently, a constant coefficient of intergenerational inequality aversion, $1/\sigma$, where σ indicates the elasticity of intertemporal substitution:

$$\text{(A1)} \qquad \begin{aligned} U(C/L) &= \left[(C/L)^{1-1/\sigma} - 1 \right] / (1 - 1/\sigma), \quad \sigma > 0, \sigma \neq 1, \\ U(C/L) &= \ln(C/L), \quad \sigma = 1. \end{aligned}$$

The country has to decide how much to invest in production capital I_K, infrastructure I_S, and human capital I_H, how much to consume C, and how much of national saving to allocate across the different assets. It does this by maximizing the discounted utilitarian social welfare function

$$\text{(A2)} \qquad \int_0^\infty LU(C/L)e^{-\rho t} dt,$$

subject to the following constraints:

(A3a) $\dot{F} = rF + AY(K,S,HL) + \left[P(N) - \Psi\right]N - C - I_K - I_S - I_H,$

(A3b) $\dot{K} = I_K - \delta_K K, \quad K(0) = K_0,$

(A3c) $\dot{S} = I_S - \delta_S S, \quad S(0) = S_0,$

(A3d) $\dot{H} = I_H - \delta_H H, \quad H(0) = H_0,$

(A3e) $\dot{R} = -N, \quad R(0) = R_0,$

where δ_K, δ_S and δ_H denote the depreciation rates of physical capital, infrastructure and human capital, respectively, and ρ is the social rate used to discount welfare units.

Denoting the marginal values of net foreign assets, physical capital, infrastructure, human capital and natural resources by λ_F, λ_K, λ_S, λ_H and λ_R respectively, we get the first-order optimality conditions:

(A4a) $U'(C/L) = \lambda_F,$

(A4b) $\dot{\lambda}_F = (\rho - r)\lambda_F, \quad \lim_{t\to\infty} \lambda_F(t)F(t)e^{-\rho t} = 0,$

(A4c) $\lambda_F = \lambda_K = \lambda_S = \lambda_H \equiv \lambda, \quad \lim_{t\to\infty} \lambda_K(t)K(t)e^{-\rho t} = 0, \quad \lim_{t\to\infty} \lambda_S(t)S(t)e^{-\rho t} = 0, \quad \lim_{t\to\infty} \lambda_H(t)H(t)e^{-\rho t} = 0,$

(A4d) $AY_K(K,S,HL) = r + \delta_K, \qquad AY_S(K,S,HL) = r + \delta_S, \qquad ALY_{HL}(K,S,HL) = r + \delta_H,$

(A4e) $(1 - 1/\varepsilon)p(N) = \Psi + \lambda_R,$

(A4f) $\dot{\lambda}_R = r\lambda_R, \quad \lim_{t\to\infty} \lambda_R(t)R(t)e^{-\rho t} = 0.$

Equation (A4a) sets the marginal utility of per-capita consumption to the marginal value of net foreign assets. Equations (A4a) and (A4b) together give rise to the Keynes-Ramsey rule or Euler equation:

(A5) $\dfrac{\dot{C}}{C} - n = \sigma(r - \rho).$

Equation (A4c) indicates that the marginal value of the various assets should be equalized, so we can speak of the marginal value of wealth λ for short. The transversality conditions stated in (A4b) and (A4c) should also be satisfied. It follows from equation (A4c) that the marginal products of physical capital, infrastructure and human capital should equal the same user cost as indicated by equations (A4d). Equation (A4e) states that the marginal revenue of natural resources sold on world markets should equal the sum of their marginal extraction cost Ψ and their Hotelling rent λ_R. The Hotelling rent itself should grow at the market rate of interest in order for society to be indifferent between keeping an extra unit in the soil and taking it out of the soil, as indicated by equation (A4f). Combining equations (A4e) and (A4f), we obtain:

(A6) $$\dot{p} = r\left[p - \frac{\Psi}{1-1/\varepsilon}\right], \quad \dot{N} = -\varepsilon r\left[1 - \frac{\Psi}{(1-1/\varepsilon)\,p(N)}\right]N.$$

With isoelastic demand and zero extraction cost, we have:

(A6′) $$\dot{p} = rp, \quad \dot{N} = -\varepsilon rN.$$

Natural resource wealth is defined as the present value of natural resource revenue and from (A6′) it is:

(A7) $$\int_t^\infty p(s)N(s)e^{-r(s-t)}ds = \frac{p(t)N(t)}{\varepsilon r} = p(t)R(t).$$

From equation (A6′) and the condition for asymptotic depletion of natural resources $\int_t^\infty N(s)ds \le R(t),$ we get $N = \varepsilon rR$ and thus natural resource wealth indeed equals the value of in-situ reserves, $pR,$ as indicated by the last equality in (A7).

Defining total wealth of the nation as the sum of net foreign assets, physical capital, infrastructure, human capital and natural resource wealth, $V \equiv F + K + S + H + pR,$ we can combine equations (A3a)-(A3e) and the Hotelling rule (A6′) to get the dynamics of total wealth of the nation:

(A8) $$\begin{gathered}\dot{V} = \dot{F} + \dot{K} + \dot{S} + \dot{H} + \dot{p}R + p\dot{R} = rF + AY(K,S,HL) - C - \delta_K K - \delta_S S - \delta_H H + rpR = \\ r(F + K + H + pR) - C = rV - C,\end{gathered}$$

since under constant returns to scale we have $AY(K,S,HL) = (r+\delta_K)K + (r+\delta_S)S + (r+\delta_H)H.$ The present-value budget constraint corresponding to equation (A8) states that the present value of aggregate consumption, $\int_t^\infty C(s)e^{-r(s-t)}ds = C(t)/\left[(1-\sigma)r + \sigma\rho - n\right]$ (from the Keynes-Ramsey rule (A5)), cannot exceed total wealth of the nation, $V(t)$. At an optimum the aggregate consumption function thus equals:

(A9) $$C = \left[(1-\sigma)r + \sigma\rho - n\right]V.$$

Upon substitution of (A9) into (A8), we get the optimal dynamics for the total wealth of the nation:

(A10) $$\dot{V} - nV = \sigma(r-\rho)V.$$

Since consumption per capita grows at the rate $\sigma(r-\rho),$ wealth per capita (V/L) also grows at this rate.

If $\rho = r$, it follows from equations (A5) and (A10) that consumption per capita and total wealth per capita are fully smoothed ($\dot{C} - nC = 0, \dot{V} - nV = 0$). To see how this is achieved, it helps to consider the dynamics of non-resource wealth in efficiency units (e.g., $\hat{F}(t) \equiv F(t)e^{-(n+g)t}$):

$$\text{(A11)} \quad \dot{\hat{F}} + \dot{\hat{K}} + \dot{\hat{S}} + \dot{\hat{H}} = p\hat{N} - (r-g-n)p\hat{R} = \left[(\varepsilon - 1)r + g + n\right]p\hat{R} \quad \text{if} \quad r = \rho.$$

Natural resource prices, in practice, do not follow Hotelling paths very closely. Hence, we also consider the case where the time path of natural extraction follows an exogenous, possibly ad hoc path:

$$\text{(A12)} \quad \begin{aligned} C &= (r-n)V = (r-n)(K+S+H+V^R), \\ \dot{\hat{F}} + \dot{\hat{K}} + \dot{\hat{S}} + \dot{\hat{H}} &= \left[p\hat{N} - (r-g-n)\hat{V}^R\right] + \left[\sigma(r-\rho) - g\right]\hat{V}, \end{aligned}$$

where V^R denotes the present value of natural resource revenues corresponding to the extraction path (which need no longer equal $p\,R$) and $(r-n)V^R$ is the permanent value of natural resource revenues.

Appendix II: Volatile commodity prices and the liquidity fund

We use a mean-reversion model for commodity prices:

$$\text{(A13)} \quad dP(t) = \left\{\eta_P\left[m_P + \upsilon_P t - \log(P(t))\right]P(t) + \upsilon_P\right\}dt + \sigma_P P(t)dW(t),$$

where $W(t)$ is a Wiener process satisfying $W(t) - W(s) \sim \mathrm{N}(0, t-s)$ for $t \geq s$. The constants υ_P and σ_P are the percentage drift and the percentage volatility, respectively. This can be rewritten as a homoskedastic AR(1) process for $\log(P(t))$:

$$\text{(A13}'\text{)} \quad d\log(P(t)) = \left\{\eta_P\left[m_P^* + \upsilon_P t - \log(P(t))\right] + \upsilon_P\right\}dt + \sigma_P dW(t),$$

where $m_P^* = m_P - \sigma_P^2 / 2\eta_P$ (from Itō calculus). The government now maximizes the expected value of (A2) subject to the constraint

$$\text{(A14)} \quad \dot{F} = rF + \left[P(N) - \Psi\right]N - C$$

whilst taking the time path for $(P - \Psi)N$ as exogenous. This yields the stochastic Euler equation:

$$\text{(A15)} \quad \frac{1}{dt}\mathrm{E}_t\left[dC\right] = \sigma(r-\rho)C + \frac{1}{2}CRP\left(\frac{\partial C}{\partial P}\right)^2\left(\frac{\sigma_P P}{C}\right)^2 C\,.$$

The expected growth in consumption and the degree of precautionary saving are higher if commodity price shocks are less transient because $\frac{\partial C(t)}{\partial P(t)} = \left[(1-\sigma)r + \sigma\rho - n\right]\int_t^{\infty} \frac{\partial \mathrm{E}_t\left[P(\tau)\right]}{\partial P(t)} O(\tau) e^{-r(\tau-t)} d\tau$, where $\left[(1-\sigma)r + \sigma\rho - n\right]$ is the marginal propensity to consume out of wealth and from (A13) we get

$$\text{(A16)} \quad \frac{\partial \mathrm{E}_t\left[P(\tau)\right]}{\partial P(t)} = \frac{\mathrm{E}_t\left[P(\tau)\right]}{P(t)} e^{-\eta_P(\tau-t)} = \frac{e^{m_P\left[1-e^{-\eta_P(\tau-t)}\right]+\log(P(t))e^{-\eta_P(\tau-t)}}}{P(t)} e^{-\eta_P(\tau-t)} < 1$$

for $\tau \geq t$. Hence, if $\eta_P = 0$, all expected future prices increase by the same amount as the initial shock. If $\eta_P = \infty$, shocks have no effect on future expected commodity prices.