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An application to Norwegian petroleum revenues

by

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Efficient consumption of revenues from natural resources – An application to Norwegian petroleum revenues

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March 1, 2005

Abstract

This paper addresses the so-called natural resource curse by devising a rule that can reduce macroeconomic costs associated with the consumption of revenues from natural resources. It assumes that such macroeconomic costs are mainly brought about by changes in the real exchange rate, which adjusts in order to maintain external balance. Thus it derives a consumption rule, denoted as the efficient consumption rate, that would make the behaviour of the real exchange rate mimic that of the real exchange rate in the absence of natural resources. Accordingly, growth of exports and imports of traditional goods and services, and implicitly the sectoral composition of the economy, become largely immune to the consumption of natural resources. The theoretical framework is applied to estimate and evaluate an efficient consumption rate for Norway's sizeable petroleum revenues.

Key words: *Natural resources, Dutch disease, real exchange rate.*

JEL classification: Q38, F17, F41, F47.

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1 Introduction

Natural resources are often treated as a mixed blessing because their consumption may lead to the "Dutch disease" and slow economic growth, see e.g. Sachs and Warner (1995) and Gylfason et al. (1999). In particular, their consumption is associated with large sectoral adjustment costs owing to the expansion of sheltered sectors at the expense of sectors for traditional tradable goods and services to meet higher demand for sheltered goods.[1] Later, when natural resources are depleted, or become smaller than the level required to ensure external balance, the initial expansion of the sheltered sectors has to be reversed to rebuild the exposed sectors to avoid balance of payment problems. Real exchange rates are commonly believed to play a main role in bringing about such sectoral adjustments.

Sectoral adjustments tend to be lengthy processes and are often associated with internal and external imbalances, as known from the literature on the "Dutch disease", see e.g. Corden (1984). Also, a large number of recent studies have pointed out negative effects of natural resources on social and political institutions, investment in human, financial and physical capital, and economic growth, see e.g. Sachs and Warner (1995), Gylfason et al. (1999) and the references therein.

Yet, from a normative perspective, there seem to be only a few studies on consumption of natural resources. These studies do not, however, focus on the role or behaviour of real exchange rates. Often, consumption of natural resources is discussed in the light of John Hicks' concept of income, which (narrowly interpreted) suggests consumption of permanent income from natural resources, see e.g. Hannesson (2001, ch. 3). However, attention is not paid to macroeconomic implications of this rule itself. Matsen and Torvik (2004) derive optimal consumption of natural resources in a model where natural resources lower economic growth by crowding out the exposed sector, which is assumed to have positive spillover effects on the productivity of the overall economy. However, the real exchange rate in the model is kept insulated from the consumption plan of the natural resources. Sala-i-Martin and Subramanian (2003) is another recent study from a normative perspective,

[1] Sectoral adjustments are costly partly because physical and human capital usually contain production-specific components that may depreciate in value when transferred from one sector to another. This may also occur if a sectoral adjustment is reversed at a later date, because of depreciation and outdating of physical and human capital over time and due to technological progress.

but this proposes institutional arrangements to manage petroleum resources so that one is able to replicate the economic growth rate that would have prevailed in the absence of petroleum resources.

This paper derives a consumption rule for natural resources which minimises macroeconomic costs, in terms of sectoral adjustment costs, associated with their consumption. The paper assumes that natural resources affect the sectoral composition of an economy through the real exchange rate. By ascribing this role to the real exchange rate, the paper simplifies the analytical problem to an issue of finding a consumption rate that would enable one to replicate the behaviour of the real exchange rate in the absence of natural resources, cf. Sala-i-Martin and Subramanian (2003). We denote this consumption rate as the efficient consumption rate.

The paper employs a simple partial equilibrium model of foreign trade, where external balance is ensured by real exchange rate adjustments, conditional on internal balance. Accordingly, the real exchange rate becomes a function of the share of imports that is financed by drawing on revenues from natural resources, or of the share of imports that has to be covered by exports of traditional goods and services. The latter share is suggestive of the size of the exposed sector.

We denote the real exchange rate implied by the efficient consumption rate as the Efficient Equilibrium real Exchange Rate (EEER). This will be consistent with not only internal and external balance, but would also minimise variations in the sectoral composition of the economy. This additional property of the equilibrium real exchange rate is not shared by the large number of other concepts of equilibrium real exchange rates that have been proposed in the literature, such as BEER, CHEER, DEER, FEER etc., see e.g. MacDonald and Stein (1999) and the references therein.

The general theoretical framework and concepts are applied to discuss the appropriate consumption path of revenues from Norway's sizeable petroleum wealth. In particular, we estimate the efficient consumption rate and the efficient equilibrium real exchange rate for Norway and evaluate their implications for foreign trade and sectoral composition against those of the standard consumption rule inspired by Hicks' concept of income, hereafter the Hicks' rule.

The paper is organised as follows. Section 2 briefly outlines the tradeoff between consumption of natural resources and sectoral adjustment costs and their relationship with the real exchange rate. Section 2.1 presents the partial trade model and derives an equilibrium real exchange rate for an economy with and without natural resources. Section 3 derives the efficient consumption rate and defines the efficient equilibrium real exchange rate. Section 4 presents an econometric model of Norwegian foreign trade that has been developed in the light of the model in Section 2.1. It also sets out our assumptions regarding internal and external balance for the Norwegian economy. Section 5 evaluates the implications for the equilibrium real exchange rate and foreign trade when Norwegian petroleum resources are consumed in accordance with the Hicks' rule and the efficient consumption rule. The last section concludes.

2 Mixed blessing

In order to fully reap the benefits of natural resources, the sectoral composition of an economy needs to adjust. However, such adjustments are associated with costs. For the sake of simplicity, we ignore other possible direct and indirect effects of natural resources on the aggregate income level.

The mixed blessing nature of natural resources can be characterised by the following periodic loss function of a policy maker:

$$L = (Y^e/Y^s - \theta)^2 + \lambda\{\Delta(Y^e/Y^s)\}^2 \tag{1}$$

where Y^e/Y^s denotes the size of exposed sectors (Y^e) relative to that of sheltered sectors (Y^s). This ratio represents the actual sectoral composition of the economy, while θ denotes the sectoral composition in equilibrium, i.e. in a state of internal and external balance. λ is a positive scaling parameter less than one, while Δ is the first difference operator.

The first term, $(Y^e/Y^s - \theta)^2$, represents opportunity costs of deviating from the equilibrium level of the sectoral composition. These costs have to be weighed against those of altering the sectoral composition. The second term represents costs that have to be incurred when the sectoral composition is adjusted e.g. towards θ. The quadratic second term also implies that a fast sectoral adjustment is more costly than a gradual adjustment.

We assume that the equilibrium level θ varies inversely with the share of imports that can be financed by revenues from net foreign assets, including those from (exportable) natural resources. For example, larger revenues from net foreign assets imply that a relatively smaller share of imports must be financed by exports of e.g. manufactured products in order to maintain external balance. The sheltered sectors may therefore increase relative to the exposed sectors, without compromising the economy's ability to pay for its imports. Accordingly, θ can become smaller. If revenues from net foreign assets can finance all imports, θ may become negligible. In the absence of revenues from net foreign assets, however, θ must be relatively high, say equal to θ_H, and represent a sectoral composition where all imports are financed by exports.

The sectoral composition θ may therefore vary between 0 and θ_H, i.e. $0 \leq \theta \leq \theta_H$, depending on the share of imports that can be financed by revenues form net foreign assets. When revenues from net foreign assets can be saved and invested, their use in one period will affect the stream of revenues in the subsequent periods. More specifically, if the consumption of revenues from net foreign assets is less (more) than the income stream from net foreign assets in a period, net foreign assets in the subsequent periods will be higher (lower). Hence, a higher (lower) share of imports can be financed by revenues from net foreign assets in the subsequent periods. It follows that the consumption plan for revenues from net foreign assets will affect the path of θ over the whole time horizon.

Changes over time in the equilibrium composition θ are costly for two reasons. First, it is costly to adjust the actual composition (Y^e/Y^s) to the equilibrium composition (θ). And second, the actual composition will tend to deviate from the equilibrium composition over time since the loss function favours a gradual adjustment rather than a swift one, see equation (1).

The policy maker is therefore faced with the issue of deciding on a consumption plan for revenues from net foreign assets (including natural resources) that will by itself lead to minimum variation in θ over time and thereby minimise the costs associated with the use of revenues from net foreign assets.

Let us assume that the sectoral composition of an economy depends on the real exchange rate between the home country and abroad, *ceteris paribus*. Thus the actual and equilibrium composition can be seen as functions of the actual and equilibrium real exchange rates, R and EER, respectively. If we assume a unique mapping between the sectoral composition and the real exchange rate, the loss function (1) can be alternatively expressed as:

$$L^* = (R - EER)^2 + \lambda\{\Delta R\}^2.$$

Now the equilibrium real exchange rate EER can be considered a function of the share of imports that is financed by revenues from net foreign assets. The opportunity costs of deviating from the equilibrium sectoral composition are now expressed as a function of the deviation between the actual and the equilibrium real exchange rate. Similarly, sectoral adjustment costs are represented by changes in the real exchange rate which brings about shifts in the sectoral composition.

The loss function suggests that a constant value of the EER can minimise the loss. This is because R will remain constant at the EER after converging towards it. Thus one could set the share of imports that is financed by revenues from net foreign assets to a level that would lead to a constant EER. However, such a policy would not only eliminate possible changes in the EER owing to consumption of revenues from natural resources, but it may also eliminate changes in the EER brought about by factors that would have affected the real exchange rate (and sectoral composition) even in the absence of natural resources.

We assume that a policy maker requires that the consumption plan for the revenues only minimise the loss L^* relative to the loss in the absence of revenues from natural resources. This can be achieved if the consumption plan for revenues makes the behaviour of the equilibrium real exchange rate EER largely mimic that of the equilibrium real exchange rate in the absence of natural resources.

Such a consumption plan is determined by the efficient consumption rate, which is derived along with the efficient equilibrium real exchange rate in Section (3). The next section (2.1) presents a model of foreign trade which can be used to derive a relationship between natural resources and the real exchange rate.

2.1 Natural resources and the real exchange rate

We assume a small open home economy whose import volume (B) measured in terms of domestic product units increases with its income level (Y) and the strength of the real exchange rate (R; low values of R indicate a strong real exchange rate). Such an import function can be expressed by equation (2):

$$B = Y^{\beta_1} R^{-\alpha_1}, \tag{2}$$

where the Greek letters are constant parameters with positive values. β_1 represents the income elasticity of imports and $-\alpha_1$ denotes the price elasticity of imports, i.e. sensitivity to changes in the real exchange rate.

Similarly, the home country's export volume (A) in terms of domestic product units is assumed to increase with the income level abroad Y_f but fall with the strength of the real exchange rate, as expressed by the export function (3):

$$A = Y_f^{\beta_2} R^{\alpha_2}. \tag{3}$$

Here, β_2 and α_2 denote the income elasticity and price elasticity of exports, respectively.

The trade deficit (TD) can now be expressed as a function of domestic and foreign income and the real exchange rate. By inserting the import and export functions in the definition of the trade deficit, we get:

$$TD \equiv B - A = Y^{\beta_1} R^{-\alpha_1} - Y_f^{\beta_2} R^{\alpha_2}. \tag{4}$$

The import and export functions suggest that the trade deficit increases with the domestic income level, but falls when the real exchange rate weakens and the foreign income level rises.

Equation (4) implies a unique negative relationship between the trade deficit and the real exchange rate for given values of domestic and foreign income. It can therefore be used to find the real exchange rate that is consistent with a given level of the trade deficit (for given values of domestic and foreign income). This possibility can be expressed more explicitly by inverting equation (4) and solving it with respect to R:

$$R = \left[\frac{Y^{\beta_1}}{Y_f^{\beta_2}} \left(1 - \frac{TD}{B} \right) \right]^{1/(\alpha_1 + \alpha_2)} . \tag{5}$$

This relationship indicates that the real exchange rate must depreciate when domestic income rises in order to offset the increase in the trade deficit caused by higher imports, see equations (4) and (2). Similarly, the real exchange rate must appreciate when foreign income increases, so that the trade deficit does not fall as a result of higher exports, see equations (4) and (3). The net effect on the real exchange rate will depend on the evolution of income-determined import demand (Y^{β_1}) relative to that of income-determined export demand ($Y_f^{\beta_2}$), $Y^{\beta_1}/Y_f^{\beta_2}$. This ratio can be interpreted as the income-determined trade deficit.

The equilibrium real exchange rate (EER) can be defined as the real exchange rate level that results when there is internal and external balance, that is when the trade deficit and domestic and foreign income levels are at their equilibrium levels, PI, $\overline{Y}$ and $\overline{Y}_f$, respectively:

$$EER = \left[\frac{\overline{Y}^{\beta_1}}{\overline{Y}_f^{\beta_2}} \left(1 - \frac{PI}{B} \right) \right]^{1/(\alpha_1 + \alpha_2)} . \tag{6}$$

$\overline{Y}$ and $\overline{Y}_f$ can be set equal to potential GDP in the home country and abroad, while PI denotes a sustainable level of revenues from net foreign assets that can finance the trade deficit (TD). In the following, we assume for simplicity that net foreign assets consist solely of an estimated value of natural resources, say of petroleum wealth. Thus PI is hereafter considered as consumption of revenues from petroleum resources.

In the absence of the revenues, the trade deficit must equal zero ($TD = PI = 0$) and import expenditures have to be covered solely by income from exports. In that case, the EER becomes a function of the income-determined trade deficit $\overline{Y}^{\beta_1}\overline{Y}_f^{\beta_2}$. Thus, the EER would be constant over time if growth rates of income-determined imports and exports are equal, i.e. if $\beta_1 \Delta\overline{y}_t = \beta_2 \Delta\overline{y}_{f,\,t}$, where $\Delta\overline{y}_t$ and $\Delta\overline{y}_{f,\,t}$ denote the trend growth rate of domestic and foreign income, respectively.

Consumption of petroleum revenues ($PI > 0$) leads to a stronger equilibrium exchange rate relative to the case of no petroleum revenues. The relative strength increases with the share of imports that can be financed by petroleum income (PI/B), see equation (6). PI/B is equal to $(B - A)/B$ in a state of external balance. It may therefore be interpreted as the share of imports that can financed by petroleum income, whereas ($1-$ PI/B) can be seen as the share of imports that is financed by exports.

Consumption of petroleum revenues ($PI > 0$) also increases variation in the equilibrium exchange rate (relative to the case of no petroleum revenues). This is because petroleum revenues, and thereby also the sustainable level of the trade deficit, are often revised due to changes in the rate of return on petroleum assets, new discoveries of petroleum resources or revaluations in the face of fluctuations in e.g. oil and gas prices. Petroleum revenues may also contribute to changes in the equilibrium rate, even if they remain constant over time. This would occur if import demand increases over time due to economic growth at home. The import share that can be financed by petroleum income (PI/B) will thus decline over time. In order to keep the trade deficit equal to (desired) consumption of petroleum income, the real exchange rate has to depreciate steadily to slow imports and boost exports.

In the long run, however, the equilibrium exchange rate can become almost independent of petroleum income.[2] This is because PI/B may become insignificant in the long run, i.e. $PI/B \longrightarrow 0$, if growth in import demand continues. The bulk of imports will then have to be financed by exports. This could happen even if (consumption of) petroleum income rises over time, as long as imports rise at a higher rate than the petroleum income. Thus the equilibrium exchange rate (EER) conditional on $PI > 0$ will converge towards the EER conditional on PI = 0, EER|PI = 0, which balances trade with other countries.

[2]The EER will equal 1, as in the theory of absolute purchasing power parity, if imports and/or exports are extremely sensitive to changes in the real exchange rate, that is if if $(\alpha_1 + \alpha_2) \longrightarrow \infty$. In such cases, the EER will neither depend on revenues from abroad nor on income at home and abroad. Intuitively, an arbitrary trade deficit can be achieved and sustained through minor changes in the real exchange rate when price elasticity is extreme. If, for example, the domestic income level becomes much higher than in other countries, the real exchange rate only needs to depreciate marginally in order to offset the income effect on imports so that the trade deficit does not exceed *PI*.

In summary:

$$EER \longrightarrow \left[\frac{\overline{Y}^{\beta_1}}{\overline{Y}_f^{\beta_2}}\right]^{1/(\alpha_1 + \alpha_2)} \text{ if } \frac{PI}{B} \longrightarrow 0.$$

The expression for the EER, (6), also implies that changes in petroleum income are of more importance to the equilibrium exchange rate in the short run (when PI/B is large) than in the long run (when PI/B is small).

The expression for the depreciation rate of the equilibrium exchange rate (Δeer_t) highlights the relationship between growth in the income-determined trade deficit, the share of imports financed by petroleum income and growth rates of imports and petroleum revenues:

$$\Delta eer_t = \frac{1}{\alpha_1 + \alpha_2}(\beta_1 \Delta \overline{y}_t - \beta_2 \Delta \overline{y}_{f,\, t}) + \frac{1}{\alpha_1 + \alpha_2}\left[\frac{PI_t/B_t}{1 - PI_t/B_t}\right]\left[\frac{\Delta B_t}{B_t} - \frac{\Delta PI_t}{PI_t}\right]. \qquad (7)$$

We note that the depreciation rate is zero when $PI = 0$ and $\beta_1 \Delta \overline{y}_t = \beta_2 \Delta \overline{y}_{f,\, t}$. However, if $\frac{\Delta B_t}{B_t} > \frac{\Delta PI_t}{PI_t}$, the exchange rate will depreciate over time at a rate that rises with the size of PI_t/B_t. Thus, changes in petroleum income will be of more importance to the equilibrium exchange rate in the short run (when PI/B is large) than in the long run (when PI/B is small).

3 Efficient consumption and equilibrium exchange rate

The relationship between petroleum income and exchange rate changes can be broken if PI/B is kept at a fixed level. This requires that consumption of petroleum revenues keeps pace with imports over time, i.e. $\frac{\Delta PI_t}{PI_t} = \frac{\Delta B_t}{B_t}$, see equation (7). This section derives a rule for consumption of petroleum revenues (efficient consumption rate) which ensures this. Thereafter, it defines the efficient equilibrium real exchange rate (EEER).

3.1 Efficient consumption rate

We assume a given initial stock of petroleum wealth W_0, that earns an exogenously given constant rate of return ar. We also assume that a constant share cr of petroleum wealth at the end of a period is consumed during the subsequent period: $PI_t = crW_{t-1}$. Thus, growth in the consumption of petroleum revenues will be equal to that of the petroleum wealth, which will grow at the saving or reinvestment rate $ar - cr$:[3]

$$\frac{\Delta PI}{PI} = \frac{\Delta W}{W} = ar - cr. \tag{8}$$

Growth in consumption (and wealth) will be zero if $cr = ar$, that is when the permanent income from the wealth is consumed.

In the following we derive a value of cr that would make changes in the equilibrium real exchange rate invariant to the share of imports that can be financed by petroleum revenues, PI_t/B_t. Consequently, changes in the equilibrium exchange rate will largely imitate changes in the equilibrium rate in the absence of petroleum revenues, i.e. when PI = 0. More specifically, we derive a value of cr that leads to the same rate of depreciation with and without consumption of petroleum revenues: $\Delta eer_t = \Delta eer_t|_{PI=0}$, where Δeer_t refers to the case where $PI > 0$. We denote this value of cr as the efficient consumption rate.

Equation (8) can be used to derive the efficient consumption rate cr at a given value of ar by determining $\Delta PI_t/PI_t$. To determine $\Delta PI_t/PI_t$, we consider the reduced form of equation (7) for the rate of depreciation with and without petroleum income:

$$\begin{aligned} \Delta eer_t &= \frac{(1 - PI_t/B_t)}{\alpha_1 + \alpha_2(1 - PI_t/B_t)}(\beta_1 \Delta \overline{y}_t - \beta_2 \Delta \overline{y}_{f,\, t}) + \\ & \quad \frac{PI_t/B_t}{\alpha_1 + \alpha_2(1 - PI_t/B_t)} \left[\beta_1 \Delta \overline{y}_t - \frac{\Delta PI_t}{PI_t}\right] \end{aligned} \tag{9}$$

and

$$\Delta eer_t|_{PI=0} = \frac{1}{\alpha_1 + \alpha_2}(\beta_1 \Delta \overline{y}_t - \beta_2 \Delta \overline{y}_{f,\, t}). \tag{10}$$

The reduced form expression for the rate of depreciation in the case of $PI > 0$, (9), can be

[3] Assume that petroleum wealth in period 0 is W_0, while the rate of return is constant and equal to ar. Then return or income from petroleum would be arW_0 and one can reinvest $(ar - cr)W_0$ if the rate of consumption is constant and equal to cr. Thus, petroleum wealth at the beginning of next period (W_1) would be equal to $(W_0 + (ar - cr)W_0)$. Accordingly, one may consume crW_1 in period 1. It follows that growth in consumption of petroleum income will become: $(crW_1 - crW_0)/crW_0 = (W_0 + (ar - cr)W_0 - W_0)/W_0 = ar - cr$.

obtained by inserting the following expression for growth in imports, in a state of internal and external balance, into equation (7):

$$\frac{\Delta B_t}{B_t} = \beta_1 \Delta \overline{y}_t - \alpha_1 \Delta eer_t. \tag{11}$$

This expression for import growth is implied by the import function (2).

If we require that rates of depreciation with and without petroleum income be equal to each other, $\Delta eer_t = \Delta eer_t|_{PI=0}$, the right-hand sides of equations (10) and (9) must also be equal to each other:

$$\begin{aligned} & \frac{1}{\alpha_1 + \alpha_2}(\beta_1 \Delta \overline{y}_t - \beta_2 \Delta \overline{y}_{f,\, t}) = \frac{(1 - PI_t/B_t)}{\alpha_1 + \alpha_2(1 - PI_t/B_t)}(\beta_1 \Delta \overline{y}_t - \beta_2 \Delta \overline{y}_{f,\, t}) \\ + \quad & \frac{PI_t/B_t}{\alpha_1 + \alpha_2(1 - PI_t/B_t)}\left[\beta_1 \Delta \overline{y}_t - \frac{\Delta PI_t}{PI_t}\right]. \end{aligned} \tag{12}$$

This identity will be satisfied if the growth in petroleum consumption ($\Delta PI_t/PI_t$) is:

$$\frac{\Delta PI_t}{PI_t} = \frac{1}{\alpha_1 + \alpha_2}(\alpha_2 \beta_1 \Delta \overline{y}_t + \alpha_1 \beta_2 \Delta \overline{y}_{f,\, t}). \tag{13}$$

The right-hand side of this equation is equal to the expression for import growth when $\Delta eer_t = \Delta eer_t|_{PI=0}$:

$$\begin{aligned} \frac{\Delta B_t}{B_t} &= \beta_1 \Delta \overline{y}_t - \alpha_1 \Delta eer_t|_{PI=0} \\ &= \frac{1}{\alpha_1 + \alpha_2}(\alpha_2 \beta_1 \Delta \overline{y}_t + \alpha_1 \beta_2 \Delta \overline{y}_{f,\, t}). \end{aligned} \tag{14}$$

This expression suggests that imports grow because of income growth at home and abroad. The effect of foreign growth is due to an appreciation of the real exchange rate when exports rise.

We get the following expression for the rate of reinvestment by inserting the expression for $\Delta PI_t/PI_t$ (from equation (13)) into equation (8):

$$ar - cr = \frac{1}{\alpha_1 + \alpha_2}(\alpha_2 \beta_1 \Delta \overline{y}_t + \alpha_1 \beta_2 \Delta \overline{y}_{f,\,t}).$$

This expression suggests that the reinvestment rate must equal the growth rate of imports, cf. equation (14).

The efficient consumption rate can be found by rearranging the expression for the reinvestment rate:

$$cr = ar - \frac{1}{\alpha_1 + \alpha_2}(\alpha_2 \beta_1 \Delta \overline{y}_t + \alpha_1 \beta_2 \Delta \overline{y}_{f,\,t}). \tag{15}$$

This shows a one-to-one relationship between the rate of consumption and rate of return, *ceteris paribus*. An increase in growth of imports owing to higher trend growth at home or abroad contributes, however, to lowering the consumption rate. This raises the reinvestment rate and makes petroleum wealth and consumption grow at the same rate as imports. Thus, the share of imports that can be financed by petroleum income (PI/B) stays the same over time. Note that the rule (15) suggests consumption of permanent income, $cr = ar$, only when growth in imports is zero, that is when $\beta_1 \Delta \overline{y}_t = \beta_2 \Delta \overline{y}_{f,\,t} = 0$.

The expression for the consumption rate (15) can be simplified as:

$$cr = ar - \beta_1 \Delta \overline{y}_t, \tag{16}$$

if income-determined growth in imports and exports are equal ($\beta_1 \Delta \overline{y}_t = \beta_2 \Delta \overline{y}_{f,\,t}$). In this case, the equilibrium exchange rate will become constant as if petroleum revenues were zero, PI = 0, see equation (10). Then growth of imports will be solely determined by income growth, that is $\frac{\Delta B_t}{B_t} = \beta_1 \Delta \overline{y}_t$, cf. equation (11).

3.2 Efficient Equilibrium real Exchange Rate (EEER)

The efficient equilibrium real exchange rate (EEER) can be defined as the equilibrium real exchange rate that is consistent with efficient consumption of petroleum revenues. More precisely, the EEER can be defined by the following equations (17)–(18):

$$EEER_t = \left[\frac{\overline{Y}_t^{\beta_1}}{\overline{Y}_{f,\,t}^{\beta_2}}\left(1 - \frac{PI_t}{B_t}\right)\right]^{1/(\alpha_1 + \alpha_2)}, \tag{17}$$

$$\frac{PI_t}{B_t} = cr^* \frac{W_{t-1}}{B_t} = \frac{cr^* W_{t-1}}{\overline{Y}_t^{\beta_1} EEER_t^{-\alpha_1}}, \tag{18}$$

where cr^* denotes the efficient consumption rate, i.e. the cr that satisfies equation (15). The EEER is determined simultaneously with PI_t/B_t, as indicated by the expression for the import level at the efficient equilibrium exchange rate ($\overline{Y}_t^{\beta_1} EEER_t^{-\alpha_1}$). One may also say that the EEER is an EER that additionally satisfies restrictions on PI_t, cf. (6).

cr^* ensures that the import share financed by petroleum revenues PI_t/B_t remains constant over time, through equal growth of wealth and imports. In other words, cr^* implies that the remaining life of petroleum wealth at a given import level (W/B) remains the same over time.

A constant import share (PI_t/B_t) implies that the equilibrium real exchange rate remains at a stronger rate than in the case of no petroleum income, $PI = 0$, see equation (17). The relative strength of the EEER depends on the value of PI_t/B_t. Note also that, the EEER will be constant if $\beta_1 \Delta\overline{y}_t = \beta_2 \Delta\overline{y}_{f,\,t}$, but at a stronger rate than in the case of $PI = 0$.

Even if PI_t/B_t remains constant over time when $cr = cr^*$, it may jump to another sustainable level if there is a revaluation of petroleum wealth W. Consequently, the EEER would also jump to another level. For example, if W_{t-1} is revised upward, PI_t and PI_t/B_t will increase immediately together with the strength of the real exchange rate, see equations (17)–(18). This will increase imports. However, if the increase in imports does not counteract fully the effect of higher PI_t on PI_t/B_t, the efficient consumption rate will stabilise the PI_t/B_t at a relatively higher level, and thereby the equilibrium exchange rate at a stronger level than initially. The efficient rate ensures this by making imports and wealth grow at equal rates after the jump. An increase in the consumption rate itself due to e.g. a higher rate of return can have similar effects on PI_t/B_t and the EEER.

4 Empirical analysis

We draw on the empirical analysis in Akram (2004) of Norwegian foreign trade to estimate the efficient consumption rule, and to calculate equilibrium real exchange rates for Norway conditional on the Hicks' rule and the efficient consumption rate of petroleum revenues. In the following, we briefly present some of the main variables, estimates of key parameters and an econometric model of Norwegian imports and exports of non-petroleum products and services. This model has been developed within the theoretical framework of Section 2.1.

4.1 Data and model

In the empirical analysis, imports (B) and exports (A) refer to imports and exports of non-petroleum goods and services measured in NOK billion at fixed 1999 prices. These are explained by Norwegian mainland GDP (Y), trading partners' GDP (Y_f) and the trade-weighted real exchange rate (R). The real exchange rate is defined as $R \equiv EP^f/P$, where E is the trade-weighted nominal exchange rate index, and P^f/P is the ratio of foreign to domestic (Norwegian) consumer price indices. Use of consumer price indices facilitates the construction and updating of the foreign general price index, which covers 25 of Norway's main trading partners. The empirical model has been specified and estimated on quarterly data for the period 1979q1–2001q4.

Figure 1 presents the time series of imports, exports and the implied trade deficit ($TD = B - A$) over the sample period. It suggests that the import and export volumes grew more or less continuously in the sample period. However, imports have grown at a swifter pace than exports, thus increasing the trade deficit (TD) over time. In general, imports and exports have also expanded over time as shares of mainland GDP.

The share of imports that has not been financed by exports, i.e. TD/B, has been 17% on average, but it has fluctuated in the range of 5–32% in the sample period. It was about 23% at the end of 2001. The deficit as a share of mainland GDP has varied in the range of 1–14% over the sample period. This share was about 10% in the late 1990s.

Table 1.A presents estimates of the (long run) income and price elasticities of imports

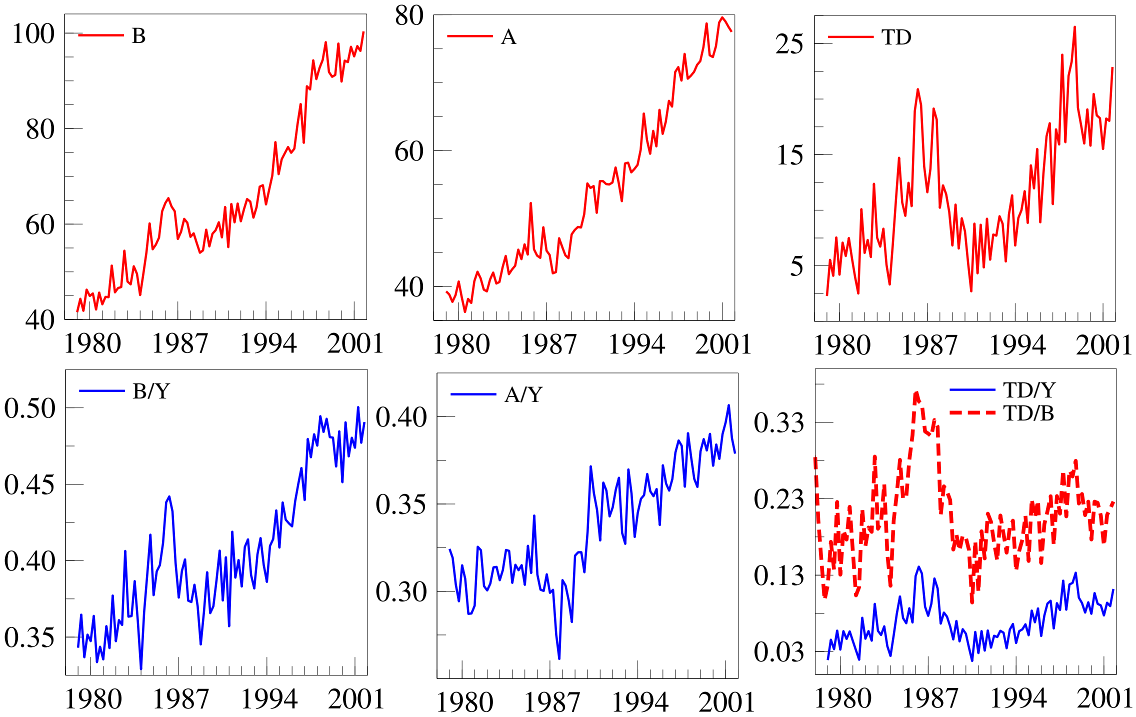

Figure 1: *The top row presents quarterly data for imports, exports and the trade deficit (TD) measured in NOK billion at fixed 1999 prices. The bottom row charts imports, exports and the trade deficit measured as shares of Norwegian mainland GDP (Y). The trade deficit is also measured as a share of imports, TD/B. The time series of TD/B characterises the evolution over time of the import share that is not financed by (current) exports.*

Table 1: Estimates of key parameters and the trade model

A. Estimates of income and price elasticities				
Parameters:	β_1	β_2	α_2	α_2
Estimates:	1.5	1.5	0.7	0.7
B. Tests for cointegration				
Variable/Term:	t-ADF	DF-model with intercept is augmented by:		
$b - (1.5y - 0.7r)$:	-4.13	Δb_{t-4}.		
$a - (1.5y_f + 0.7r)$:	-4.60	Δa_{t-4} and Δa_{t-5}.		
ADF-critical values: 5%: -2.89; 1%: -3.50.				
MacKinnon (1991)'s-critical values: 5%: -3.84; 1%: -4.36.				
C. Model of non-oil foreign trade in equilibrium correction form				
$\Delta\widehat{b}_t = \underset{(-2.68)}{-1.14} - \underset{(-2.69)}{0.17}\,[b-(1.5y-0.7r)]_{t-1}+$ short run effects,				
$\Delta\widehat{a}_t = \underset{(3.23)}{2.81} - \underset{(-3.22)}{0.25}\,[a-(1.5y_f+0.7r)]_{t-1}+$ short run effects.				
Estimation method: FIML				

Note: The estimation period is 1979q1–2001q4 for the parameters, tests and the model. The empirical results have been obtained by using PcGive, see Doornik and Hendry (2001).

and exports, 1.5 and 0.7, respectively. We note that these are symmetric, i.e. $\beta_1 = \beta_2$, while $\alpha_1 = \alpha_2$. This property as well as their estimated values are largely consistent with other empirical studies of industrial countries, including those of Norway, see e.g. Hinkle and Montiel (1999, p. 355, 475, and 489), Goldstein and Khan (1985) and references therein.[4]

Panel B sets out results of tests which suggest that the estimates of the income and price elasticities define valid long run relationships for imports and exports; names of variables in small letters indicate logarithms of variables. These results also lend support to the theoretical model of Section 2.1, which specifies imports and exports as functions of only income and the real exchange rate.

Panel C presents a dynamic model of imports and exports in equilibrium correction form. This model is used to derive paths of equilibrium real exchange rates, and the associated development in imports and exports, conditional on different consumption rates. A number of statistical tests have suggested that this model adequately characterises the behaviour of imports and exports over the sample period.

4.2 Assumptions

Table 2: Assumptions about internal balance and petroleum wealth

A. Internal balance: $\overline{\Delta_4 y} = \overline{\Delta_4 y_f} = 2\%$; 0.5% per quarter				
	1979q1–2001q4	1980q1–1989q4	1990q1–2001q4	
$\overline{\Delta_4 y} =$	2.2%	2.0%	2.3%	
$\overline{\Delta_4 y_f} =$	2.2%	2.2%	2.2%	
B. Petroleum wealth, real rate of return and permanent income				
Petroleum wealth W_{2001}				2619 bn NOK
Real rate of return ar				4%
Permanent income arW_{2001}				105 bn NOK

Sources: Panel A. Own calculations. Panel B. Norwegian Ministry of Finance (Nasjonalbudsjettet 2003; St. meld. no. 1, Table 3.6, p. 65.).

Table 2.A specifies our assumptions regarding internal balance. It is characterised by domestic mainland GDP and foreign GDP growing at a trend growth rate of 0.5% per quarter (2% per year). Both the level of and equality between the domestic and foreign

[4]Estimates of income elasticities greater than one are very common in the empirical trade literature. A number of explanations have been offered to solve this puzzle, see e.g. Krugman (1989) and ch. 3 in Marquez (2002).

growth rates are supported by empirical evidence from the sample period.[5]

We assume that our small home economy is in external balance when the trade deficit (TD) can be financed by petroleum revenues, i.e. with a part or whole of the return on the petroleum wealth, which is comprised of petroleum resources under the seabed and the Norwegian Petroleum Fund. Accordingly, the sustainable level of the trade deficit is not affected by how fast petroleum resources are extracted and deposited in the Fund.

Table 2.B presents official estimates of the current value of the petroleum wealth, real rate of return and the implied permanent income. The total petroleum wealth at the end of 2001 has been estimated at NOK 2619 bn, which is a sum of the market value of the Fund (NOK 619 bn) and the estimated current value of proven petroleum resources. In line with the official estimates by the Norwegian Ministry of Finance, the discount rate as well as the rate of return (ar) has been assumed to be 4% per annum. The annual permanent income from the petroleum wealth therefore becomes NOK 105 bn.

We have chosen to disregard other net foreign assets, as total net foreign assets for Norway have largely consisted of petroleum wealth, particularly from the late 1990s. Norway's net financial assets abroad since the late 1990s have been mainly those of the central government, which are almost totally comprised of the Norwegian Petroleum Fund. The private sector's net financial assets abroad have on average been close to zero in the 1990s.

5 Evaluation of different consumption rules

This section investigates implications of different consumption rules for the equilibrium real exchange and foreign trade. First, it considers consumption of the permanent income (the Hicks' rule), that is when $cr = ar$, and thereafter the efficient consumption. The results are compared against each other and with those in the hypothetical case of no petroleum wealth. All calculations and projections of equilibrium exchange rates and foreign trade are conducted for the period 2002q1–2070q4 by using the model in Tab. 1.C.

[5]The assumption of fixed trend growth rates is obviously made for simplification, as there is a lot of empirical evidence of stochastic trends in GDP of industrialised countries. Moreover, the assumed exogeneity of trend growth rates leads to neglect of potential interdependencies between the real exchange rate and the growth rates. However, the results of Driver et al. (2001) are to some extent comforting as they show that, when present, such interdependencies tend to have negligible effects on estimates of equilibrium exchange rates.

5.1 Consumption of permanent income

Figure 2 shows projections of the equilibrium exchange rate when the trade deficit is financed by the permanent income from petroleum wealth and if we had required trade balance in the absence of revenues from petroleum wealth (and other net foreign assets). Figure 3 shows movements in imports, exports and the trade deficit that are consistent with the equilibrium exchange rate in the former case.

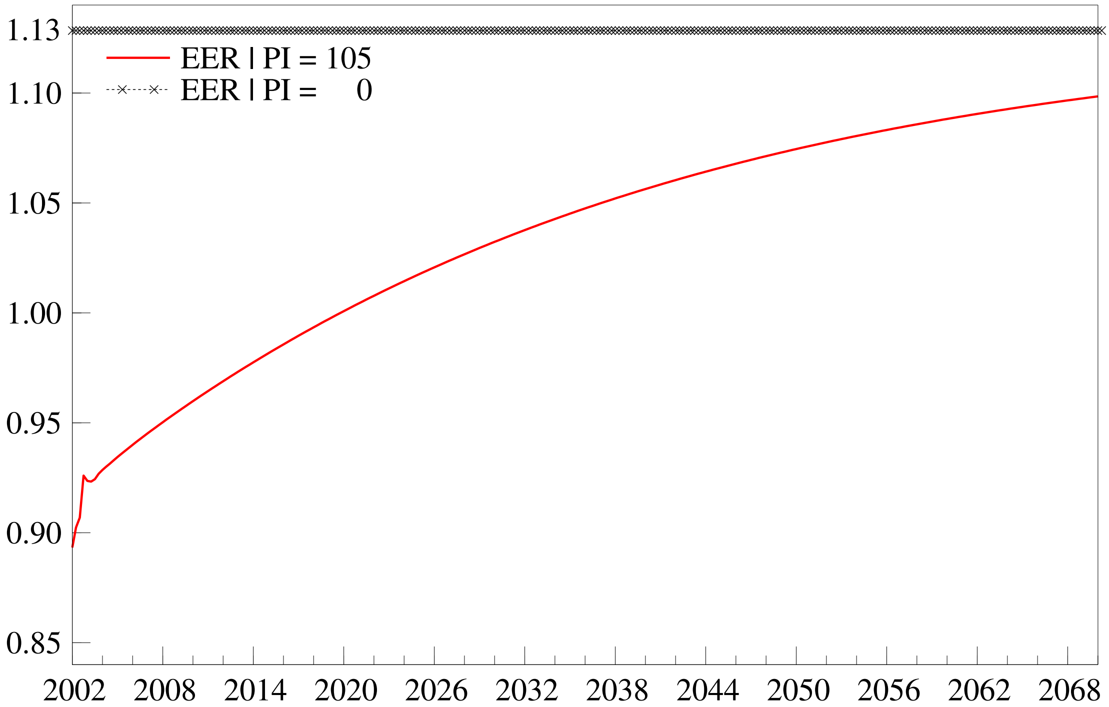

Figure 2: *The continuous rising curve plots the EER when the trade deficit equals permanent income at NOK 105 billion, i.e. 26.25 (= 105/4) billions per quarter. The straight curve represents the EER when external balance is defined as trade balance at each point in time, i.e. PI = 0.*

The equilibrium exchange rate that ensures external balance by way of balancing the trade, i.e. EER|PI = 0, is constant over time. This is because estimated growth in the income-determined imports and exports are equal to each other: $\beta_1 \Delta \overline{y} = \beta_2 \Delta \overline{y}_f = 1.5 \times 0.5 = 0.75$. The estimate of EER|PI = 0 is about 1.13.[6] This level contributes to a

[6]In general, the estimate of EER|PI = 0 depends on the initial level of the income-determined trade deficit $(Y^{\beta_1}/Y_f^{\beta_2})$. A number of simulations, however, suggested that variations in the income-determined trade deficit in the range of observed values during the 1990s do not lead to numerically large deviations from 1.13.

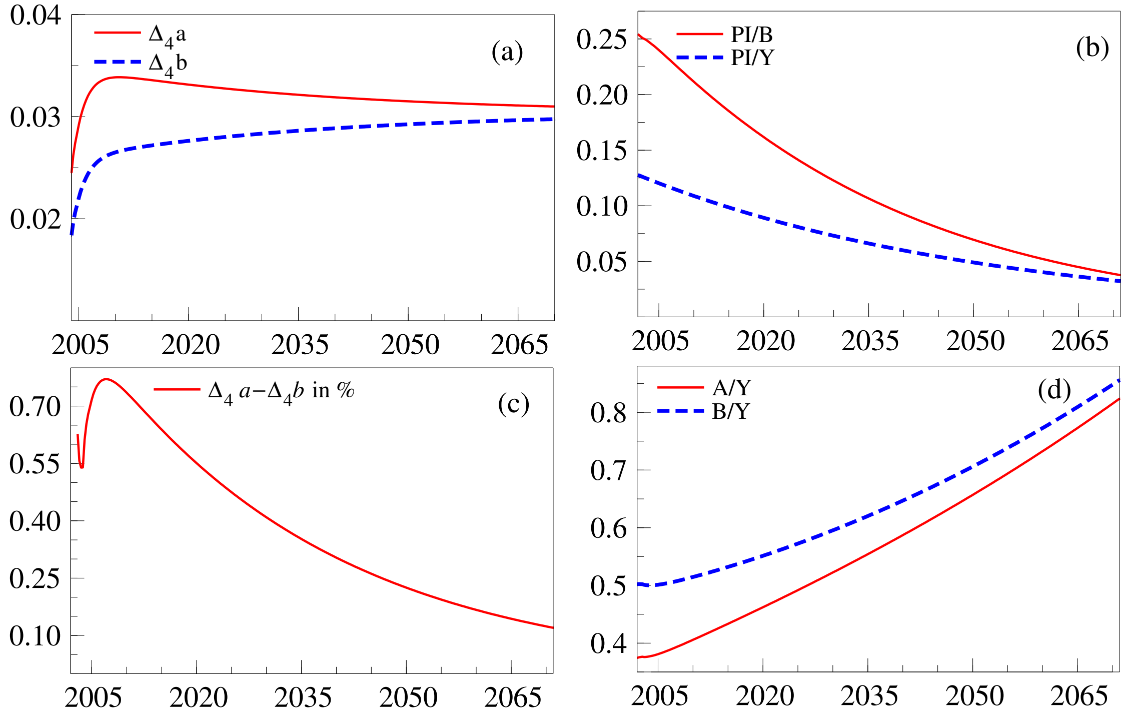

Figure 3: *Paths of imports and exports that are consistent with EER|PI = 105, which is displayed in 2. (a): annual growth in imports $\Delta_4 b$; (b) import share financed by permanent income (PI/B) and trade deficit relative to mainland GDP (PI/Y); (c) percentage growth differential between imports and exports per year $\Delta_4 b - \Delta_4 a$ and (d) paths of import and export shares relative to mainland* GDP, *B/Y and A/Y, respectively.*

sectoral composition where all imports are financed by exports (of traditional goods and services).

The equilibrium exchange rate conditional on the permanent income (EER|PI = 105) is initially about 20% stronger than EER|PI = 0. Accordingly, the level of exports becomes lower and that of imports becomes higher than in the case of no petroleum revenues, PI = 0. The relatively strong value of the equilibrium exchange rate may lead to a large contraction of the exposed sector and a transfer of resources to sheltered sectors.

However, the equilibrium real exchange rate, EER|PI = 105, becomes weaker over time. Figure 2 shows that it converges towards EER|PI = 0 by depreciating continuously over time. The depreciation reflects the steady decline in the share of imports that can be financed by petroleum income (PI/B). This share seems to have a half-life of 35 years. Figure 3.b shows that permanent income can finance 25% of imports in 2002, but less than

10% after 2035 and only 5% in 2070. The trade deficit or permanent income as a share of mainland GDP is 13% in 2002, but less than 7% after 2035.

The steady decline in the importance of the permanent income as a financing source for increasing imports must be compensated by higher exports in order to ensure external balance. The depreciation of the exchange rate dampens the growth of imports and stimulates the growth of exports. In the long run, almost all of the imports are financed by exports and the equilibrium exchange rate becomes fairly close to the rate conditional on zero petroleum revenues. One may also say that the sectoral composition of the economy increasingly resembles the composition in the case of no petroleum wealth.

The behaviour of imports and exports over the simulation horizon is shown in Figures 3.a, c and d. Figure 3.a shows that exports grow faster than imports, but slower than in the case of zero petroleum income. In the latter case, both exports and imports grow at a rate of 3% per annum over the whole simulation horizon. The positive growth difference between exports and imports in Figure 3.c contributes to closing the wedge between the level of exports and imports over time. Figure 3.d shows that exports as a share of mainland GDP converges towards the level of imports as a share of mainland GDP. These shares grow over time because of income elasticities greater than one. However, growth in imports is subdued by the depreciation of the equilibrium real exchange rate, particularly in the early years of the simulation horizon. Consequently, the share of imports increases only from 50% to 55% in the period 2002–2020, and in 2035, it is still not higher than 60%. The income effect becomes only fully effective in the long run when the EER has become constant.

5.2 Efficient consumption

This section calculates the efficient consumption rate and the efficient equilibrium real exchange rate (EEER). It appears that the efficient consumption rate implies a constant EEER and stable growth in foreign trade, as in the absence of petroleum wealth. In contrast to the no-petroleum wealth scenario, however, the equilibrium real exchange rate becomes permanently stronger and the level of imports and exports reflects a stable sectoral composition where a constant import share is financed by petroleum income for ever.

5.2.1 Efficient consumption rate

The efficient consumption rate may be determined by equation (16), as there is empirical evidence of equal trend growth and income elasticities of imports and exports, see Table 2. One may therefore use the following equation to calculate the efficient consumption rate at different values of trend growth:

$$cr^* = 4 - 1.5\Delta_4\overline{y}, \tag{19}$$

where 4 refers to the presumed real rate of return (ar) on petroleum wealth while 1.5 is the estimated income elasticity of imports (β_1). However, trend growth must satisfy the requirement that $4 > 1.5\Delta_4\overline{y}$, in order to rule out zero or negative consumption of petroleum revenues ($cr^* \leq 0$).[7] The efficient consumption rate is equal to 1% per annum when trend growth is 2% per annum. It follows that 3 percentage points ($= ar - cr^*$) of the real return on petroleum wealth, which at the outset only consists of the petroleum wealth, are reinvested. Accordingly, net foreign assets and the associated consumption of petroleum revenues (PI) grow by 3% per annum.

Figure 4 shows the evolution of net foreign assets and the consumption of revenues from abroad, when the permanent income is consumed ($cr = 4\%$) and when the consumption is efficient ($cr = 1\%$). In the latter case, the trade deficit becomes lower than the permanent income in the short run, but exceeds that by an ever increasing amount from 2047 onwards.

The evolution of Norwegian foreign assets conditional on efficient consumption might give the impression that Norway's net foreign assets could increase so much that foreigner's net debt to Norway would become unsustainable in the very long run, see Figure 4. It

[7] Furthermore, use of this (empirical) rule at widely different trend growth rates requires that the real rate of return and income elasticity of imports remain invariant to changes in the trend growth. One may argue that the real rate of return is correlated with trend growth at home and abroad. Thus, when calculating cr^* at alternative values of trend growth, an increase (decrease) in trend growth should be accompanied by an increase (decrease) in the real rate of return.

Interestingly, the 45-degree rule $\beta_1\Delta_4\overline{y} = \beta_2\Delta_4\overline{y}_f$ suggests that income- determined growth in imports ($\beta_1\Delta_4\overline{y}$) is independent of a partial increase (decrease) in domestic trend growth ($\Delta_4\overline{y}$), because β_1 would then decrease (increase) and leave the product $\beta_1\Delta_4\overline{y}$ unchanged. In the case of a partial change in domestic trend growth, i.e. at unchanged foreign trend growth, the real rate of return is likely to remain constant. Accordingly, cr^* is likely to remain invariant to partial changes in domestic trend growth.

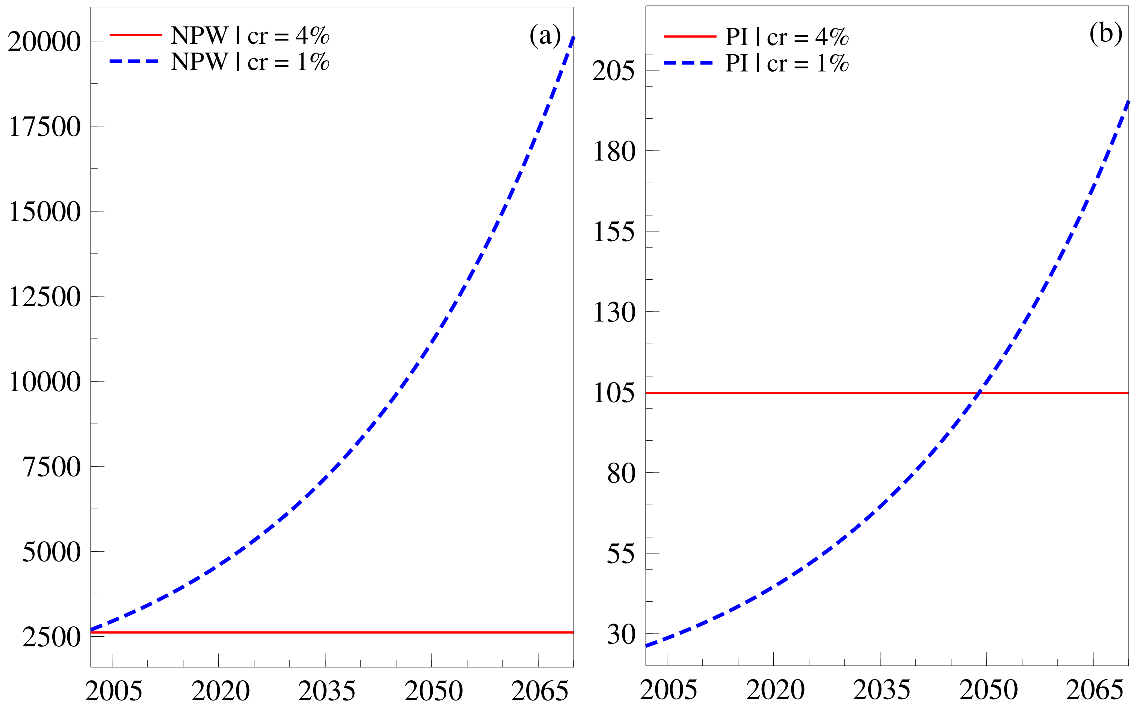

Figure 4: *(a) Net foreign assets when permanent income is consumed ($cr = ar = 4\%$) and when the consumption is efficient ($cr = 1\%$), ceteris paribus. (b): Consumption of petroleum revenues, or trade deficit, at the two consumption rates, 4% and 1%, respectively.*

should be noted, however, that Norway's net assets abroad would increase by the reinvestment rate ($ar - cr$), while the real rate of return on investment abroad is ar. Thus, Norway's share of net foreign assets cannot increase, but would decline over time owing to $cr > 0$.

Figure 5 offers an illustration of the relative size of Norway's net foreign assets over time. It shows the value of the net foreign assets relative to the estimated value of stocks listed on the New York Stock Exchange (NYSE) over time. It appears that in 2001 one could exchange Norway's net foreign assets for 3.2% of the value of the NYSE. This share is halved in the course of 70 years when consumption is efficient, but in less than 20 years if the permanent income is consumed.[8]

[8] Even though Norway's net foreign assets will constitute a declining share of foreign debt over time, Norwegian foreign assets relative to domestic GDP will increase over time. This is because our estimate of the income elasticity, which is higher than one, makes imports grow at a higher rate than GDP growth. However, if we assume that the income elasticity will converge to one or below one, net foreign assets relative to GDP will become stable over time. For example, if we assume that the income elasticity of imports will decline from 1.5 to 1 in a period of 70 years, the ratio of net foreign assets to GDP will become constant at a level that would just be the twice of its current level.

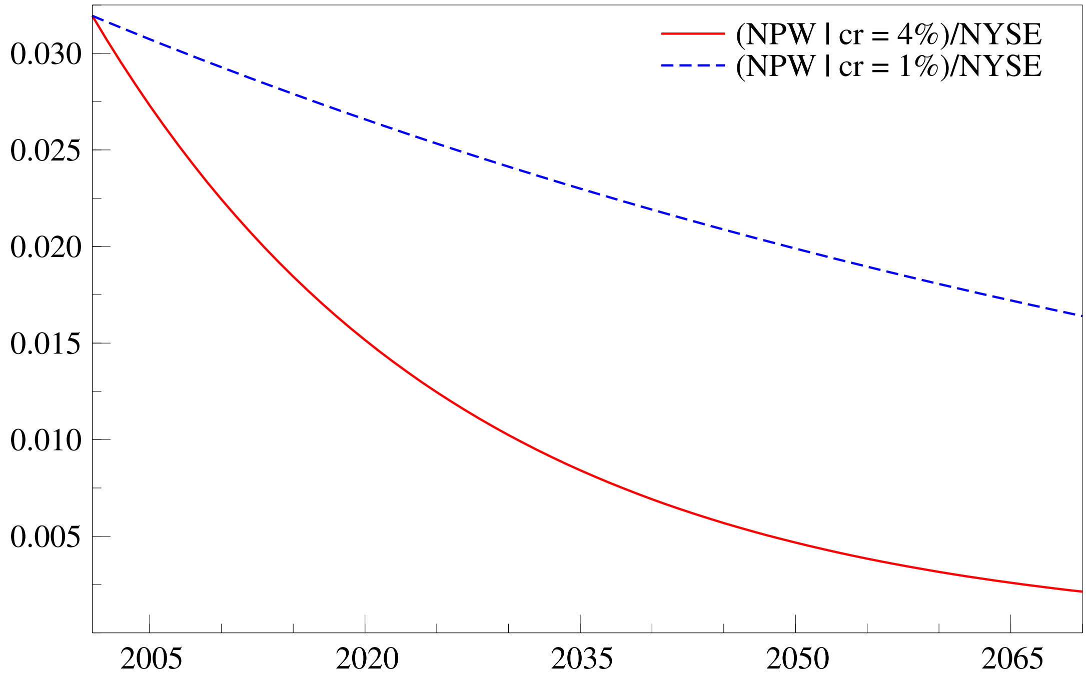

Figure 5: *Norwegian net foreign assets relative to the estimated value of all stocks listed on the NYSE conditional on the two consumption rules, see Figure 4.(a). The market value of the NYSE is assumed to increase at a rate of 4% from 2001 onwards. The market value of the NYSE in 2001 was about USD 11.7 trillion, This value has been converted to NOK 82 000 bn at an exchange rate of NOK 7 per USD.*

5.2.2 Efficient equilibrium real exchange rate and foreign trade

The efficient equilibrium real exchange rate (EEER) becomes constant because estimated income-determined imports and exports are equal, see Section 3. Figure 6 shows that the efficient consumption rate leads to a constant value of 1.07 for the EEER, which is stronger than the equilibrium exchange rate that balances foreign trade in absence of petroleum revenues (1.13).

The efficient equilibrium real exchange rate (EEER) is weaker than the equilibrium exchange rate conditional on the consumption of permanent income (EER|PI=105) during the first 45 years of the simulation horizon, see Figure 6. The deviation is particularly large in the first 20 years, but decreases over time as the later equilibrium exchange rate (EER|PI = 105) converges towards the equilibrium rate in the case of no petroleum wealth. Thus, the EER|PI = 105 becomes weaker than the EEER in the long run. In general,

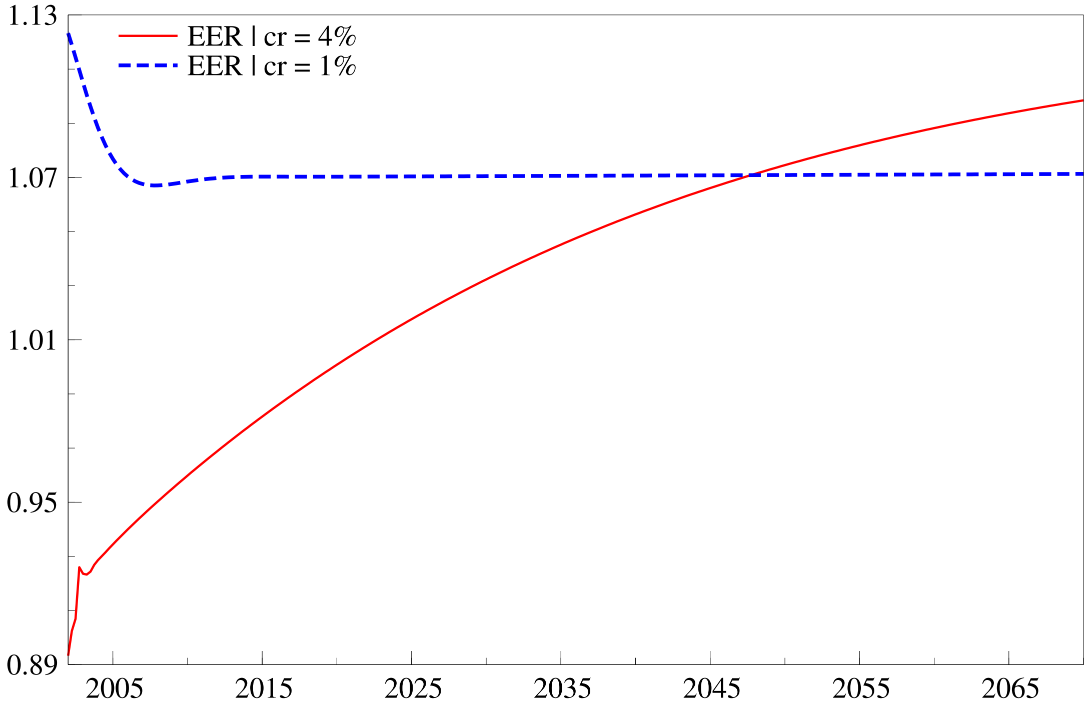

Figure 6: *The efficient equilibrium real exchange rate (EEER) and the equilibrium real exchange rate conditional on consumption of permanent income from petroleum wealth (solid line). These equilibrium rates are denoted* $EER|cr = 1\%$ *and* $EER|cr = 4\%$*, respectively.*

consumption rates greater (smaller) than the efficient consumption rate imply stronger (weaker) equilibrium rates than the EEER in the early years of the simulation period, but weaker (stronger) in the long run.

Figure 7 shows that the efficient consumption rate leads to constant growth rates of imports and exports. They are determined only by the income growth in the home country and abroad, as in the case of zero petroleum income. The figure indicates that both imports and exports as shares of mainland GDP run parallel to each other.[9] This may be interpreted as a sign of a stable sectoral composition over time. The development would not be parallel if the consumption rates were different from the efficient rate, cf. the evolution of imports and exports in the case of consumption of permanent income in Figure 3.d.

Equal growth of imports and exports implies that a constant share of imports can be

[9]The weak sign of divergence, despite equal growth rate is due to differences in initial levels of imports and exports.

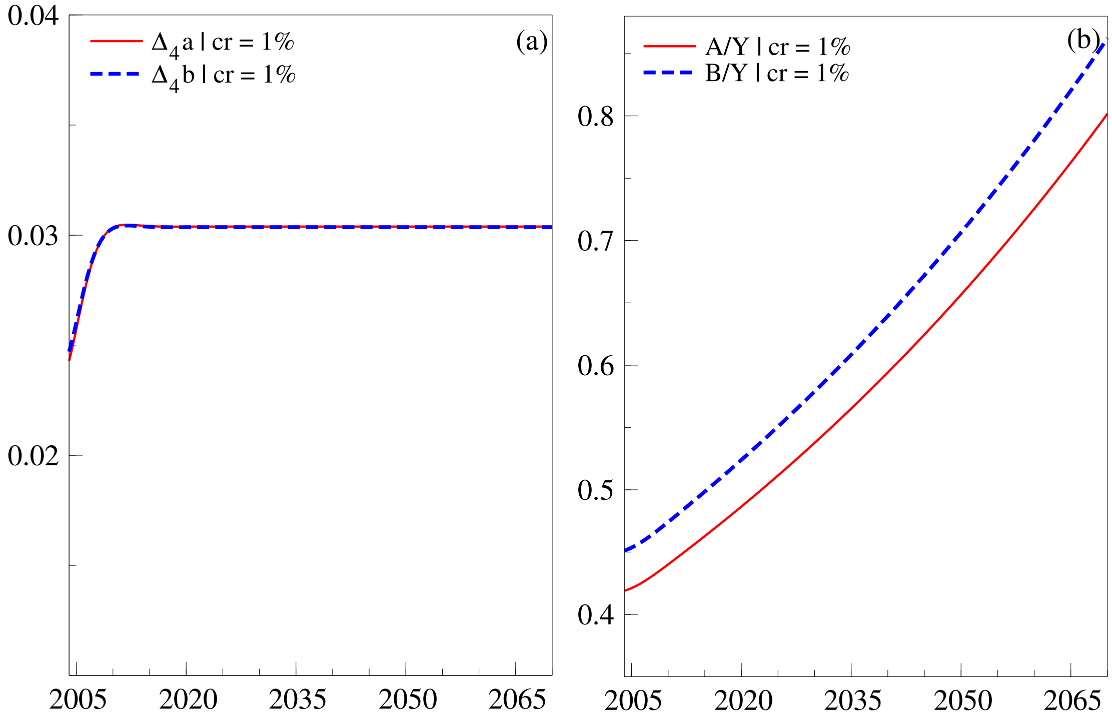

Figure 7: *(a): Annual growth rates of imports and exports (solid line) at the efficient consumprion rate of 1%. (b): Imports and exports as shares of mainland GDP when the consumption rate is efficient.*

financed by petroleum revenues in each period. Figure 8.a shows that this share remains at 7%, while the corresponding share in the case of consumption of permanent income converges towards zero from a level of 25%.

Figure 8.b shows that the efficient consumption rate leads to a slight increase in the trade deficit as a share of mainland GDP (PI/Y) over time, from 3% in 2002 to about 6% in 2070. This doubling of the trade deficit ratio over a period of 70 years is due to growth difference of 1% per annum between consumption of petroleum income (3%) and mainland GDP (2%). The increase in PI/Y over time stands in contrast to the case of consumption of permanent income, where the trade deficit converges towards zero as a share of mainland GDP, see Figure 8.b.

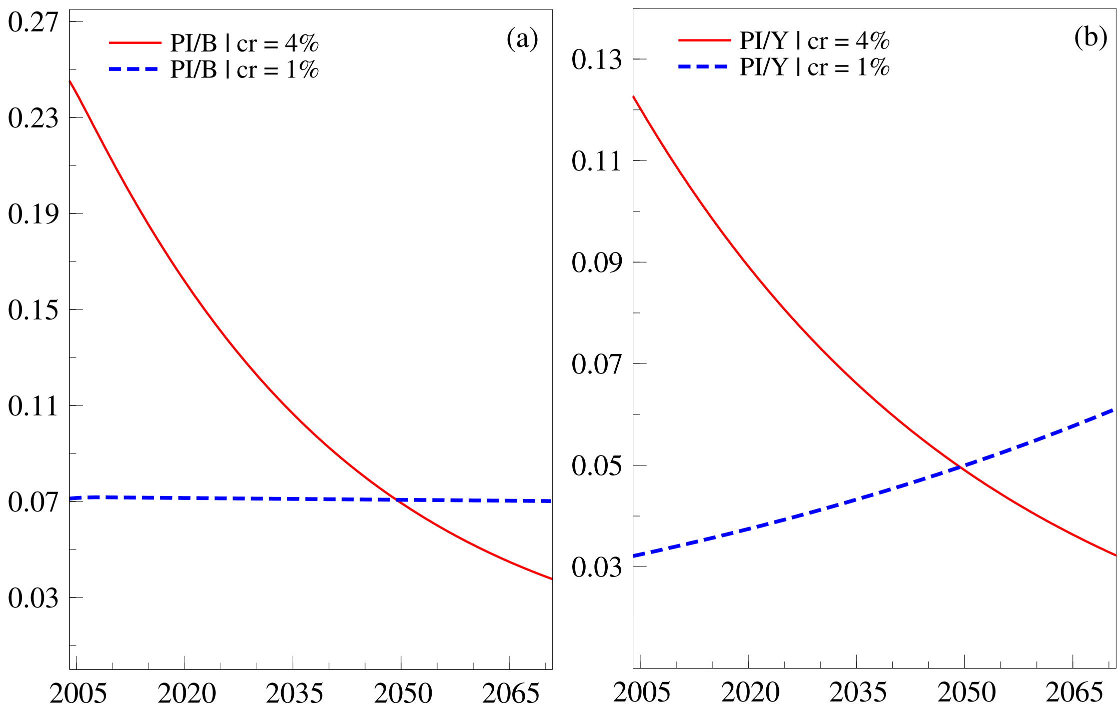

Figure 8: *Left: Share of imports financed by petroleum income (PI/B) when the consumption rate is 4% and when it is at the efficient rate (1%). Right: Import surplus/trade deficit financed by petroleum income relative to mainland GDP at the two consumption rates.*

6 Conclusions

This paper is a contribution to the normative literature on consumption of revenues from exportable natural resources. Consumption of such revenues is commonly associated with a contraction of exposed sectors relative to sheltered sectors which is later reversed in order to avoid balance of payment problems. Sectoral adjustments are costly and can lead to internal and external imbalances over a long period.

This paper considers a way of minimising sectoral adjustments costs by way of avoiding ex-ante temporary sectoral adjustments. It derives the rate of consumption that can lead to balanced growth between sectors and a stable sectoral composition over time. Accordingly, the evolution of sectors and sectoral composition is made largely independent of revenues from natural resources.

It assumes that changes in the sectoral composition are brought about by fluctuations in the real exchange rate. Analytically, the problem at hand has therefore been limited to deriving the consumption rate that would make the behaviour of the real exchange rate imitate that of the real exchange rate in the absence of revenues from natural resources. We denote such a consumption rate as the efficient consumption rate, and the equilibrium exchange rate that follows as the efficient equilibrium real exchange rate (EEER). This equilibrium exchange rate will not only be consistent with internal and external balance, but also minimise fluctuations in the sectoral composition. The addition of the latter property to an equilibrium real exchange rate is a novel contribution to the literature on equilibrium real exchange rates.

We show that the efficient consumption rate is equal to the real return on natural resources in excess of the saving rate required to ensure that consumption of revenues grows at the same rate as the demand for imports. Consequently, a constant share of imports can be financed by revenues from natural resources for ever. Thus, changes in the real exchange rate are not required to affect the evolution of imports and exports to maintain external balance. A deviation from the efficient consumption rate would make the share of imports that can be financed by revenues from natural resources increase or decrease over time. This would contribute to either a persistent strengthening or weakening of the real exchange rate aimed at ensuring external balance, given internal balance.

Our empirical results for Norway suggests that the efficient consumption rate is 1% of the Norwegian total petroleum wealth, if we assume a real of return of 4% and trend growth of 2% for domestic and foreign GDP. It appears that the Norwegian equilibrium real exchange rate in the absence of petroleum revenues is constant. The efficient equilibrium real exchange rate also becomes constant, but at a permanently stronger rate than the equilibrium exchange rate in the absence of petroleum revenues.

This paper has focused on the central role of the real exchange rate which seems to have been overlooked in existing studies of natural resources from a normative point of view. Our results presuppose that minimisation of sectoral adjustment costs is a desirable aim. However, society may be willing to bear some costs in order to deviate from the efficient consumption rate. Future research may take this into account by employing a more general equilibrium model where macroeconomic costs are included explicitly as well as a more complex loss function for society.

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