Planbureau voor de Leefomgeving

RELATIVE PRICE INCREASE FOR NATURE AND ECOSYSTEM SERVICES IN COST-BENEFIT ANALYSIS

Background study

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Contents

Abstract

In 2015, the Dutch working group on discount rates (*Werkgroep Actualisatie Discontovoet*) recommended using the standard discount rate in cost-benefit analyses (CBAs) of nature, while taking into account annual relative price increases of 1% for the effects on ecosystem services. The increase is not to be applied if the particular ecosystem service is substitutable. In this report, we examine for which ecosystem services CBA researchers need to apply the 1% increase. At issue is the change in the ecosystem services that directly affect people's welfare, known as *final ecosystem services*, such as food supply, drinking water, flood protection, quality of the environment, green recreation and natural heritage. Changes in intermediate services, such as pollination and carbon sequestration, have an indirect impact on welfare, through their effects on final services and conventional consumption.

Two matters play an important role in determining the relative price increase: the relative growth rate of nature compared to the growth rate of consumption, and the degree to which nature is substitutable. If nature grows more slowly than consumption and is not or only partly substitutable, it will become scarcer in the future. This justifies the application of a relative price increase. The data show that, over the past few decades, ecosystem services have become comparatively scarcer in the Netherlands: the annual growth rate of GDP was between 0 and 3% higher than that of ecosystem services. However, data published in international studies reveal that the elasticity of substitution between ecosystem services and conventional consumption is generally greater than 1. Therefore, substitution of ecosystem services with other goods or services is, to a certain extent, possible. Combining both insights, it appears that on the basis of historical data a relative price increase of 1% is defensible for a large share of ecosystem services, even though they are all substitutable to some degree. A look at the latest WLO scenarios (CPB/PBL, 2015a) about future growth rates of nature and consumption provides comparable results.

When highly location-dependent ecosystem services become comparatively scarce in or near urban areas, their marginal utility increases, which means that a relative price increase of more than 1% can be justified. Several provisioning services, such as those related to food, wood and energy, should not be subject to relative price increases, because technology-based substitutions or imported goods ensure that the growth in their supply keeps pace with the growth in consumption. In contrast, a worldwide decline in provisioning services could give rise to the application of a relative price increase.

1. Introduction

1.1 Background and definition of the problem

A CBA appraises an intervention's positive and negative effects on welfare, that is to say, the measure's costs and benefits for society. The benefits and the costs are often spread out over time. Ideally, future developments in prices and values are used to calculate future costs and benefits, so that differences in the relative scarcity of goods and services are taken into account in a CBA and in policy decisions based on the analysis. In a CBA, relative prices are often assumed to remain stable over time (i.e. the discount rates for several goods and services are assumed to be equal to each other), and as a result, future variations in relative scarcity are not reflected. The assumption is made because estimating future prices is a complicated task. This applies not only to conventional consumption, but especially to estimates of prices or values of goods and services for which no market exists. Particularly with regard to public goods and services which are becoming comparatively scarce, such as nature and the ecosystem services it provides, the assumption that relative prices remain stable, proves to be problematic because these prices may not be assigned enough weight in the CBA (the CBA balance) nor, consequently, in the decision-making process.

For this reason, the following recommendation was included in the report by the working group on discount rates (Werkgroep Actualisatie Discontovoet, 2015: p. 6), and adopted by the Dutch Government (see Ministerie van Financiën, 2015):

For the discounting of nature (operationalised, for example, as ecosystem services, biodiversity and landscape), the working group recommends using the standard discount rate, while allowing for an annual 1% price increase for nature. This results in an effective discount rate of 2%. Nevertheless, nature should be discounted at the standard rate and without applying price rises, if it can be demonstrated that the features of nature in question are substitutable.

As of yet, there is hardly any scientific literature that supports the application of relative price increases for nature in CBAs. On the basis of their recent empirical study, Baumgärtner et al. (2015) promote the idea that there are good reasons for applying a relative price increase for nature and ecosystem services. The recommendation of the 1% price increase put forward by the Dutch working group on discount rates is partly based on this article. There are two factors underlying this result. First, the growth rate of ecosystem services is lower than that of conventional consumption (which in that study is measured by means of GDP). Second, ecosystem services and conventional consumption are not (perfect) substitutes. Both observations are derived from global data and scientific literature on ecosystem services.

For researchers who are drawing up CBAs that involve nature effects or are aimed at supporting nature policies, this report provides a preliminary recommendation, stating how to determine whether they need to apply a relative price increase of 1%, and if so, which changes in nature or ecosystem services are subject to the increase. To support this advice, it is particularly important to verify if the empirical evidence collected by Baumgärtner et al. also applies to the Netherlands. To do this, we look at two aspects. First, we check whether in the Netherlands too, the growth rate of ecosystem services is lower than the growth rate of conventional consumption. Second, we research and argue the extent to which ecosystem services and conventional consumption are substitutable, and how this varies for each ecosystem service. In the next section we discuss the applied conceptual framework, and describe the structure of the rest of this report.

1.2 Conceptual framework

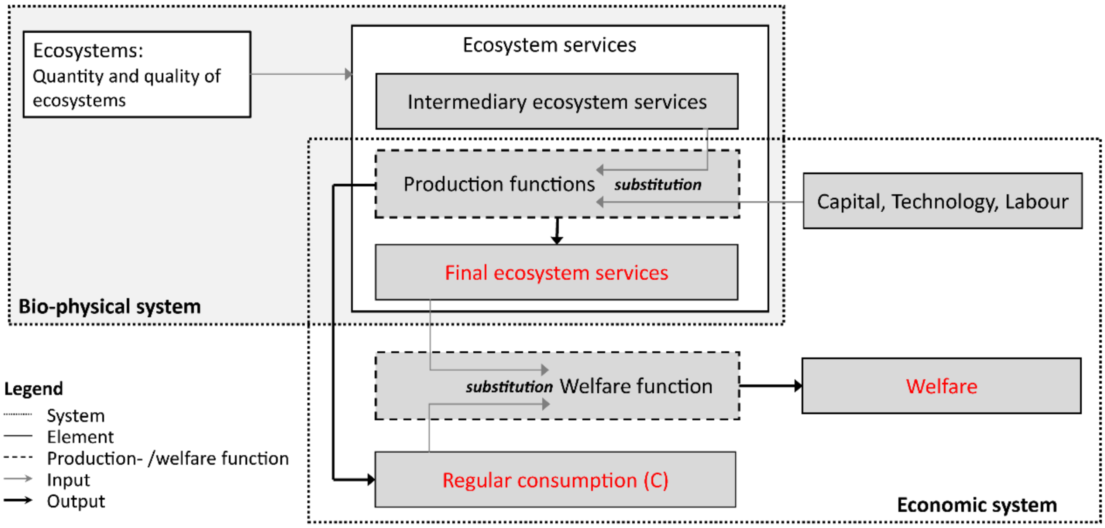
A CBA produces an estimate of the welfare effects of an intervention. Before discussing which theoretical considerations are to form the basis for determining whether a relative price increase or a lower discount rate should be applied to nature in CBAs, this section first present a conceptual framework that describes how nature affects welfare. In this framework, we make a distinction between the biophysical system and the economic system (see Figure 1).

The biophysical system describes nature as a collection of different ecosystems, such as forests, heathlands, grasslands and lakes. Interventions assessed by a CBA can affect both the spatial extent and the quality of ecosystems. These ecosystems provide humans with all kinds of goods and services, often referred to in short as *ecosystem services*. The CICES-system distinguishes the following groups (see also Figure 2 and De Knegt et al., 2014):

- provisioning services, such as food, fish, biomass, drinking water and genetic resources;
- regulating services, such as soil fertility, water regulation, pollination, natural pest suppression and carbon sequestration;
- cultural services, such as green recreation, natural heritage and the symbolic value of nature.

The quality, or health, of an ecosystem is also measured by means of the biodiversity within it. A high degree, or a certain degree, of biodiversity is particularly important for the provision of ecosystem services in the future.

Figure 1. Conceptual framework, distinguishing between intermediate ecosystem services and final ecosystem services, and between substitution in welfare functions and substitution in production functions[1]



For CBAs, it is important to gain insight into the changes in ecosystem services that lead directly to a change in their utility for humans, that is, a change in human welfare. To do so,

[1] In this report, we initially do not take into account the role of intermediate ecosystem services as an input factor in the production functions, and start our analysis on the assumption that conventional consumption and final ecosystem services are both exogenous (Chapter 2). In Chapter 6 we expand the framework and open a discussion on the influence these production functions may have on a relative price increase.

we make a distinction between intermediate ecosystem services and final ecosystem services. Human welfare is directly affected by changes in final services, such as the provision of food, drinking water, flood protection, environmental quality (e.g. air quality and protection against hot weather), green recreation, nature's symbolic value and natural heritage.[2] Changes in intermediate services, such as soil fertility, pollination and carbon sequestration, indirectly lead to changes in welfare as they affect the supply of both conventional consumption and final services.[3] Conventional consumption and final services are provided through production functions, which also use capital, labour and technology as input factors, in addition to intermediate ecosystem services (see Figure 1).[4] Substitution between these input factors is, to a certain extent, possible. This concerns *substitution between factors in the production function of final services*. Examples include the substitution of natural pest control with the application of pesticides or the substitution of the soil's water purifying capacity by water treatment plants.

Figure 2. Overview of the various types of ecosystem services in the CICES system

Source: PBL, WUR, CICES 2014

[2] The CICES classification of ecosystem services categorises the symbolic value of nature and natural heritage as cultural ecosystem services. This is a case of non-material ecosystem output that affects people's physical and mental condition (de Knegt et al., 2014). In the Netherlands, symbolic value is mainly related to the importance that people attach to the preservation of emblematic plant and animal species, such as the white-tailed eagle, the stork, the grouse, the goose, the seal, the fox, the wolf, the viper and the large copper. The value of natural heritage has to do with the willingness to pay for nature to be preserved as a legacy for future generations. Examples of this are the preservation of rare species on the *Red List* (list of endangered species) and of target nature types as defined in the Birds and Habitats Directives.

[3] The distinction between intermediate and final services is meant to avoid double counting in the CBA. For example, double counting occurs when both the decline in soil fertility and the decline in agricultural production are measured, or when the increase in carbon sequestration is measured along with the decrease in the impact of climate change.

[4] In the report by the working group on discount rates, technology is identified as a factor that can affect the demand for certain goods and services, in reference to both conventional consumption and consumption of ecosystem services. The report also states that technological development in particular is difficult to predict. This is very much comparable to the role played by technology as input in production functions, as illustrated in Figure 1.

In our framework, welfare in the economic system is determined by conventional consumption and consumption of final ecosystem services. They both are input factors in the welfare function, and combined, they ultimately produce welfare. This also means that they may be substitutes for each other. That is to say that, theoretically, a decline in welfare due to a decrease in the provision of final ecosystem services can be partly offset by an increase in conventional consumption. Examples of this are substituting a walk in a forest for a visit to an amusement park and replacing tap water with imported bottled water. The point at issue is *substitution among the components of the welfare function*. This form of substitution is also the central feature in the underlying scientific literature on discount rate differentiation. The report by the working group on discount rates (*Werkgroup Actualisatie Discontovoet,* 2015) uses substitution in a broader sense, and assigns an important role to substitution in the production functions. Substitution between intermediate ecosystem services and technological input factors in the production functions is also important for the question of whether a different discount rate may be used for changes in nature, and is relevant for measuring the effects on final services when carrying out a CBA. In this report we make a clear-cut distinction between the two forms of substitution. Firstly, because they affect the discount rate in two different ways, and secondly, because the distinction is important to avoid misunderstandings arising between ecologists and economists.

1.3 Report structure

The rest of this report is structured as follows. In **Chapter 2**, we start with a discussion of the theoretical framework. Conform the better part of the international literature on discount rates, we use the Ramsey growth model (1928) and the pertinent Ramsey rule. This rule states that two aspects determine whether a relative price increase for ecosystem services is justifiable.

Firstly, we need to compare the historical growth rate of ecosystem services to that of conventional consumption. The intuitive understanding is that, if ecosystem services become relatively scarcer, they will also become relatively more valuable. The analysis of the growth rates of ecosystem services and consumption is carried out in **Chapter 3**. It reveals, among other things, that there is only a limited amount of historical data on final ecosystem services, which means we have to resort to historical data on nature and intermediate services as indicators.

Secondly, we need to assess the degree to which final ecosystem services and conventional consumption can substitute each other in the welfare function. After all, if a decrease in utility caused by the relative scarcity of ecosystem services can be fully offset by a rise in conventional consumption (i.e. perfect substitution), then that relative scarcity will not produce an increase in the relative price, and therefore CBAs of ecosystem services have no basis for the application of a relative price increase. This leads to the examination in **Chapter 4** of the extent to which ecosystem services and conventional consumption are substitutable.

In **Chapter 5** we investigate the range for the relative price increase, using the Ramsey rule described in Chapter 2, the relative growth rates from Chapter 3 and the information on options for substitution from Chapter 4. A key assumption in this step is that the relationship between intermediate ecosystem services and final ecosystem services is linear. The assumption is necessary because we only have growth rates for intermediate services at our disposal, but these are in principle not factored in when determining the effects on welfare in the CBA. We present the ranges of historical growth rates and of the assumptions about growth rates in the most recent WLO scenarios (CPB/PBL, 2015) covering the period 2010-2050.

In **Chapter 6** we expand our framework and discuss the role of production functions of final ecosystem services and the role of substitution between, on the one hand, nature and intermediate ecosystem services, and on the other hand, technology. This chapter serves two purposes. First of all, we look into the potential consequences of deviations from the assumption made in the previous chapter, i.e. an examination of the effects that non-linear production functions have on the discount rate. Secondly, we investigate the degree to which the existence of tipping points in production functions can be a reason for using data on the ecological system itself and for applying precautionary principles in the CBA.

The key findings from our analyses in Chapters 2 to 6 are presented in **Chapter 7**, which also puts forward our recommendations on the use of relative price increases for ecosystem services. **Chapter 8** rounds off the report with conclusions and a discussion, and a deliberation on the lines of follow-up research on ecosystems and ecosystem services that are critical for gaining broader and deeper insights into the relative price of nature and ecosystem services.

2. Theoretical framework and the Ramsey rule

Ideally, a CBA contains costs and benefits for the present and the future, expressed in monetary terms. This means that, among other things, both the current and future monetary value of ecosystem services needs to be measured. Considerable progress has been made in the area of valuing goods and services that are not traded on markets (known as *non-market valuation*; for an overview of valuation practices, see Koetse et al., 2015, and several other publications). However, at present, it is difficult to establish the monetary value for many ecosystem services, let alone to make meaningful statements about *future preferences and prices* on the basis of present-day valuation studies.

This report uses a theoretical framework to gain insight into future relative prices, without the need for measuring them explicitly. The model is based on the fundamental economic idea that the price of a good increases when it becomes scarcer, and by extension, that in the case of imperfect substitution, the *relative* price of a good increases when it becomes *relatively* scarcer. This model is also used in Baumgärtner et al. (2015), and takes the form of an extended version of the Ramsey growth model (1928), which uses a utility function[5] applicable to a representative consumer and makes a distinction between conventional consumption (*C*) and consumption of ecosystem services (*E*), where both *C* and *E* are exogenous. The model only considers those ecosystem services that can be categorised as *final ecosystem services*, i.e. those services which benefit humans in a direct manner. This is in line with CBA practice in the Netherlands, where only final services may be factored in to avoid double counting of welfare effects. The welfare function used by Baumgärtner et al. (2015) is as follows:

$$W = \int_{t=0}^{\infty} U\left(C_t, E_t\right) e^{-\rho t} dt \,. \qquad (1)$$

Here, ρ represents the growth rate of pure time preference. The standard Ramsey rule for the welfare function in (1) does not consider ecosystem services separately and is given by:

$$r = \rho + \frac{-\frac{d}{dt} U'\left(C_t\right)}{U'\left(C_t\right)} \,. \qquad (2)$$

The marginal productivity of capital, interest rate *r,* must be equal to time preference rate *ρ* minus the growth rate of marginal utility *U′(C)*. Conversely, therefore, the interest rate is the same as the discount rate. As consumption increases, the marginal value falls and the discount rate rises. For a standard CRRA (constant relative risk aversion) utility function $U(C) = C^{1-\gamma}/(1-\gamma)$ the Ramsey rule acquires its well-known form:

$$r = \rho + \frac{-C_t U''\left(C_t\right)}{U'\left(C_t\right)} \frac{\dot{C}_t}{C_t} = \rho + \gamma g \,, \qquad (3)$$

where *g* represents the growth rate of consumption. If the consumption of ecosystem services does not increase (because nature is not growing), but conventional consumption

[5] In this report, the terms *welfare function* and *utility function* are assumed to be equivalent.

does increase, it is necessary to apply a lower discount rate for ecosystem services. The Ramsey rule (2 and 3) can easily be extended to separate the discount rates for conventional consumption and the consumption of ecosystem services, based on the welfare function (1). This gives the formulas (see Weikard and Zhu, 2005):

$$\begin{aligned} r_C &= \rho + \gamma_{CC} g_C + \gamma_{CE} g_E , \\ r_E &= \rho + \gamma_{EC} g_C + \gamma_{EE} g_E \end{aligned} , \qquad (4)$$

where r_C and r_E are the discount rates for consumption and ecosystem services, respectively, g_C and g_E are the corresponding growth rates, and the four elasticity values are $\gamma_{CC} = -CU_{CC}/U_C$, $\gamma_{CE} = -EU_{CE}/U_C$, $\gamma_{EC} = -CU_{EC}/U_E$ and $\gamma_{EE} = -EU_{EE}/U_E$.

The difference between discount rates r_C and r_E can be expressed in the growth rate of the relative price of ecosystem services compared to consumption, P, which is given by:

$$g_P = \frac{\dot{P}}{P} = \frac{\frac{d}{dt}\left(U_E / U_C\right)}{U_E / U_C} . \qquad (5)$$

Using (4) to work out (5) gives the simple equation $r_C - r_E = g_P$ (see Weikard and Zhu, 2005, and other publications). This means that the difference between discount rates r_C and r_E is, in simple terms, equal to the growth rate of the relative price of ecosystem services compared to consumption. In actual practice, it is then possible to use a fixed discount rate r_C, while making adjustments to the discount rate for ecosystem services r_E by conducting research into developments in relative prices.

It is also important to include the possibilities for substitution of ecosystem services in the derivations. A further specification of the utility function *U(C,E)* as a *CES* utility function with a constant elasticity of substitution σ (Hoel and Sterner, 2007) implies that the growth rate of the relative price, and therefore the difference between the discount rates, can be expressed as:

$$r_C - r_E = g_P = \frac{1}{\sigma}\left(g_C - g_E\right) . \qquad (6)$$

This means that the difference between the discount rates of (in the case at hand) ecosystem services and consumption is related to the *difference in growth rates* and the *degree of substitution* between the two variables. The underlying idea here is that future relative scarcity of a good or service (lower growth rate) will lead to an increase in the relative price ─ that is, a lower discount rate. It is important to note that setting a difference between discount rates in a CBA is equivalent to applying a relative price increase which equals the difference between the two discount rates. In other words, a 1% decrease in the discount rate for ecosystem services is the same as a 1% increase in their relative price. The formula also shows that the two discount rates are the same if there is perfect substitution ($\sigma \rightarrow +\infty$), or if the growth rates are equal ($g_C = g_E$).[6] This also shows that two essential elements are involved in determining relative price: the difference between the growth rates of final ecosystem services and of consumption (relative scarcity), and the potential for substitution.

When an ecosystem service, or the potential for delivery of the service, grows more slowly than consumption or is on a downward trend, then that may be reason to apply a relative price increase. As shown in Baumgärtner et al. (2015), there is quite a bit of variation in these growth rates, both within countries and for the world as a whole. However, the average growth rate of ecosystem services was significantly lower than that of consumption

[6] The use of a CES utility function means that the applicable discount rate itself is not constant over time. Since this report deals mainly with the relative discount rate, we are not taking this complicating factor into account at this stage.

in the period covered by their study. The fact that something becomes relatively scarcer does not automatically imply that a relative price increase must be applied. For if the ecosystem service in question is to a large degree substitutable with conventional consumption, the relative growth rate is less important. Therefore, to approve the application of a relative price increase, it must be demonstrated that the ecosystem service is not substitutable with conventional consumption. However, the degree of substitutability between goods and services lies on a continuum from zero (goods are perfect complements) to infinite (goods are perfect substitutes). It is therefore, as will become apparent later, almost impossible to prove that an ecosystem service is *not* substitutable with conventional consumption, because a certain degree of substitution is always conceivable. Therefore, when deciding whether to establish a relative price increase for ecosystem services, it is far more important to consider the relative growth rate of ecosystem services compared to consumption and *the degree to which* ecosystem services can be substituted with consumption.

Finally, we need to restate that a CBA should, in principle, measure changes in final ecosystem services, but that intermediate services, regulating services in particular, are needed for the production of final services. A drop in the provision of intermediate services may lead to a decrease in the capacity to provide final services in the short or long term. As long as a decrease in intermediate services can be translated into a decrease in final services, this is not an issue, since the reduction in final services can be included in a CBA. However, as the next chapter shows, there are only very limited data on final ecosystem services and their evolution. For this study, data on nature itself or data on intermediate services can be used as indicators for trends in final services, whereby an assumption must be made about the relationships between nature and intermediate services on the one hand, and final services on the other. This is discussed in more detail in the following chapters.

3. Growth rates of ecosystem services and conventional consumption in the Netherlands

Data on the historical development of final ecosystem services in the Netherlands are very limited. An exception to this is the data collected on, mainly, provisioning services.[7] Some final services, such as green recreation, quality of the environment, symbolic value of nature and natural heritage, have not been unambiguously defined yet. Consequently, not much is known about final services, not to mention the fact that the long data series needed to calculate growth rates are unavailable. However, we do know that the provision of final services depends on a number of indicators for ecosystem quality and ecosystem quantity. These elements are necessary for the provision of final services and therefore they can be used as indicators for changes there. For these indicators, longer data series do exist.

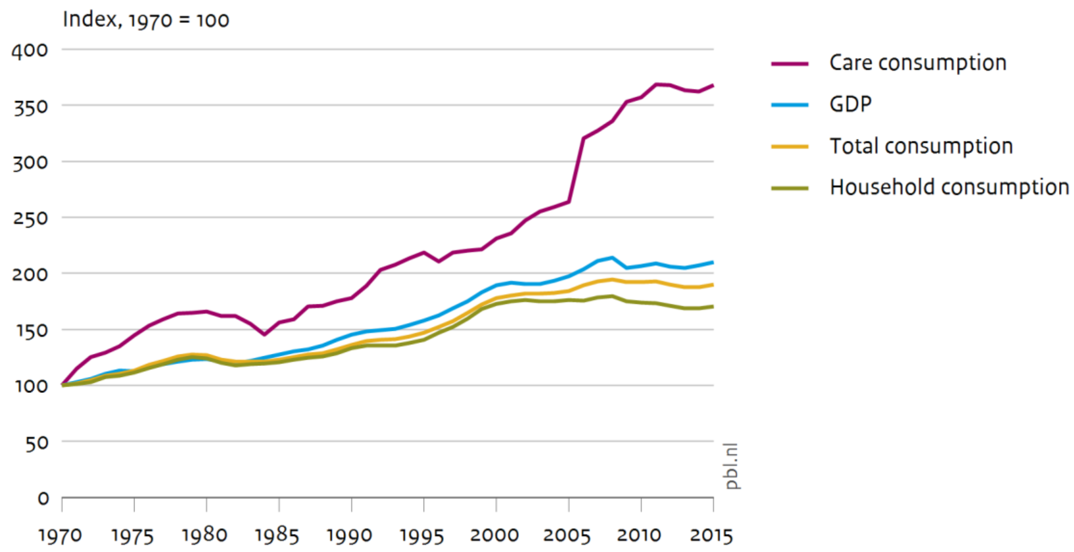
Accordingly, the analysis presented in this chapter does not provide a hard estimate of the growth rate of final ecosystem services. Our aim is to make a plausible argument that the growth rates of conventional consumption and final services diverge, but not to indicate exactly by how much. Later, we will make assumptions about the relationship between our indicators and final ecosystem services (i.e. the production function), but at this point we limit ourselves to measuring the growth rates of the indicators for ecosystem quality and ecosystem quantity.

For the distinction between quality and quantity of ecosystems, we differentiate between data on biodiversity, as an indicator for *quality*, and data on land-use surface areas, as an indicator for *quantity*. Both offer clues about changes in green recreation, quality of the environment, symbolic value of nature and natural heritage. The growth rates are compared to the growth rate of real conventional consumption in the Netherlands, and all figures are converted to per-capita values, using the Dutch population trends from Statistics Netherlands (CBS StatLine). The data on conventional consumption have been retrieved from the Central Economic Plan drawn up by CPB Netherlands Bureau for Economic Policy Analysis (CPB, 2017). The real household consumption and care consumption indices for the 1970–2015 period are taken from the annex to the Central Economic Plan, and a weighted average is calculated from these two series using the respective nominal volumes of household consumption and care consumption as weights. The resulting series is our indicator for real conventional consumption. The reason for refraining from using GDP, as in Baumgärtner et al. (2015), is that consumption is part of the Ramsey rule rather than GDP.

[7] Note that the historical data on agricultural production provide little insight into the provision of intermediate ecosystem services or the quality of the ecosystem because a large part of the increase in agricultural efficiency is the result of technological input factors.

The growth rates of consumption and GDP are not equal. This is shown in Figure 3, which contains the indices of real GDP and three real consumption series, for the 1970–2015 period. It shows that household consumption grew less than GDP and that the increase in the consumption of care services was substantial. As a result, total consumption grew slightly less than GDP. The growth rate for GDP per capita over the whole period was 1.66%, while the growth rate for total consumption was 1.40%, a difference of about a quarter of a percentage point.

Figure 3. Indices of per capita GDP, household consumption, care consumption and total consumption, 1970 – 2015

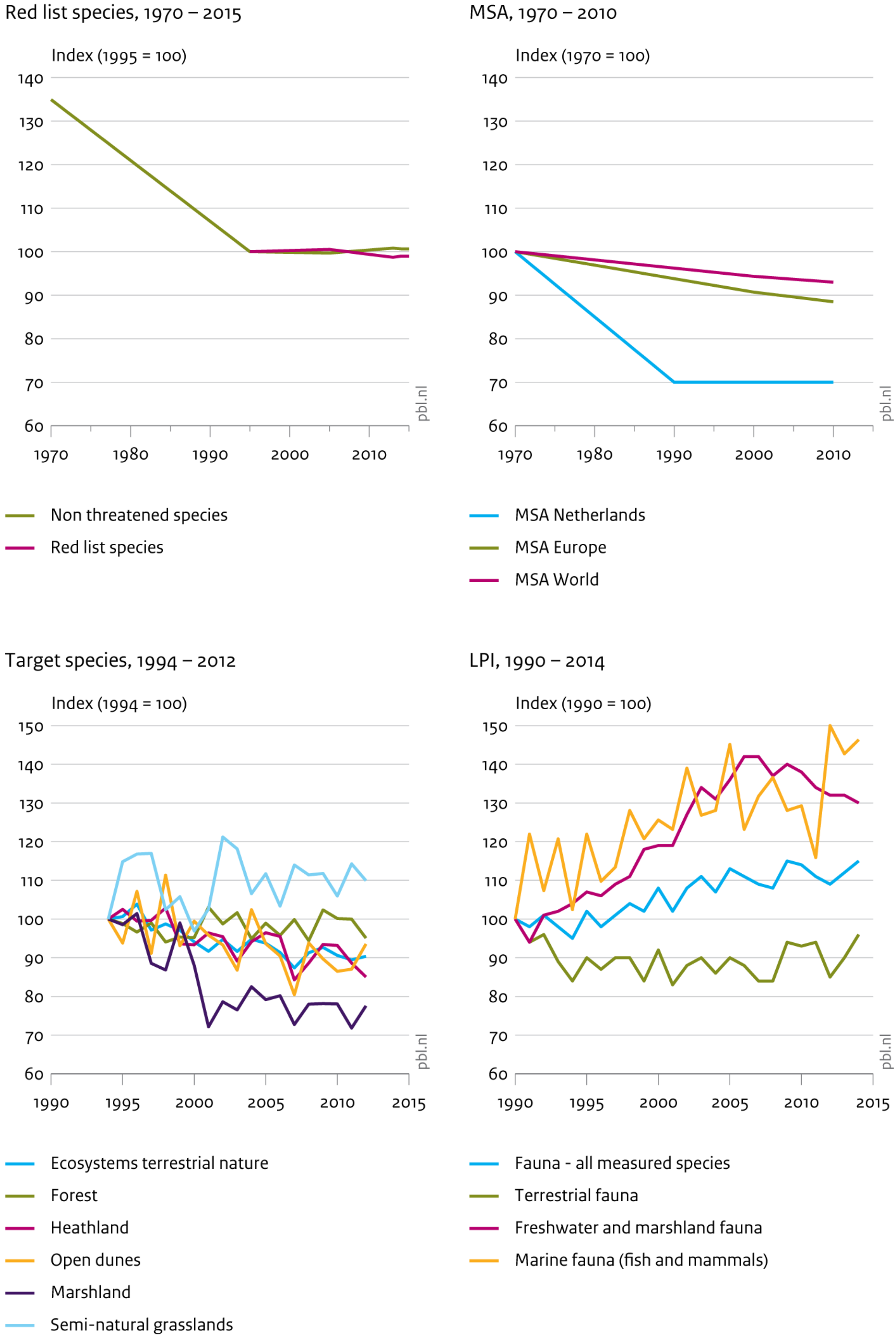


Source: CBS and CPB

3.1 Indicators for ecosystem quality: biodiversity in the Netherlands

To gain insight into changes in the quality of our ecosystem, we need historical data on the indicators that are used in environmental impact assessments. However, since these data are not available, we use data on developments in biodiversity. These are obtained from the website of CLO (Environmental Data Compendium) and measure plant and animal species that are, and those that are not on the Red List, mean species abundance (MSA), target species, and the living planet index (LPI). Combined, they tell us something about trends in biodiversity in the Netherlands and they also give an indication of changes, particularly those affecting the symbolic value of nature. Figure 4 shows the indices of these data sets, which are the basis for the calculation of yearly growth rates. In contrast to the growth rate of conventional consumption, these series and growth rates are not calculated per capita, as they are non-rival ecosystem services. The growth rates of ecosystem quality are presented in Table 1, along with the growth rate of per-capita conventional consumption for the same periods. Virtually all indices are found to have a flat or a slightly declining trend, while consumption over the studied periods has grown steadily. The result is that biodiversity (as an indicator for ecosystem quality) is becoming relatively scarcer in relation to conventional consumption.

Figure 4. Indices of biodiversity indicators



Note: Top left: threatened and non-threatened species; top right: mean species abundance (MSA) in the Netherlands, Europe and worldwide; bottom left: target species for several ecosystems; bottom right: living planet index (LPI) for several ecosystems)

Table 1. Growth rates of indicators for biodiversity (not per capita) in relation to growth rate of conventional consumption per capita

Indicator	Period	Growth rate
Red List		
Red List	1995–2015	-0.03%
Consumption	1995–2015	1.31%
Non-threatened species	1970–2015	-0.65%
Consumption	1970–2015	1.44%
MSA		
the Netherlands	1970–2010	-0.89%
Europe	1970–2010	-0.31%
World	1970–2010	-0.18%
Consumption	1970–2010	1.64%
Target species		
Terrestrial nature	1994–2012	-0.56%
Forest	1994–2012	-0.28%
Heathland	1994–2012	-0.90%
Open dunes	1994–2012	-0.37%
Marshland	1994–2012	-1.40%
Semi-natural grassland	1994–2012	0.53%
Consumption	1994–2012	1.42%
LPI		
All species	1990–2014	0.58%
Terrestrial fauna	1990–2014	-0.17%
Freshwater fauna	1990–2014	1.10%
Marine fauna	1990–2014	1.60%
Consumption	1990–2014	1.34%

3.2 Indicators for ecosystem quantity: surface area of nature in the Netherlands

The provision of ecosystem services is directly related to the surface areas of the different kinds of ecosystems from which they originate. Data on areas for various types of land use are obtained from the StatLine database from Statistics Netherlands. We have retrieved data on the surface areas of recreation sites, agriculture, forests and open natural land, and surface waters. The per-capita indices of these data series, presented below in Figure 5, show slightly upward or stable trends in the case of recreation sites and surface water, but for forests, open natural land and agriculture the surface areas are steadily decreasing. Table 2 shows the per-capita growth rates of these surface areas compared to per-capita conventional consumption in the same time periods. From this it is clear that the growth rate of the surface area dedicated to parks and public gardens is higher than that of consumption. The same applies to the growth rate of the total area of surface waters. The growth rates of other surface areas — other kinds of recreation sites, agriculture and forests and open natural land — are considerably lower than the growth rate of consumption.

Figure 5. Indices of per capita area for different types of land use

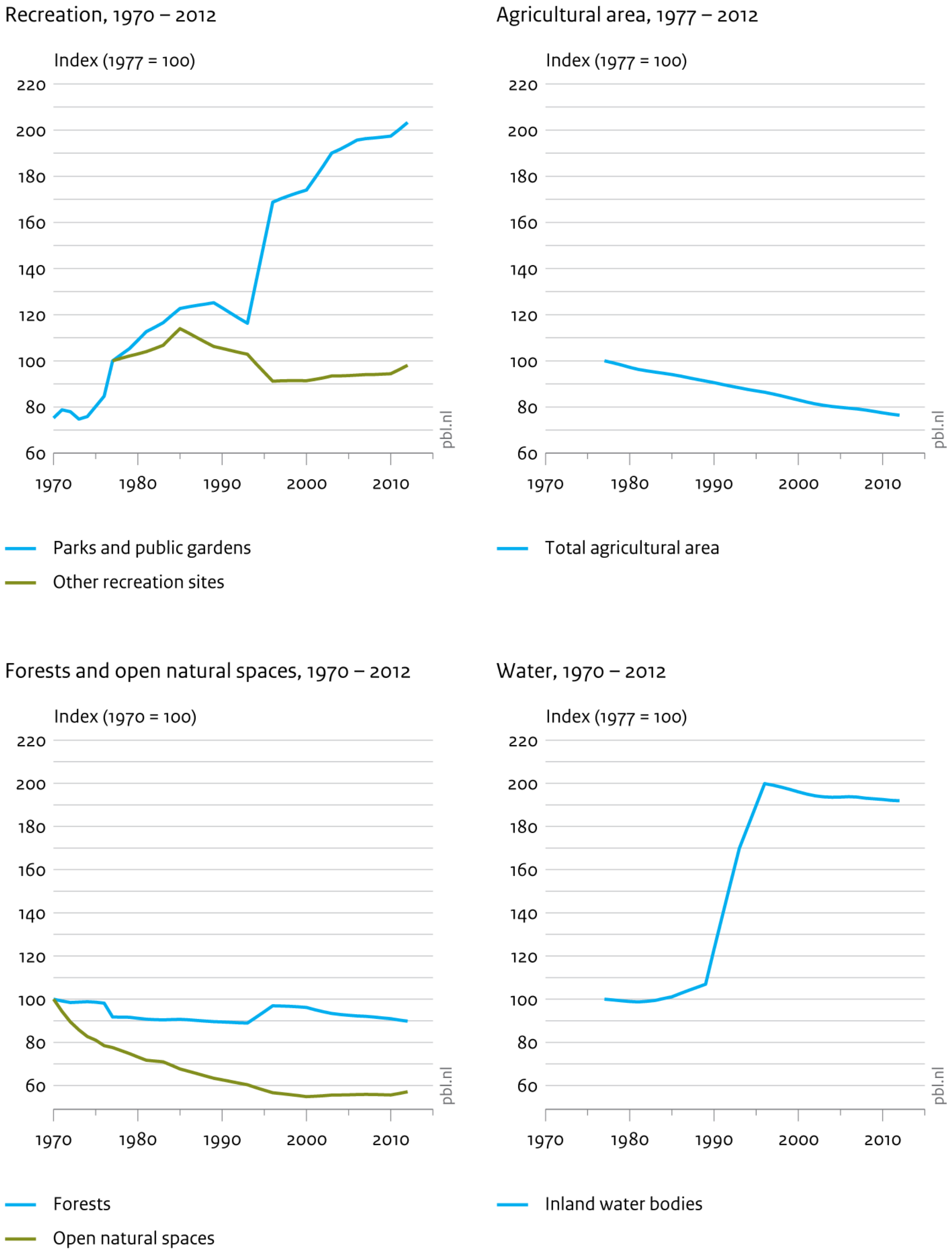


Table 2. Per-capita growth rates of land-use surface areas compared to growth rate of conventional consumption per capita

Indicator	Period	Growth rate
Recreation		
Parks and public gardens	1970–2012	2.40%
Consumption	1970–2012	1.54%
Other land used for recreation	1977–2012	-0.06%
Consumption	1977–2012	1.28%
Agriculture		
Total surface area for agriculture	1977–2012	-0.78%
Consumption	1977–2012	1.28%
Woodland and natural open land		
Woodland	1970–2012	-0.26%
Natural open land	1970–2012	-1.32%
Consumption	1970–2012	1.54%
Water		
Inland water	1977–2012	1.87%
Consumption	1977–2012	1.28%

3.3 Regional developments

In addition to studying developments for the Netherlands as a whole, it is also interesting to consider developments in several regions within the country, in order to draw conclusions about regional differences in the relative scarcity of ecosystem services. This may be relevant to those ecosystem services that are provided locally. Examples are cultural services (including green recreation and the aesthetic value of the living environment) and regulating services (including air quality and water quality). For the twelve provinces, data compiled by Statistics Netherlands (CBS) are available on the surface areas of land use for the period 1987–2011. Unfortunately, no realistic figures are available for conventional consumption at the provincial level, and therefore we use GDP as an indicator for consumption. The resulting regional differences will only be distorted if the difference in growth between consumption and GDP varies (greatly) among provinces; for example, if in North Holland consumption grows less rapidly than GDP, while both grow at the same pace in Gelderland. The figures for province-level nominal GDP for the period 1988–2015 have been obtained from Statistics Netherlands. They have been converted to real GDP in 1988 prices and adjusted for GDP price changes for the Netherlands using figures from the Central Economic Plan drawn up by CPB (CPB, 2017). Since population trends also vary among provinces, the figures for GDP and surface areas of land use are expressed per capita. To achieve this, the study uses data from Statistics Netherlands on population trends in each province for the period 1988–2015. Table 3 presents the growth rates of real GDP per capita and of surface area of forms of land use per capita for the 12 provinces over the period 1988–2012.

Considerable differences exist among provinces in terms of both income and trends in surface areas of land uses and these could in theory also lead to differences in the relative prices for consumption (expressed by means of GDP in this part of the study) and ecosystem services. It is interesting to look at differences between the provinces in Randstad (a conurbation in the western part of the country, covering large parts of North Holland, South Holland and Utrecht) and the other provinces. Table 4 presents the average growth rates for different types of land use and real GDP for the Randstad provinces and for the other provinces. The difference between the GDP growth rates is very small, and the same applies to woodland, natural open land and agricultural land. The most striking difference is that in the Randstad conurbation both inland water and parks and public gardens are becoming relatively scarcer in relation to GDP; in both cases the GDP growth rate is about 0.7 percentage points higher. In municipalities outside the Randstad, these types of land use are not becoming relatively scarcer. One conclusion that could be reached from this is that a CBA needs to give more weight to changes in those two types of land use (inland water, and parks and public gardens) in the Randstad conurbation than in other regions. In other words, changes in inland water, and parks and public gardens in the Randstad conurbation could be given a relative price increase of 1%, while in other regions they would not qualify for this kind of adjustment. It should be noted that, when measuring geographical differences in cultural services, the province is in all likelihood not the most suitable scale and it is probably more appropriate to use an additional distinction based on level of urban development. A distinction of this kind would undoubtedly also reveal significant regional and local differences.

Table 3. Per-capita growth rates of real GDP and surface area of forms of land use by province for 1988–2012

	Real GDP	Inland water	Woodland	Natural open land	Parks and public gardens	Agricultural land
Groningen	3.04%	0.94%	2.87%	0.93%	1.80%	-0.38%
Friesland	1.71%	4.57%	0.49%	-0.08%	2.60%	-0.48%
Drenthe	1.52%	1.71%	0.27%	-0.11%	4.17%	-0.71%
Overijssel	2.09%	-0.19%	-0.32%	-0.85%	1.97%	-0.83%
Flevoland	2.11%	3.63%	-2.08%	-3.17%	0.78%	-2.80%
Gelderland	2.23%	0.22%	-0.19%	-0.92%	1.88%	-0.70%
Utrecht	2.50%	-1.48%	-0.90%	-1.31%	1.87%	-1.21%
N. Holland	2.45%	4.09%	0.55%	-0.74%	1.86%	-0.88%
S. Holland	2.07%	-0.18%	2.14%	-0.18%	1.43%	-0.96%
Zeeland	1.02%	0.08%	1.76%	0.29%	2.63%	-0.49%
N. Brabant	2.67%	0.35%	-0.19%	-0.69%	2.36%	-0.82%
Limburg	2.03%	1.61%	0.37%	-0.77%	3.78%	-0.35%

Table 4. Per-capita growth rates of real GDP and land use for Randstad provinces and rest of provinces in the period 1988–2012

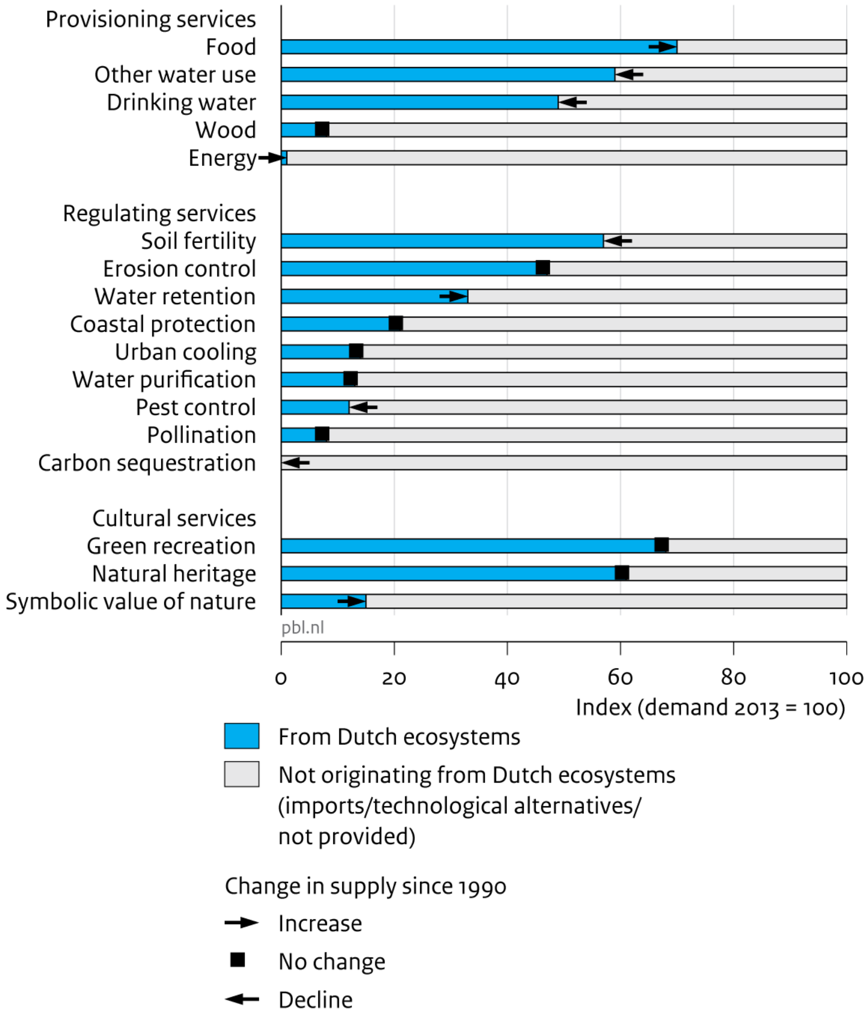
	Real GDP	Inland water	Woodland	Natural open land	Parks and public gardens	Agricultural land
Randstad	2.30%	1.65%	0.28%	-0.58%	1.63%	-0.95%
Other	2.26%	3.04%	-0.01%	-0.47%	2.43%	-0.71%

3.4 Data on ecosystem services

As mentioned above, data and information on the provision of ecosystem services in the Netherlands are limited, and important insights into the functional relationship between ecosystems and ecosystem services are still lacking. An exception to this is a report by De Knegt (2014), which, among other things, maps the provision of a range of both intermediate ecosystem services and final services. While the list is not exhaustive, it does contain a large number of important services and draws a good picture of the diversity among them. Figure 6, taken from the report, shows that the provision of many ecosystem services in 2013 had decreased or remained stable compared to 1990.

This means that the growth rate of those services is considerably lower than that of conventional consumption, and can be even negative. It does appear that the rates for food and energy production, water retention capacity and the symbolic value of nature increased in that period. However, it is not likely that these growth rates are equal to or higher than that for consumption, which grew by 1.92% per year on average in the period 1990–2013, but there are no data available to verify this. The Natural Capital Accounts, which are currently being developed by Statistics Netherlands within the environmental accounts system, may be able to provide additional insights into this in the future.

Figure 6. Supply of goods and services, 2013



Source: PBL; Alterra, Wageningen UR 2014 www.pbl.nl

It is important to realise that the list in Figure 6 contains both final services and intermediate services. Although final services do, in principle, play a role in the CBA and intermediate services do not, in actual practice it is often difficult to assess measures for their effects on final services, while their effects on intermediate services and nature are evaluated more easily. This is why assessments of the relative scarcity of intermediate services and nature continue to be of relevance.

3.5 Conclusion and discussion

Data on the evolution of supply and demand in regard to ecosystem services are scarce, but the amount available does reveal that the growth rate of most ecosystem services is falling behind that of conventional consumption. It should be noted that the information is often incomplete, of a qualitative nature or based on estimates. However, data on the underlying ecosystems and nature also show that, in the vast majority of cases, these are becoming relatively scarcer compared to consumption. Based on these two sources, we conclude that ecosystem services are, generally speaking, becoming relatively scarcer compared to conventional consumption.

The data on ecosystems and nature serve, of course, as indicators for the final ecosystem services which ideally we would prefer to measure directly. After all, the question we are addressing is not whether biodiversity is becoming relatively scarcer, but rather, whether such scarcity means that the provided final ecosystem services are becoming relatively scarcer. This highlights the need to collect more data and information on the evolution of ecosystem services, and the need to acquire knowledge about their characteristics, quality and production functions, and the role of ecosystems in these functions (see also Chapter 6). At this stage, we assume that there is a linear relationship between the indicators we use and the final ecosystem services. Under this assumption, our results show that the growth rate of consumption is higher than that of ecosystem services, and that therefore ecosystem services have become relatively scarcer in recent decades. In quantitative terms, the difference between both annual growth rates varies between 0% and 3%.

4. Substitution between ecosystem services and consumption in the utility function

To determine the relative price increase of ecosystem services, it is important to have a clear picture of not just the relative growth rate of the services, but also the possibilities of replacing or substituting them with conventional consumption. For our purposes, it is therefore relevant to gain insight into the possibilities for substitution between ecosystem services and consumption in the welfare function. The core concept here is *elasticity of substitution* (see Equation 6). In virtually all analyses on this subject, a CES function is used, which is characterised mainly by a constant elasticity of substitution between — in our case — consumption (*C*) and ecosystem services (*E*). Ebert (2003:452–453) shows that in a CES utility function, the elasticity of substitution σ between *E* and *C* is derived from the income elasticity of willingness to pay (WTP) for *E*. This is equal to $1/\sigma$ and measures the percentage change in WTP for *E* which results from a 1% increase in income. The literature contains many estimates of this elasticity. Baumgärtner et al. (2015) use an estimate derived from a meta-analysis of contingent valuation studies on WTP for biodiversity (Jacobsen and Hanley, 2009). This meta-analysis uses 145 different estimates of WTP for biodiversity, taken from 46 contingent valuation studies. The analyses in this study give an average income elasticity of 0.38, which means that an income increase of 1% causes WTP for biodiversity to rise by 0.38%. This corresponds to an elasticity of substitution of approximately 2.6. It appears that biodiversity and conventional consumption are to some extent substitutable.

This result is in agreement with other findings in the literature. An overview of parameters in Drupp (2016) shows that values of the elasticity of substitution reported in the scientific literature are, almost without exception, higher than 1, with many even well above 1 (see Table 5). The work also shows that this applies to a wide variety of services, including biodiversity, woodland services, wetland services, air quality, water quality, landscape amenities and recreation (for other recent publications see Brander and Koetse, 2011).

Studies specific to the Netherlands are scarce. Bouma and Koetse (2017) have conducted a contingent valuation study of Dutch citizens’ willingness to pay for extensive agriculture which brings substantial biodiversity benefits. The authors have found a positive correlation between income and WTP for biodiversity, with a corresponding elasticity of substitution between 1.7 and 2, depending on the chosen model specification.

Table 5. Estimates found in the literature of elasticity of substitution between ecosystem services and conventional consumption

Study	Ecosystem service	Elasticity of substitution σ
Martini and Tiezzi (2014)	Air quality improvement	0.86
Schläpfer and Hanley (2003)	Landscape amenities	1.11
Lindhjem and Tuan (2012)	Biodiversity	1.37
Hökby and Söderqvist (2003)	Collective ecosystem services	1.47
Ready et al. (2002)	Water quality improvement	1.69
Liu and Stern (2008)	Collective marine ecosystem services	2.38
Jacobsen and Hanley (2009)	Biodiversity	2.63
Broberg (2010)	Contingent value of predator species	2.70
Carlsson and Johansson-Stenman (2000)	Air quality improvement	3.13
Chiabai et al. (2011)	Collective woodland ecosystem	3.23
Söderqvist and Scharin (2000)	Water quality improvement	3.70
Wang and Whittington (2000)	Air quality improvement	3.70
Barbier et al. (2015)	Water quality improvement	3.85
Whitehead et al. (2000)	Recreation services improvement	4.17
Hammitt et al. (2001)	Preservation of wetlands	4.55
Wang et al. (2013)	Water quality improvement	4.76
Yu and Abler (2010)	Air quality improvement	5.00
Barton (2002)	Water quality improvement	7.14

Source: Calculations based on Table 1 in Drupp (2016)

These estimates indicate, almost without exception, that the elasticity of substitution σ is greater than 1. This means that, generally speaking, conventional consumption and ecosystem services are substitutable in the welfare function, but also that they are not perfect substitutes. The estimates also suggest that the possibilities of substitution in the welfare function differ somewhat from one ecosystem service to another.

Location-specific ecosystem services

Ecosystem services that are strongly tied to their location are a possible exception to these insights. Important examples of this are the provision and quality of outdoor recreation in the living environment, and the quality of the living environment itself (not only with regard to aesthetics but also to air quality). This might also apply, to a lesser degree, to the working environment. Particularly in areas with high levels of urban development, the provision of these services is under pressure. The central debate here is about the extent to which these services can be substituted with conventional consumption. For example, to what degree can a decline in utility, caused by a lack of supply or poor quality of recreation in the living environment, be substituted with utility obtained from additional consumption or indoor recreation (e.g. watching TV, gaming, visiting theatres and cinemas)? The answer to this question will vary per person, but many will strongly argue that these things are highly complementary, and that therefore outdoor recreation is only substitutable with consumption and indoor recreation to a limited extent.[8] However, empirical literature on this specific issue is largely lacking, and therefore further research is desirable.[9] Until the moment such research reveals otherwise, it seems sensible to assume that possibilities for substitution are limited in those places where the provision of local ecosystem services is under pressure and

[8] Outdoor recreation may, to a limited extent, also be substitutable with holidays abroad.
[9] In a theoretical study, Drupp (2016) examines the presence of what he calls *subsistence levels*, and the consequences they have on a relative price increase of ecosystem services. The finding was that subsistence levels cause the relative price of ecosystem services to go up. Our considerations concerning scarcity of local-level ecosystem services share similarities with these subsistence levels. The argumentation is that if, for example, the local air quality falls below a certain level, this will have a significant effect on the welfare of the people living and working at that particular location. Further research is required into the existence of such tipping points in the utility function.

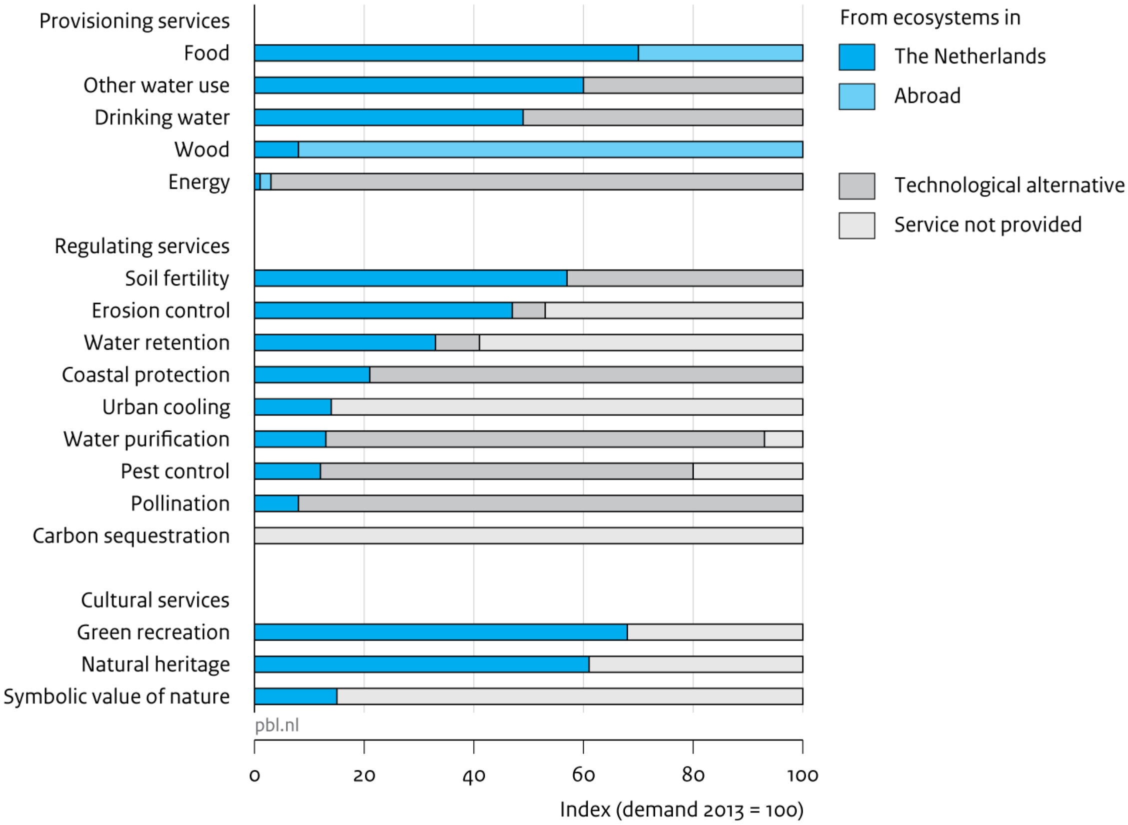
therefore becoming relatively scarce than GDP. This, logically, will apply particularly to highly developed urban areas.

Substitution with technology and imports

In addition to substitution with conventional consumption in the welfare function, there is also substitution of ecosystem services in the production function. Those (intermediate) ecosystem services that are a factor in production systems can be substituted with technology. Examples include the use of fertiliser and pesticides in agriculture, and the use of digital technology to improve the quality of recreation. Some final ecosystem services, the provisioning services in particular, can also be substituted with imports. Strictly speaking, we are dealing with forms of substitution which ensure that the relative growth of final services keeps pace with conventional consumption (see Chapter 6 for details).

A report by De Knegt (2014) provides information on these two forms of substitution and, for several intermediate and final services, presents estimates of substitution with imports and with technological alternatives. An overview is provided in Figure 7. Substitution with imports is particularly relevant for provisioning ecosystem services, especially food, wood and energy. In fact, any natural product that is traded on international markets is substitutable with foreign products. The underlying assumption is that, at the global level, provisioning services are not becoming scarcer. The facts also indicate that provisioning services have a global nature and that their growth rates are important at the international level. Technological alternatives are available, particularly for water supply, water retention, soil fertility, coastal protection, water purification and pest control. Of these services, especially water supply and water retention can, to some degree, be labelled as final services which can be replaced (in part) by technological alternatives. This would be a case of substitution in the welfare function. The other categories are intermediate services, where technological alternatives are a case of substitution in the production function. Examples of this include fertilisers and pesticides, which are used as a substitute for natural soil fertility and natural pest control produced by ecosystems. In Chapter 6 we discuss this form of substitution in greater detail. It is important to note that technological substitution often brings about externalities, which play an important role in cost-benefit analyses. These may affect other ecosystem services, but also the very service for which the technology is the substitute. Soil productivity is, once again, a good example: while productivity can be improved by the use of fertilisers and pesticides, these technological tools produce negative effects in the longer term. These externalities should be identified and included in the cost-benefit analysis.

Figure 7. Substitution of ecosystem services by imports and technological alternatives, 2013



Source: PBL; Alterra, Wageningen UR 2014

5. Relative price increase for ecosystem services

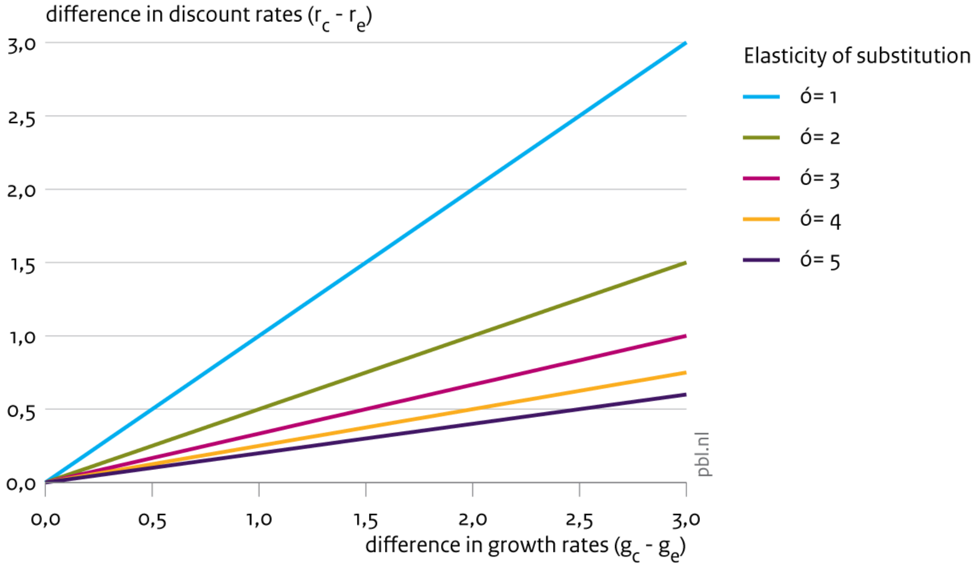
In this chapter we determine the range in which the relative price increase of ecosystem services may fall. This is based on data on growth rates and the potential for substitution, as presented above. For the growth rates we use, firstly, data on surface areas of ecosystems and intermediate services, because growth rate figures on final ecosystem services are largely lacking. Secondly, we rely on an assumption about the relationships between ecosystems and intermediate services, on the one hand and the final services they provide on the other. The reason for this assumption is that there is hardly any quantitative knowledge about these relationships. If not stated otherwise, in this report we assume that the relationships are proportional. Chapter 6 provides a detailed discussion of the possible consequences of relationships which are not proportional. Working under the given assumption, this chapter describes the range of the relative price increase, based on historical data (Section 5.1) and on assumptions made in the latest WLO scenarios (Section 5.2).

5.1 Historical data on relative price increase

Under the assumption of a proportional relationship, we calculate the relative price increase for ecosystem services according to the Ramsey rule (equation 6) based on substitution elasticities found in the literature (Chapter 4) and the historical growth rates of GDP and ecosystem services (Chapter 3). For the difference between growth rates g_c and g_e we use values ranging from 0 to 3%, and for σ we use values from 1 to 5. The result of this exercise is presented in Figure 8.

The figure shows that a 1% relative price increase for ecosystem services can be justified for a large range of the growth data as we found in the previous chapters: the relative price increase is more often than not greater than 0.5 for the figures used in the simulation. In addition, a relative price increase for ecosystem services greater than 1% can also be justified in cases where there are relatively limited possibilities for substitution. The figure also shows that the range of values is wide and that theoretical justification of a relative price increase depends greatly on the relative scarcity and the possibility for substitution.

Figure 8. Differences in discount rates between conventional consumption and ecosystem services compared against historical data



5.2 Relative price increase in the WLO scenarios

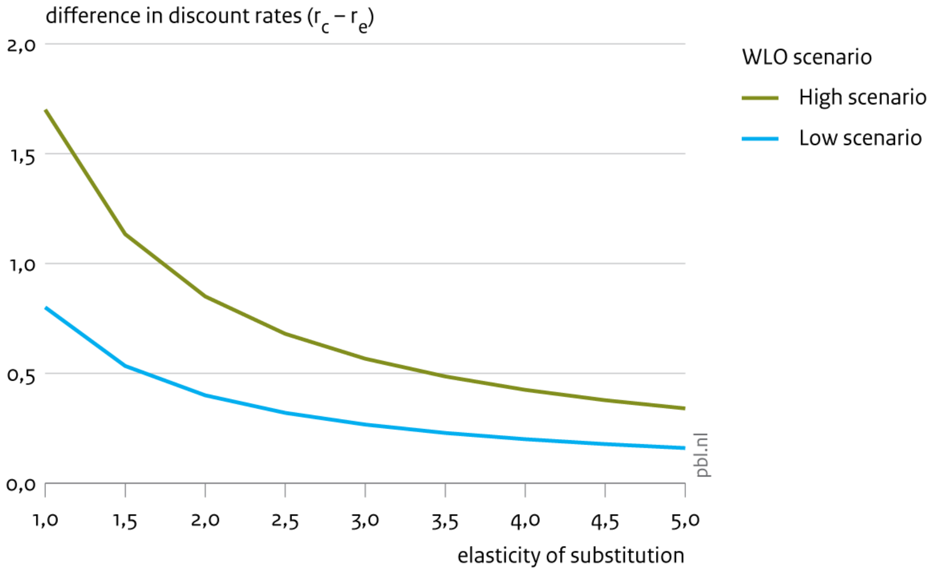
In this section we investigate the degree to which the assumptions made in the most recent WLO scenarios (CPB, PBL, 2015a) affect the range of a relative price increase for ecosystem services. Real economic growth in the period 2010–2050, is assumed to be 2% per year in the High scenario and 1% per year in the Low scenario. We assume that growth rates of conventional consumption are equal to those of GDP in this period.[10] In these WLO scenarios, between 2010 and 2050, the surface area occupied by nature is set to grow by 50,000 hectares (9%) in the Low scenario, and by 75,000 hectares (13%) in the High scenario (see CPB/PBL, 2015b, pp. 30–31). This comes down to a yearly growth rate for nature of 0.22% in the Low scenario and 0.32% in the High scenario. To work out the per-capita growth rates, we use the yearly population growth rates of the WLO: -0.05% in the Low scenario and 0.37% in the High scenario. This results in per-capita growth rates of GDP (C) of 1.05% and 1.63% in the Low and High scenarios, respectively, and per-capita growth rates of nature of 0.27% and -0.04% in the Low and High scenarios, respectively.

The difference between the two growth rates in the WLO study is therefore 0.78% in the Low scenario and 1.67% in the High scenario. Figure 9 shows the relative price increase for these differences in growth rates plotted against elasticity of substitution (for presentation reasons the graph shows the results for growth rate differences of 0.8% and 1.7%). This leads to three conclusions. First, a relative price increase of more than 1% can only be applied in the High WLO scenario in cases with relatively limited possibilities for substitution. Secondly, a relative price increase rounded to 1% is appropriate when the elasticity of substitution is between 1 and 3.5 in the High scenario, and below or equal to 1.5 in the Low scenario. In these cases, the relative price increase is at least over 0.5%. Finally, it is appropriate to refrain from applying relative price increases when the elasticity of substitution is greater than 1.5 in the Low scenario and when it is equal to or greater than 3.5 in the High scenario:

[10] Our calculations are performed with the growth rate of GDP rather than that of conventional consumption *C*. Historically, growth in consumption has been lower than growth of GDP, and so, computations based on GDP produce overestimates of the relative price increase. However, in the next few decades growth of *C* will be slightly higher than growth of GDP. Due to the ageing population, pension dissavings will outweigh pension savings, which on balance results in extra purchasing power. The higher purchasing power causes *C* to increase faster than economic growth. By using GDP in this chapter, we obtain a slight underestimate of the relative price increase. See the Annex for further details.

in these cases the relative price increase is below 0.5%. It is, of course, in practice virtually impossible to specify the elasticity exactly, but these figures show that there is scope for heterogeneity in the level of the relative price increase to be applied.

Figure 9. Relative price increase of ecosystem services under WLO scenarios with various elasticities of substitution



6. Production functions of final ecosystem services

When no information on final ecosystem services is available, data on nature and intermediate ecosystem services may serve as indicators for them. This applies to the historical development of final services — which is important for this study — but also to the measuring of impacts in CBA practice. Another issue is that Chapter 2 assumes that both conventional consumption and consumption of final ecosystem services are exogenous, while they might be endogenous and depend not only on intermediate ecosystem services but also on capital, technology and labour. It is therefore crucial to gain insight into the relationships between nature and intermediate ecosystem services on the one hand, and conventional consumption and final ecosystem services on the other. Without such insights, we depend on assumptions about the scale and the nature of the relationships, which can lead to errors when estimating the growth rates of consumption and final services, and determining effects in a CBA.

Therefore, in this chapter we broaden the standard theoretical framework to a utility function in which ecosystem services are present as final services (E^f) but also play a role as an input factor (or as intermediate services, E^i) in the production of C and E^f. The main characteristic of this extension is that C and E^f are no longer exogenous but endogenous, and therefore depend on E^i, among other things. The two main reasons for this extension are to survey the effects on the relative price increase brought about by: (1) the inclusion of intermediate ecosystem services in the production function of C and E^f and (2) non-linear relationships (e.g. a relationship with a tipping point) between intermediate ecosystem services and final ecosystem services. With this approach, we want to demonstrate how both final ecosystem services and intermediate ecosystem services can affect the relative price increase, and also show that they can play a role of their own accord in CBAs. The restated welfare function is as follows:

$$W = \int_{t=0}^{\infty} U\left(C_t, E_t^f\right) e^{-\rho t} dt \,, \qquad (7)$$

and:

$$C_t = h\left(K_t, L_t, E_t^i\right), \qquad (8)$$

$$E_t^f = h\left(K_t, L_t, E_t^i\right), \qquad (9)$$

where K stands for capital and technology, and L for labour. This welfare function also directly reveals the usefulness of a distinction between *substitution in the utility function* on the one hand (substitution between C and E^f in equation 7), and *substitution in the production function* on the other (substitution between K and L and between C and E^i in equations 8 and 9).

The different forms of substitution in the production functions are relevant because they have a bearing on the relative growth rates of final ecosystem services and consumption. An example of substitution in the production function in equation 8 is the negative effect of air pollution on labour input and productivity. Examples of substitution in the production function in equation 9 are the use of fertilisers and pesticides to increase agricultural productivity, and the construction of dykes instead of using dunes for coastal protection. Yet another example is the use of digital technology in regulating the demand for and quality of recreation: real-time, location-specific information on overcrowding at recreation sites can enable better spatial distribution of visitors and therefore lead to higher quality of recreation. The distinction between substitution in the welfare function and substitution in the production function is that the first affects the relative price increase through elasticity of substitution, while the second does so through the differences in growth rates (see equation 6). Ultimately, however, increases in either form of substitution lead to a reduction in the relative price increase for ecosystem services.

6.1 Implications of the new welfare function for insights into relative price increases

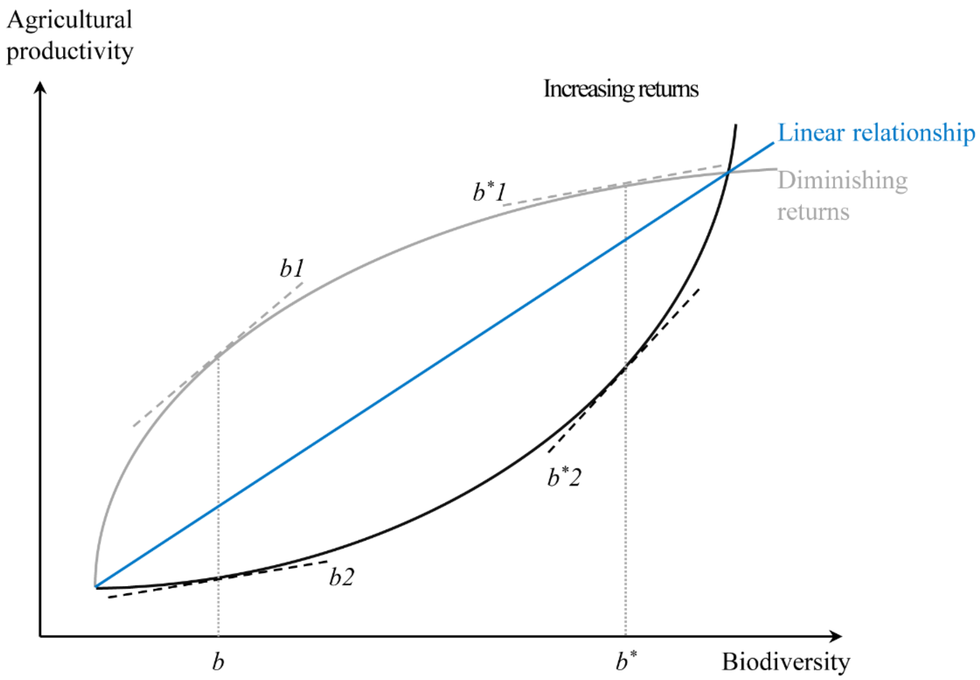
The central question in this section is what relative price increase should be applied to final ecosystem services (E^f) in cases where E^i also affects C and E^f. The problem in answering this question is that, for many ecosystem services, it is not known how profound the effects are of E^i on C and E^f (i.e. the form of the production functions is unknown). Nor do the WLO scenarios explicitly incorporate trends in E^i when determining C and E^f. It should be noted that historical time series of the growth rate of consumer goods C do take, by definition, the influence of E^i into account. Insights into the effects of E^i on C and E^f are particularly important to discover how the growth rate of E^i and substitutability interact and affect the relative price increase of E^f. Knowledge on the issue is extremely limited and in this report we restrict ourselves to identifying some lines along which future research could be carried out. First of all, it is important to make a theoretical deduction within the Ramsey framework about the possible implications of the effect that E^i has on C and E^f. Secondly, it is necessary to examine the form of the production functions on the basis of empirical data. These two lines of research should lead to greater insights into the effects that a broadening of the theoretical framework can have on the several discount rates and a relative price increase for ecosystem services in the CBA.

6.2 Implications of non-linear production functions for insights into relative price increases

For most ecosystem services, the form of the production function in (8) is not known, at least not in quantitative terms. When determining a relative price increase in the previous chapter, we assumed the production function to be linear, that is to say that there is a proportional relationship between nature and intermediate ecosystem services, on the one hand, and final services on the other. In some cases, this will be a valid assumption, for example for the relationship between forest area and the production value of wood, but in others it will not, for example, for the relationship between biodiversity and soil productivity. Research into E^f production functions is therefore essential, and for our purposes it is particularly important to explore what the consequences may be, in qualitative terms, of non-linear production functions for insights into relative price increases. To be able to make an assessment, we will take the relationship between biodiversity and agricultural productivity as an example. Figure 10 gives a graphical depiction of a linear relationship alongside two others with increasing and diminishing returns. In a linear relationship, the influence of biodiversity on agricultural productivity is constant and equal to the slope of the line. In the non-linear relationships, this marginal influence is equal to the slope of the tangent line, which is different at each point on the curve. Let us first consider the marginal influence on agricultural productivity of biodiversity value *b*. In the relationship with diminishing returns, the marginal influence is equal to the slope of tangent line *b1*, and thus greater than that of the linear relationship. In the relationship with increasing returns, the marginal influence is equal to the slope of tangent line *b2*, and thus less than that of the linear relationship. However, for biodiversity value *b**, this is exactly the other way around, that is to say, in the case of the diminishing returns relationship, the marginal influence (slope of tangent line *b*1*) is less than that of a linear relationship, while in the case of increasing returns it is greater (slope of tangent line *b*2*) than that of a linear relationship.

In conclusion, when the relationship between intermediate ecosystem services and final ecosystem services is non-linear, our assumption of a linear relationship may lead to both over- and underestimates of the growth rate of final services. To be able to say something realistic about the suitability of intermediate services as an indicator for final services, it is therefore crucial to gain insight into the functional relationship between ecosystems and the services they provide, *and* into the current situation, in other words, the point which the system has reached at this moment.

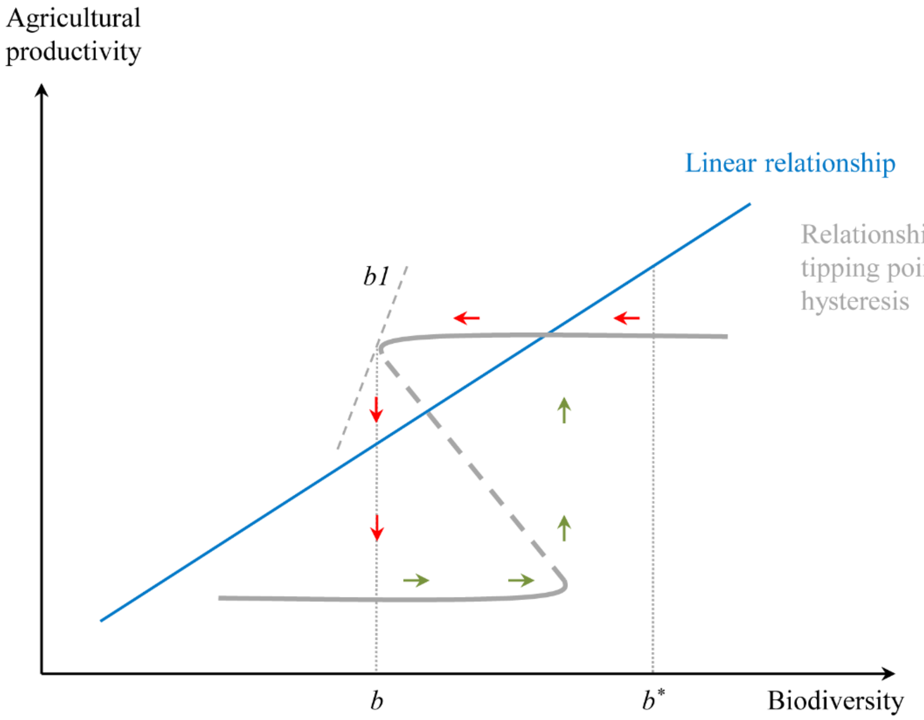
Figure 10. Illustration of relationships between biodiversity (E^i) and agricultural productivity (E^f): linear, with increasing returns, with diminishing returns



6.3 Production functions with tipping points and hysteresis

In cases where deviations from a linear relationship are minor, the assumption of a linear relationship will still lead to slight errors in the estimates of marginal effects on final ecosystem services. But deviations from linearity can be considerable, such as those in relationships characterised by tipping points and hysteresis, in other words, relationships typified by a transition between two stable states. Figure 11 gives an illustration of this kind of relationship.

Figure 11. Illustration of a relationship between biodiversity (E^i) and agricultural productivity (E^f) characterised by a tipping point and hysteresis



Suppose that a decline in biodiversity occurs. At value b^* this clearly has no impact on agricultural productivity, nor, therefore, on welfare. At point *b*, a decline in biodiversity brings about a very abrupt, dramatic effect (slope of line segment *b1*), the system undergoes a shift and reaches a new equilibrium with significantly lower productivity (red arrows). What is problematic in this system is that it is difficult to return from this new, low-productivity equilibrium to the former equilibrium with high productivity (hysteresis; green arrows). In the most extreme case, not the situation depicted in Figure 11, recovering the former equilibrium is even impossible (irreversibility). The graph also reveals that, over a wide range of biodiversity values, marginal declines do not bring on changes in the relative scarcity of soil productivity and are therefore apparently not critical. This view does not make a correction for the fact that every marginal drop brings the system closer to a tipping point. If the location of such a tipping point is known, approaching it does not necessarily directly lead to problems, as long as it is possible to avoid actually reaching it in a timely manner. In practice, however, the presence and location of tipping points is very uncertain, which means that any marginal decrease (in biodiversity) increases the risk of marked negative effects on welfare. Still, from the dynamics of the ecological system, it can be deduced that we are approaching a tipping point. Increased dynamics in the system may hint at this and are therefore labelled as an *early warning signal* (see Scheffer et al., 2009). In cost-benefit analyses, it is extremely important to include both the direct effects on welfare *and* the risk of far-reaching effects in the future.[11] In these cases, it is possible to incorporate a precautionary principle in the cost-benefit analysis, even though it is not clear under what circumstances, and the principle itself is only vaguely defined.

6.4 Concluding remarks

When no information is available on the historical or the future development of final ecosystem services, data on the evolution of intermediate ecosystem services can serve as

11 There are countless examples of tipping points, or regime shifts (e.g. see www.regimeshifts.org). Note that most examples represent tipping points in an ecosystem, which is not necessarily the same as a tipping point in the production function of ecosystem services.

an indicator. Up to this point, the assumption has been made that the relationship between intermediate services and final services is linear. This brings up the question of what happens to the conclusion about the discount rate if the assumption is not correct. As demonstrated in Section 6.1, non-linear relationships, whether characterised by increasing or diminishing returns, can lead to both overestimates *and* underestimates of the historical trend in final services. In short, while there is no information on the functional form of the relationship between intermediate services and final services, a good starting point is the assumption that the relationship is linear.

If information on the development of final ecosystem services *does* exist, it is still important to know about their relationship with intermediate services. This is particularly so when the relationship is markedly non-linear and increasing scarcity of nature or intermediate services is only reflected in a very limited way in scarcity of a final service. For relationships characterised by tipping points and hysteresis, this means that effects on final services suddenly become very strong, that they are only discerned when the tipping point is exceeded, and that they are difficult to reverse because of hysteresis. In such situations, it might be sensible to monitor not only scarcity of final services but also scarcity of intermediate services so that early warning signals in ecological systems can be identified. In addition, with regard to certain territories, it is advisable to err on the side of caution and embrace a precautionary principle in order to protect them. For many years now, the Netherlands has been working on *Natuurnetwerk Nederland* (the Netherlands Network for Nature), formerly known as *Ecologische Hoofdstructuur* (Main Ecological Structure). The Network aims, for one thing, to protect rare species and nature types and establish corridors to allow species to move around, thereby preserving ecosystem services such as symbolic value of nature and natural heritage. For another, it aims to protect the proper functioning of the natural system. While there is not enough knowledge about the exact dangers for the natural system of the extinction of certain rare species and the disappearance of nature types, it is clear that a decline in the number of species makes the system more vulnerable and can ultimately lead to the reaching of tipping points in, for example, agricultural production, water quality, quality of the environment and fish stocks.

7.Key findings

As mentioned in Chapter 1, the 2015 report by the Dutch working group on discount rates recommends that cost-benefit analyses apply a relative price increase of 1% for nature, unless it can be shown that the features of nature in question are substitutable (Werkgroep Actualisatie Discontovoet, 2015). This report mainly considers substitution in the welfare function. Since most things are to a certain extent substitutable, the recommendation needs to be made with finer nuances. If nature and conventional consumption are *perfectly substitutable*, there are no grounds for the application of a relative price increase for nature and ecosystem services. However, as soon as there are indications of imperfect substitution, as all the facts suggest, it is important to look at the combination of the relative growth rate of nature and the *degree to which it is substitutable* with conventional consumption. Both substitution and relative growth determine the relative price increase. With a focus on these observations, we now present our most important findings point by point. The main question underlying these findings is whether it is possible to justify that the cost-benefit analysis assigns to ecosystem services a relative price increase of 1% compared to other goods and services. Following these findings are separate sections in which we discuss the production functions of final ecosystem services and tipping points in production functions.

7.1 Key findings on relative price increases

Finding 1
Only little empirical information is available on the historical development of many final ecosystem services. Therefore, historical data on ecosystem quality and quantity have been collected to serve as indicators for the evolution of final services. These data generally point to a growth rate which over the past decades has been lower than that of conventional consumption; for most services, the difference is between 0 and 3%. This means that, in general terms, ecosystem services are becoming scarcer relative to consumption. The qualitative data on the supply of ecosystem services also suggest an absolute decrease in the supply of several ecosystem services.

Finding 2
Two types of substitution are important: substitution between consumption and ecosystem services in the utility function, and substitution between, for example, intermediate ecosystem services and capital or technology in the production function of ecosystem services. The first type manifests itself in the substitution parameter of our simple Ramsey model. Substitution in the production function is expressed through the growth rates of ecosystem services, which are also part of the Ramsey model. If sufficient substitutes for production factors are available, these growth rates will not fall behind that of consumption. For both types, a low degree of substitutability gives rise to a higher relative price increase. In this report we concentrate on the first type: substitution between consumption and ecosystem services. Estimates on this type of substitution found in the literature show that consumption and final ecosystem services — such as recreation, water quality and air quality — can, to a certain degree and almost without exception, substitute each other. The estimates of elasticity of substitution vary from about 1 to 5. This means they are not perfect substitutes.

Finding 3
The data on differences between growth rates and the degree of substitution between ecosystem services and consumption can be used to derive a range of relative price increases for ecosystem services by applying the Ramsey rule (Equation 6). On the basis of

historical data on growth rates, it appears that it is possible to justify a relative price increase of 1% in cost-benefit analyses for a large section of the final ecosystem services, despite the fact that they are all, to a certain extent, substitutable. When working under the assumptions made in the in the most recent WLO scenarios (CPB/PBL, 2015) about future growth rates of nature and consumption, comparable results are obtained. In the WLO scenarios, determining whether to apply a relative price increase and establishing the corresponding rate depend strongly on the possibilities for substitution between ecosystem services and consumption, and on the scenario in question (High or Low). In view of this last point, it is legitimate to vary the relative price increase according to the scenario.

Finding 4
For ecosystem services that are strongly location-specific, such as recreation, it can plausibly be argued that they cannot be readily substituted by conventional consumption, although further research into the matter is necessary. In locations where these services are under pressure, urban areas in particular, they become relatively scarcer and their marginal utility increases. Especially for these services, the application of a relative price increase greater than 1% is potentially justifiable. In this context, it is important to realise that there are local ecosystem services which can be considered as regulating services but also as final services. Important examples of this are:

- air quality,
- quality of the living environment,
- urban cooling,
- flood protection.

These can be considered final services since people benefit from them directly, as is evidenced by the large body of international literature on consumer appreciation of air quality, quality of the living environment and flood risk. In addition to the regulating effects of these services and their possible effects on health, they also have a direct impact on utility and on quality of life, which means they meet the requirements for a relative price increase. It is important to note that there is still insufficient information to measure relative scarcity of these services on a local scale, and future research in this area is therefore crucial.

Finding 5
There are several provisioning services to which relative price increases should not be applied, such as the provision of food, wood and energy. This is particularly relevant when technological substitution or imports cause growth of the provision of the service to keep pace with growth of consumption (although this is achieved in part via ecosystems outside the Netherlands). The underlying assumption here is that, at the global level, provisioning services are not becoming scarcer, which also shows that these services have a marked international or global character. It is therefore important to monitor trends in provisioning services at the international level. A global decline in provisioning services can certainly give rise to the application of a relative price increase.

7.2 Production functions of final ecosystem services and substitution with technology

Intermediate ecosystem services as an indicator for final ecosystem services
An important assumption behind the findings listed above is the existence of a linear relationship between intermediate ecosystem services on the one hand, and final ecosystem services on the other. The assumption is necessary because growth rates for final ecosystem services, such as green recreation, quality of the environment, symbolic value and natural heritage, are not available, and can only be determined indirectly using a number of indicators for the quality and quantity of ecosystems. Our analysis reveals that, if the assumption is incorrect, both over- and underestimates of the growth rate of final services

can be made, and that this can occur for several non-linear functional forms and depends on the present state of the system. To gain better insight, it is crucial to conduct further research into the functional form of the relationship for several final ecosystem services, and into the current state of the system.

A limited understanding of the impacts on final services also means that measurable effects on intermediate services (e.g. regulating services) can serve as an indicator in the cost-benefit analysis. Here too, an assumption needs to be made as to how these effects bring about reactions in final services. Without putting forward any further arguments, the basic thought is that this relationship is linear. However, this approach entails a high risk of double counting and there should be a clear-cut discussion of how this is prevented.

Consequences of technological substitution in the production of final ecosystem services
Intermediate services can be used as input for the production of final services (dose-response relationships). However, in this process, some intermediate services are easily substitutable with technological alternatives (substitution in the production function). Listed below are some good examples.

- Flood risk management: for purposes of coastal protection, dunes can easily be replaced by dikes.
- Water quality: for water purification, ecosystems can easily be replaced by water treatment facilities.
- Soil productivity: natural nutrients and natural pest control can, to a certain extent, be replaced by artificial fertilisers and products for crop protection. It should be noted that this usually results in a number of externalities (leaching and pollution) and that artificial fertilisers are not a substitute for all the factors that determine soil fertility.

In these cases, a decrease in quantity or quality of the intermediate service hardly leads to a decrease in the final service, if at all. The decision to apply a relative price increase for ecosystem services is not greatly affected by this, because the issue at hand is substitution in the production function and not substitution in the welfare function. However, when measuring effects in the cost-benefit analysis, and, more specifically, when *translating effects on intermediate ecosystem services into effects on final services*, we recommend taking this form of substitution into account specifically.

Possible externalities in cases of technological substitution
Substitution of intermediate ecosystem services by technology, requires examining whether the use of the alternative methods produces externalities. The moment such externalities affect other ecosystem services, or if they affect the services that they are substituting in the long term, it may be relevant to apply a relative price increase of 1% to these externalities, depending on the ecosystem services concerned.

7.3 Tipping points, hysteresis and early warning signals

When considering final ecosystem services with highly non-linear production functions, it is recommended that decisions not only take into account the effects on final services but also the trends in the quality and scale of nature and intermediate ecosystem services. This applies particularly to relationships with tipping points and where negative effects are difficult to reverse due to hysteresis. By monitoring the actual ecosystems, it is possible to identify early warning signals and prevent the whole from reaching a tipping point.

At present, little is known about the relationships between intermediate ecosystem services and final ecosystem services, not to mention about whether they are characterised by tipping points and hysteresis. Further research into these relationships is crucial, focussing on both the functional form and the current state of the systems. Such research will serve as a basis, firstly, to make it easier to assess whether increasing scarcity of intermediate services leads to a proportionate or disproportionate change in the scarcity of final services. Secondly, to make it easier to identify which relationships are characterised by tipping points and hysteresis, and which areas may be eligible for protection on the basis of a precautionary principle.

8. Discussion and research agenda

The findings presented in the previous chapter have been made under certain assumptions. In addition, some issues have, as yet, not been given sufficient attention. In the discussion below, we deal with these assumptions and issues and the possible consequences for our findings. This will serve as a basis to round off this chapter with a research agenda for the short and long term.

First of all, we make the assumption that final ecosystem services can, in principle, be valued in monetary terms, using economic valuation methods (non-market valuation in particular). For some services, values can be found in international literature, including ones applicable to the Netherlands. For many services, knowledge is still rather limited. In this regard, follow-up research could focus on (1) identifying and prioritising those final ecosystem services which need to be valued, and (2) performing economic valuation studies on these services, in most cases on the basis of non-market valuation methods. Research along those lines will produce monetary values which can be used in cost-benefit analyses, and to which a relative price increase can be applied according to the discount rate for ecosystem services examined in this report.

Secondly, it should be recognised that there is a distinction between practice and theory in the field of relative price increases in ecosystem services. In present-day practice, a relative price increase of 1% is required for nature and ecosystem services, unless it can be demonstrated that the ecosystem service in question is substitutable. This means a distinction is being made between relative price increases of 1% and 0%. This report shows that a relative price increase of 1% is, in many cases, perfectly tenable, but that provisioning services in particular do not meet the requirements for a relative price increase. Our findings go on to show that in some cases a relative price increase of over 1% is highly defensible, and that it depends on the relative growth rate and the possibilities for substitution. Particularly those ecosystem services which are provided locally, such as green recreation, air quality, quality of life and natural heritage, can only be substituted to a very limited degree and may therefore qualify for such an increase. More research is required into the relative scarcity of ecosystem services and the possibilities to substitute them, along with a continuation of the debate on relative price increases. While our findings show that there are regional differences in matters such as recreational facilities (see Table 4), data on the relative scarcity of ecosystem services and substitutability at a truly local scale are largely lacking. New research can become the underpinning for further differentiation of relative price increases for certain ecosystem services. It is also important to monitor the actual performance of cost-benefit analyses in order to gain more insight into the ecosystem services that are most important in practice. Growing insights in these areas may also lead to alternative pieces of advice regarding the application of relative price increases.

The third issue that deserves more research is related to subsistence (see Drupp, 2016). It has not been dealt with in our analysis, particularly because it has only been on the scientific agenda for a short time. In the context of our work, the concept of *subsistence* or *subsistence level* refers to the level of services below which a sharp and sudden decrease in utility occurs, and not to something that could be labelled the *subsistence minimum*. The concept closely resembles the tipping points discussed above, but it refers to tipping points in the utility function rather than in the production function (in our case the production of final ecosystem services). Once again, good examples are found in the area of locally provided ecosystem services, such as recreation, air quality and quality of the environment. Natural recreation facilities are not plentiful in urban areas, and a further decline in the supply could lead to a serious downturn in the attractiveness of an area, and in the benefits enjoyed by the local residents. It is important to determine the degree of substitution, starting with the preliminary argumentation that for locally supplied ecosystem services this may be seriously limited. It is also important to know the degree of reversibility, or the cost of reversal. In these issues, a major role is played once more by the form of the production function. With regard to the subsistence level of local ecosystem services, we need to recognise that there is little knowledge about its actual presence, its value and the chances of reversibility if a system falls below that level. Further research, on valuation in particular, can provide insights into this matter, for example by looking at indicators such as air pollution, opportunities for recreation and quality of the living environment, and generating data on the levels at which willingness to pay or willingness to accept increase or decrease sharply.

The fourth issue is the fact that, at present, the various WLO scenarios operate with the same relative prices. Our findings show that relative prices can vary greatly, and that they depend on the relative scarcity of the ecosystem service under consideration and the extent to which it is substitutable with conventional consumption in the utility function. As for the two currently used WLO scenarios, a difference in their assumptions about the growth rate of GDP almost automatically leads to a difference in the relative price increases they apply. For this reason, it may be a good idea to set a relative price increase for each scenario, at least from a substantive point of view.

In the fifth place, application of the Ramsey rule is usually the result of a lack of insight into current and, more particularly, future relative prices of conventional consumption and of ecosystem services. For this reason, the Ramsey rule assumes, often implicitly, that in the current situation the marginal values are all the same. In our case, these are the marginal values of consumption and ecosystem services and, as a result, an increase in relative scarcity of ecosystem services entails a higher marginal value and therefore gives rise to a relative price increase. However, if the marginal values of consumption and ecosystem services are not the same in the current situation, then, in cases of increasing relative scarcity, a relative price increase is not applicable as a matter of course, and depends on the degree to which the relative prices (marginal values) of goods differ in the current situation. Consider, for example, an ecosystem service which has undergone a decline or remained stable over a long period of time, while conventional consumption has increased sharply over the same period. In this case, it can be argued that the marginal value of the ecosystem service is greater than that of conventional consumption at the end of the period. However, if the end of the period is used as input ($t=0$) in a cost-benefit analysis, then a Ramsey framework will take both marginal values to be the same. Future scenarios, such as those of the WLO, assume that at $t=0$ growth of GDP is lower and growth of the ecosystem service is higher, to make it possible for the ecosystem service to acquire the same weighting as conventional consumption. But it has just been established that the marginal value, and therefore the relative price, of ecosystem services was actually higher at $t=0$, and that unchanging relative scarcity in the future will, at most, only have the effect of that relative price not increasing any further. This implicit assumption in the Ramsey rule – that the marginal values of GDP and ecosystem services are the same at $t=0$ – may be problematic, but it does correspond to current practice in cost-benefit analyses, which starts from the premise that at $t=0$ the economic system is at an optimum, and marginal values are all equal to each other.

A final consideration is that intermediate ecosystem services not only serve as input factors in the production of final ecosystem services, but also as input for the production of conventional consumption. As mentioned in the introduction, we do not discuss this aspect in this report. In that case, ecosystem services and conventional consumption are no longer exogenous, and relative scarcity in intermediate ecosystem services may lead to a decrease in GDP. The consequences this has for the application of a relative price increase for ecosystem services need to be examined more closely. This brings us to a number of crucial issues to be explored in follow-up research. They are listed here in summarised form.

- Research into the relative scarcity and degree of substitutability of final ecosystem services, particularly those which are provided locally.
- Research into the identification, prioritisation and monetisation of (the most important) final ecosystem services.
- Research into the existence and the value of subsistence levels, a concept interpreted here as the level of ecosystem service provision below which the utility for humans decreases sharply (tipping points in the utility function). This is especially relevant for ecosystem services which are provided locally, such as air quality, quality of the living environment and options for recreation.
- Theoretical and empirical research into the relationship between intermediate ecosystem services on the one hand, and conventional consumption and final ecosystem services on the other.
- The degree of substitution between intermediate ecosystem services and technology in the production of final ecosystem services and in the production of conventional consumption.

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Annex: Growth of GDP and consumption in the WLO scenarios

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As mentioned in Chapter 5, our calculations are based on growth of GDP, rather than growth of conventional consumption (*C*). In the WLO scenarios, growth of GDP proves to be lower than that of consumption. By using GDP, we make a slight underestimate of the relative price increase. In this Annex, growth of GDP and growth of consumption are analysed in more detail.

In both the High and the Low scenarios of the WLO, purchasing power per capita increases more rapidly than economic growth per capita. With the ageing population, pension dissaving will outweigh pension saving, which on balance results in extra purchasing power. In the Low scenario, the difference between purchasing power and economic growth per capita is somewhat larger than in the High scenario. Higher purchasing power also causes private consumption to increase at a higher rate than economic growth. Public consumption demand falls behind private consumption demand. In the Low scenario, growth of public consumption demand is still slightly higher than economic growth, while in the High scenario it is lower. In both scenarios, exports also grow faster than the economy. In the Low scenario, however, growth in exports stays behind that of private consumption, the main driver of economic growth there. In both scenarios, exports grow faster than imports, which leads to a further increase of the current account surplus in the balance of payments.

Table B1. Trends in macro-economic key variables in the High and Low scenarios

	HIGH			LOW		
	2015–30	2030–50	2015–50	2015–30	2030–50	2015–50
Economic growth (GDP)	2.20	2.0%	2.1%	1.2%	1.0%	1.1%
Employment	0.6%	0.2%	0.4%	0.1%	-0.2%	-0.1%
Labour productivity	1.6%	1.8%	1.7%	1.1%	1.2%	1.2%
Private consumption	2.5%	2.3%	2.4%	1.6%	1.4%	1.5%
Public consumption	1.4%	1.2%	1.3%	1.3%	1.1%	1.2%
Exports	2.5%	2.5%	2.5%	1.3%	1.4%	1.4%
Imports	2.1%	2.1%	2.1%	0.8%	0.9%	0.8%
Population	0.43	0.3%	0.4%	0.1%	-0.2%	-0.1%
GDP per capita	1.8%	1.7%	1.7%	1.1%	1.2%	1.2%
Purchasing power per capita	1.9%	1.8%	1.8%	1.3%	1.4%	1.4%

Notes on the calculation of growth rates:
The growth rate calculations are based on information about the relationship between the growth of each key variable and the growth of GDP as used in the first WLO study of 2006. For the growth rate of each key variable, an equation is estimated with a control variable and the GDP growth rate as explanatory variables. This led to 12 observations: the growth rates established in the four scenarios of the first WLO study for the periods 2011–2020, 2021–2030 and 2031–2040. The figures resulting from the estimate are given below.

Table B2. Results of growth rate estimates

	Constant	Coefficient	R^2
Private consumption	0.36	1.04	0.96
Public consumption	0.52	1.07	0.94
Investments (except housing)	-0.37	1.32	0.63
Exports of goods (except energy)	-0.28	1.20	0.81
Exports of goods *and* services	-0.06	1.38	0.88
Imports	-0.18	1.36	0.97
Purchasing power	0.38	0.83	0.76