

The Economics of Resource Management

by

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27 October 2000

**Paper commissioned by the European Commission, Directorate General
Environment (ENV.B.2)**

1 Introduction

The objective of this paper is to provide a brief overview of the economics of resource management and to discuss policy implications. The paper is structured as follows. After a definition of the concepts of "resources" and "sustainability" in Section 2, economic theory is reviewed with regard to the capacity of markets to generate optimal time paths for the exploitation of nonrenewable resources (Section 3). Section 4 presents an interpretation of sustainability that can be applied to non-renewable resources. Section 5 develops recommendations for resource management policies and suggestions for further research.

2 Concepts

2.1 Resources

In this study, the term „resource“ refers to a *natural* resource. Natural resources are stocks of physical assets that are not produced goods and are valuable to humans. Humans may consider a resource as valuable because of its sheer existence or because the asset produces a flow of services that can be used in production or consumption.

We distinguish three different resource categories, namely renewable resources, non-renewable resources, and land as the space required for any human activity¹:

- Renewable resources are characterised by the fact that they are renewed periodically in the context of ecological cycles. Their use can be increased to a certain extent only, otherwise overexploitation will occur. As long as exploitation is not exhaustive, however, renewable resources can be used for an infinite period of time. If they are overused, they will be exhausted quickly.
- Non-renewable are deposited above or below ground and can be extracted from the ground at any time. They have been the foundation of the industrial revolution

¹ Geothermal energy is a fourth resource category that combines the characteristics of renewable resources – practically infinite usability – with the characteristics of non-renewable resources – constantly increasing usability practically without emissions. To a certain extent, this resource is already used to generate thermal energy. Relevant amounts of electrical energy from geothermal energy could, however, only be produced at costs which cannot be justified by today's prices. In addition, a few major technical problems are yet to be solved. Therefore, this resource has not been considered in this article. Any such use should nevertheless be kept in mind.

and of economic growth. Their exploitation can be increased from period to period by appropriate inputs of labour and capital. However, exploitation is limited by the amount deposited in the ground (with the stock size varying considerably across resources.) Accordingly, the stocks will be exhausted sometime.

- As a space for any human activity, land is a resource *sui generis*. It is literally the foundation for all economic activity and for all life. Basically, it is limited by the surface of the Earth. This means that alternative patterns of land use are mutually exclusive. From an ecological point of view, the following categories of use are distinguished: protective use (areas left to nature), productive use (agriculture), and sterile use (building and road construction, etc.)

Most resource management analyses ignore the third category – land as the space required for any human activity. However, the impact of the use of resources for economic activity on the natural environment cannot be assessed adequately without the consideration of land. The inclusion of land is indispensable for any comprehensive resource management which takes the major conflict potentials into account.

2.2 Sustainability

In this paper, we consider the objectives of resource management as subordinate to the general objective of sustainability as declared a general guideline for long-term economic development at the 1992 Conference on Environment and Development ("Rio Conference") on the basis of the Brundtland Report.

According to the definition of the Brundtland Report, sustainability demands that the present generation is able to meet its needs without compromising the ability of future generations to satisfy their needs. (WCED (1987)).

The concept of sustainability is based on the idea that natural resources are somehow scarce, which means that any use today may preclude a use tomorrow and vice versa that use tomorrow may require a restriction of the use today. In this context, the term "needs" is used in its broad meaning so that it covers any use to satisfy both economic and ecological needs.

At the Rio Conference, discussion of the questions arising from this concept was not systematic but more or less eclectic. The questions have since centered around the climate change caused by greenhouse gases, the threat to the biodiversity (extinction of species), as well as the various environmental stresses considered within the "Agenda 21" framework.

In the following, we proceed from the question of exhaustibility or possible over-use of the natural resources while keeping in mind the other aspects of sustainability, in particular those of environmental protection.

3 Market processes and non-renewable resource use

First of all, it must be asked whether the market process as such will lead to a sustainable extraction path, i.e. will it leave enough resource stocks for future generations or does it divert from an appropriate path?

In the first case, policies for sustainable resource management can restrict their activities to managing environmental aspects. In the second case, the extraction path itself must be considered in resource management policies.

Proponents of the prevailing strand of resource economics claim that, although subject to certain conditions, the extraction path induced by the market economy aims for sustainability because an increase in prices will gradually result in a more economical use of the resources once the resource stocks come closer to exhaustion. This is then called an optimal extraction path. The appropriate considerations are based on the so-called Hotelling rule and can be summarised as follows:

Consider the exploitation of a known and finite stock of a non-renewable resource. An optimal extraction path is one that maximizes the present value of the net benefits from extraction subject to the constraint that cumulative extraction cannot exceed the initial stock of the resource. An optimal path is characterized by three necessary conditions.

First, the marginal static benefits of resource extraction must equal its marginal static costs. Marginal benefits are equal to the price of the resource. Marginal static costs consist of extraction costs and an opportunity cost which represents the fact that future exploitation opportunities are reduced if the resource is extracted today. The

latter has frequently been referred to as the *user cost* or the *in situ value* of the resource.

The second condition refers to dynamic efficiency. The resource stock is viewed as an asset which generates a rate of return that needs to be compared to the returns from other assets. Asset market equilibrium requires that the return to holding a marginal unit of the resource is equal to the returns from any other asset considered. The return to "other" assets is measured by the rate of interest, which is treated as exogenous in a partial equilibrium context. The return to the *in situ* resource stock comprises capital gains and the marginal net benefits from holding a unit of the resource stock. Capital gains comprise increases in the user cost of the resource. Marginal net benefits from holding the resource stock are generally referred to as *stock effects*. They arise e.g. if extraction costs increase as the resource stock declines. Holding one more unit of a resource stock then represents a benefit because it leads to lower extraction costs.

The third condition is a transversality condition. It implies that, at the end of the time horizon considered, the remaining resource stock is either exhausted or worthless (i.e. its *in situ* value is zero). In other words, efficiency requires that the entire resource stock is used up as long as it is valuable. If the time horizon is infinite, the transversality condition implies that the present value of the *in situ* value of the resource stock converges to zero in infinite time.

In the simplified case where extraction costs are zero and stock effects are absent, the first condition implies that the resource price is equal to its user cost. The second condition implies that the *in situ* value of the resource increases at the rate of interest. This result is referred to as *Hotelling's rule*. Both conditions together imply that the resource price also rises at the rate of interest. If the demand structure is stationary, the quantity extracted declines over time at a rate that depends on the properties of the demand curve. If the transversality condition is fulfilled and the time horizon is infinite, the resource stock is exhausted in infinite time.

However, demand may decline to zero if the resource price increases beyond a threshold level (choke price). This case occurs when a substitute becomes available at a cost equal to the choke price. Under perfect foresight and in the absence of

stock effects, the transversality condition now requires that the resource stock is exhausted exactly when the resource price has risen to the choke price.

An increase (decrease) in the interest rate shifts the pattern of resource extraction to the present (future). In the simplified case without extraction costs or stock effects, an increase in the interest rate raises the rate at which the *in situ* value of the resource increases (second condition). This would imply a faster decline in the extraction rate compared to an extraction path that starts at the same initial value of the user cost but is governed by a lower rate of interest. However, the implied path is not optimal because it violates the transversality condition. With a higher interest rate, an optimal path requires a lower initial value of the user cost, which implies that resource extraction is *higher* initially than it would be under a lower interest rate.

The conditions on which Hotelling's rule is based do rarely prevail in reality. *Technological change* can reduce extraction costs, which makes it profitable to extract more resource units than if extraction costs were higher. As a result, the resource price may fall over a certain time interval. Ultimately, however, rising *in situ* values cause the resource price to increase again, which gives rise to a U-shaped time path of the resource price. Change in extraction technology is one of the reasons why the historical prices of non-renewable resource have not increased continuously over time.²

One of the most important prerequisite for Hotelling's rule to be valid is a precise idea of a given known resource stock or at least of a given probability distribution of future exploration possibilities.³ The more uncertain this probability, the lower the certainty of rising prices in the future and, consequently, the lower the tendency to restrict exploration of the resources known today in order to profit from rising prices later. In addition, the resource owners today might depend on a high income in the present and might not be in a position to postpone the income *sine die* into the future.

² Krautkraemer (1998), p.2069.

³ Even with known probability distributions, resource prices may fall or exhibit a "saw-tooth" pattern for some time (Krautkraemer 1998, p.2072).

Another important reservation about the validity of Hotelling's rule (in its basic form) is that it ignores capital costs. Given the capital intensity of mineral extraction activities, *capital costs* have a strong impact on the evolution of resource prices and output which can alter the conclusions of the basic model. If capital is an input into resource extraction, changes in the rate of interest have contradictory effects on the time path of extraction. As discussed above, an increase in the rate of interest lowers the initial *in situ* value of the resource. However, it increases the cost of extraction because it raises the cost of capital. This gives rise to a nonmonotonic relationship between initial extraction and the interest rate. If the interest rate is low and, consequently, the initial *in situ* value is high, an increase in the interest rate lowers the initial *in situ* value more than it raises marginal extraction costs, which causes initial extraction to increase. However, if the interest rate is high and the initial *in situ* value is low, an increase in the interest rate lowers the initial *in situ* value less than it raises marginal extraction costs, which causes initial extraction to *decrease*.⁴

Furthermore, markets that are perfectly competitive at a point in time do not necessarily ensure that the optimal exploitation paths described above are attained. In the case of non-renewable resources, market processes ensure that the static and dynamic efficiency conditions are satisfied. However, market processes do not guarantee that the transversality condition is satisfied unless a complete set of forward markets exists.⁵ As a complete set of forward markets does not exist in reality, it needs to be emphasized that markets for non-renewable resources are affected by an intertemporal market failure. As a result, the resource is either used up too early or a certain part of the resource stock will never be exploited. This also applies to finite horizon situations.

Consequently it remains open whether the market would take sustainability requirements into account by a gradual increase in prices and a decline in extraction rates. Experience has suggested the contrary so far.⁶ Over the centuries, relative prices of

⁴ Krautkraemer (1998), p.2073.

⁵ Dasgupta and Heal (1979).

⁶ However, the scarcity of *renewable resources* has increased locally in many industrialized countries, e.g. water in some regions of Spain and the United States.

the non-renewable resources on the whole tended to fall or remain unchanged at the most. Only in rare cases is there an indication of a reversal in the price trend.

Petroleum, however, could be an exception. Limitation of the stocks that are probably available – they are estimated to amount to approximately 100 times today's annual consumption – might tend to lead to a further increase in prices after some ups and downs. This might in turn have an impact on prices of other energy sources although their stocks are much larger or exploitation could be considerably increased.

On balance it must be concluded that markets in the real world generally do not generate optimal extraction paths for non-renewable resources. Considered in isolation, resource prices are not reliable as scarcity indicators. Although resource prices must ultimately rise when the existing resource stock is close to exhaustion, the price increase may come too late and too fast for an economy to adjust smoothly. It is therefore important to think about how to identify *sustainable* extraction paths for non-renewable resources. Any such deliberations must ensure that the sustainability requirements for renewable resources – no over-use! – and for land as a space for human activity as well as for various environmental impacts are met or, if possible, that meeting these requirements is even further promoted.

4 Sustainable resource management in the energy sector

The main point in question is the adequate use of the non-renewable energy resources that cover most of today's energy needs. In order to deal with this issue, it is necessary to overcome the narrow notion of ecological sustainability that originated in forestry and dominates ecological discussions to this very day, in particular in the field of energy. Sustainable forestry postulates that timber cuts should not exceed incremental forest growth, i.e. that the forest is neither over-used nor destroyed. This concept applies to all renewable resources – but only to these.

This narrow definition of sustainability suggests that the non-renewable resources should no longer be used at all because they are not renewable. Only this way could they be preserved on a sustainable basis. If the concept of sustainability is so narrowly restricted, however, we are in a logical dilemma: why should the resources be

preserved when they are not used? Come to that, if we no longer use the resources we would already have reached the point now which otherwise we would reach once all stocks have been depleted.

In order to avoid this dilemma, it is often demanded that use of non-renewable resources may continue for the time being, but only if they are gradually replaced by renewable resources. According to this concept, the use of renewable resources were to increase at the same extent as stocks of non-renewable resources decline. In the end, when all non-renewable resources have been consumed, we would have to do with nothing but renewable resources. However, this solution would only be satisfactory if the renewable resources continue to be used in a sustainable way. Given the present structure of production and consumption, this is fully impossible because the orders of magnitude in which renewable resources would have to be harvested is very high.

For example, at the beginning of the industrial revolution, timber as a renewable resource could only be saved from final extinction (i.e. the sustainable use of timber, at that time the most important renewable resource, became only possible) by replacing charcoal with the non-renewable hard and brown coal. Otherwise, forests in Europe would have been radically cleared. Since the industrial revolution, annual resource consumption has increased approximately one hundred times with non-renewable resources accounting for approximately 90% of total resource consumption.

Although the use of renewable resources can be intensified to a certain extent (as can be seen from modern agriculture), resource managers must be patient enough to wait for the resources to regenerate. Furthermore, renewable resources require large areas of land to enable the functioning of the biological and ecological cycles within which their renewal takes place. Given the manifold claims we make on land, however, it is the scarcest of all resources!

Thus, re-substitution of non-renewable resources would quickly result in their over-use, i.e. extraction would persistently exceed annual increments. In order to maintain the sustainability postulate for non-renewable resources, this very postulate would therefore have to be given up for the renewable resources for which it had originally been defined!

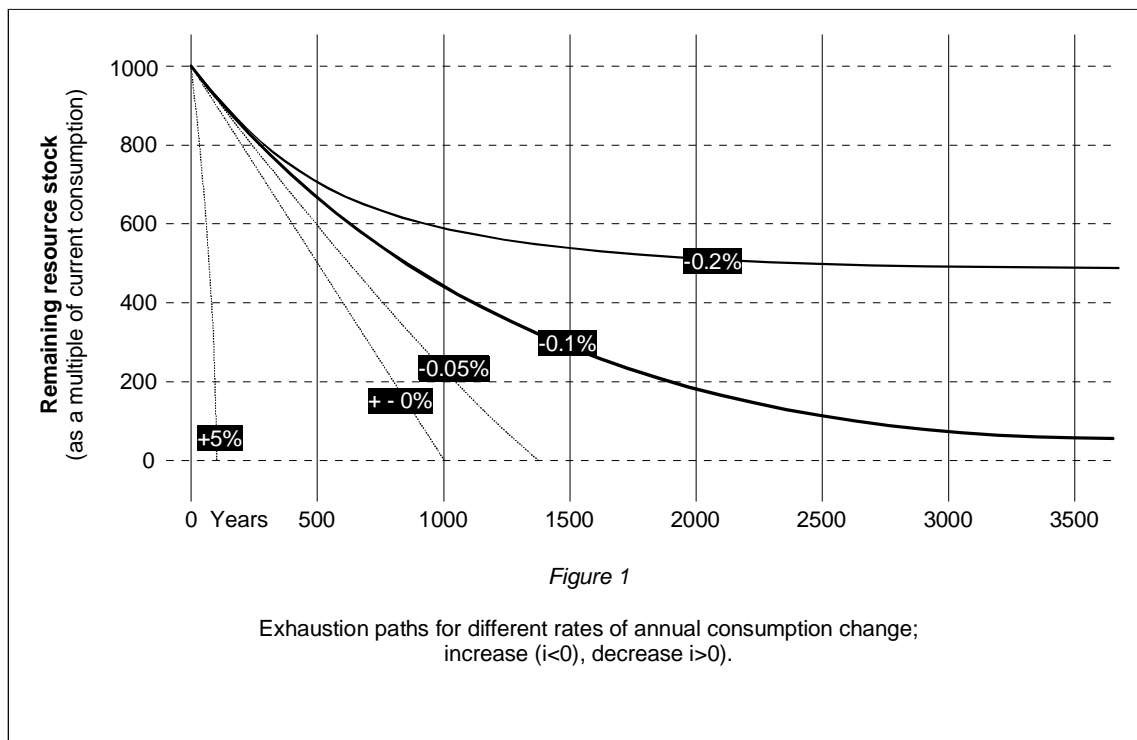
It is often claimed that using insolation to generate energy and substituting the non-renewable energy sources with solar energy might open a way out of the dilemma. The options discussed comprise the direct use of solar energy, e.g. the generation of thermal energy by solar collectors and the generation of electrical energy by photovoltaics, as well as indirect use, e.g. by burning biomass – timber, agricultural waste, biogas, energy crops like beet, rape, ramie, etc. – and production of electrical energy from wind and hydropower.

But this is a dangerous illusion. It ignores the ecological damage that can result from using solar or renewable energy if it is assumed that use of renewables can be increased to an extent where they substitute non-renewables before consumption has been drastically reduced.

Although global insolation is very high, it is so diffuse and discontinuous that large areas are required to collect and store this energy as well as to transport it from the point of collection to the urban areas where the energy is needed. Unless dual use of land is possible, this additional land consumption causes additional sterilization of land as well as a lasting loss in environment and habitat for plants, animals, and humans. Accordingly, the construction of windmill parks and photovoltaic plants outside of residential areas results in the large-scale destruction of landscapes; the construction of small hydropower plants endangers fish stocks; growing so-called renewable crops increases soil pollution due to the increasing use of fertilizers and pesticides. Therefore, the use of solar energy must necessarily be very restricted if the destruction of the environment and habitat is to be avoided.

Accordingly, a way out of the sustainability dilemma may only be found if we decide to define a pattern sustainable use specifically for non-renewable resources and to make this part of the whole sustainability concept. This is possible when we follow the logic of sustainability as *sustainable development* on which the Brundtland Report is based. In line with this logic, we therefore suggest the following definition:

Non-renewable resources are used sustainably if their extraction is continuously reduced to the extent that they are never fully depleted.



This definition needs to be clarified especially with regard to fossile energy sources. The remainder of this section discusses its implications and provides several numerical examples.

The extent to which extraction must be reduced depends, inter alia, on the size of the stocks as compared to today's production rate. This means that we must first have an idea of the size of fossile energy resource stocks that can probably be extracted. The combined stocks of coal, petroleum including oil sand and oil shale, and natural gas combine to approximately the thousandfold annual consumption.⁷ It should be explicitly pointed out that this figure refers not to already known deposits but to stocks which do likely exist due to geological considerations and where extraction is probably feasible.

When this estimation is used to calculate the duration period of fossile energy resources by means of the formula of the sum of a geometric series it follows that with a constant consumption rate, the duration period logically is 1000 years. But we can go on further and ask: What is the rate at which consumption must decrease per year

⁷ According to the World Energy Council, Report 1995 (p. 36), the known stocks of fossile biogenic energy resources plus those close to exploitation amount to 5,090 metric gigatons oil equivalent (gtoe). An additional estimated stock of 5,300 gtoe (hydrates excluded) may be added to this figure. If extraction of half the stocks is feasible, total usable stocks amount to slightly more than 7,740 gtoe. Annual consumption, on the other hand, amounts to just slightly more than 7.0 gtoe.

so that a resource will last forever? Considering our example, the answer is: one thousandth (1‰) per year.⁸

For different rates of consumption increase or, respectively, consumption decrease we can see how much time it will take to exhaust an amount of a specific resource of 1000 units if the current consumption level equals 1. This is illustrated in Figure 1. Compare the exhaustion paths of consumption increase (for example, with the rate of +5% p.a.), of constant consumption (a rate of $\pm 0\%$ p.a.), and of a very small consumption decrease (for example, with the rate of -0.05% p.a.) with the path that results if we suppose that the decrease rate is exactly one thousandth (-0.1% p.a.). In the first three cases the resource will eventually be totally exhausted. In the latter case the resource will last forever. Therefore, by a small but steady reduction of their rates of consumption even non-renewable resources can be used „sustainably“. Although the rates are small, this implies a drastic turnaround in the current pattern of global resource consumption. Of course, this will not be easy. However, we have reason to be optimistic because total reduction of the consumption level needed is of a very realistic scale. At a rate of -0.1% , it can be computed that resource consumption 100 years from now must have been reduced by 10%, consumption 500 years from now by 40%, each compared to today's level of consumption.

These reductions can be achieved by raising energy efficiency (through energy saving technologies), by the appropriate use of renewable resources, and by changes in the structure of production and consumption. Geothermal energy may play a role in the long run.

Interpreted this way, the sustainable extraction rule for non-renewable energy resources provides a *minimum standard*. Environmental objectives (e.g. CO₂-policies) may require their extraction rates to be restricted to less than what may be considered as justified on the basis of scarcity.

If the sustainable extraction rule is set in such a way that the non-renewable resource stock is exhausted in infinite time (using a rate of -0.1%), this is consistent with several features of optimal paths in neoclassical growth models. In these models, the

⁸ See Appendix for details.

resource quantities extracted decline over time and it is optimal to exhaust the resource stock in infinite time.

Our proposal differs from neoclassical interpretations of sustainability in that it provides a rationale for resource management policies that do not exclusively rely on market processes.

5 Recommendations for resource management

1. The question now is how it will be possible to implement a prudent policy of harmonizing economic and ecological aims. First of all, we must abolish state subsidies stimulating the additional use of natural resources by lowering prices or extraction costs. By doing this, we simultaneously reduce the stress on nature and lower the fiscal burden on public budgets. Today this refers primarily to the fields of energy use, transport, and waste disposal where the state supplies many services to the economy free of charge.⁹

2. In addition, it will be necessary to eliminate the indirect subsidy caused by the fiscal system that normally places high taxes on labour but exempts energy. One way to remedy this distortion of the relative prices of labour and energy is to finance the systems of social security (old-age pension schemes, unemployment insurances, health care, etc.) by a tax on energy use instead of financing it by social charges that increase the costs of labour. On the one hand, such an ecological tax reform will lead to higher employment while on the other hand it will reduce energy consumption and thereby its destructive impacts on the environment. Consequently, the payments for unemployment may be reduced as well as the expenses for end-of-pipe measures in environmental protection. Economy as well as nature would be better off!

All traded energy should be taxed. When it comes to electrical energy, such a tax is practically identical with the solution for which Germany opted in their ecological tax

⁹ See also Roodmann, 1996. He writes: "Worldwide government policies shunt at least \$500 billion a year toward activities that harm the environment from overfishing to driving cars and trucks ... An enumeration of the side effects of all these subsidies virtually catalogs today's environmental problems".

reform. In Germany, all electrical energy is taxed, i.e. it does not matter whether it is produced from renewable or non-renewable energy resources. There is one explicit exception, namely electrical power produced by the end-user or distributed by special power lines. Basically, this covers energy that is not traded. Such taxation focuses on the promotion of an ecologically sound increase in energy efficiency and energy savings as well as on renewable energy sources that generate energy for local consumption (i.e. loss of energy by transportation is avoided.) This includes mainly the passive use of solar energy, the active use of solar thermal energy, photovoltaics (as long as it is produced on the roofs of buildings and at the same time consumed locally), geothermal energy around heated buildings, and combined heat and power generation.

3. Selective direct promotion of renewable energies can make sense if all ecological criteria – including those to protect nature (biodiversity) and landscapes – are considered when assessing which energy types should be promoted. In particular those renewable energy types deserve promotion that are based on dual use of land, i.e. production of thermal or electrical energy in settlement areas or by biogas and timber grown in sustainably used forests.

It should, however, be taken into account that long-term subsidies are generally contrary to the market principle. Therefore, the measures should focus on non-financial support by research monitoring, benchmarking, recognition, and eco-labels.

4. By eliminating ecologically harmful subsidies and introducing an ecological tax reform incentives would be created to exploit cost-saving opportunities that have not been attractive so far. The economy as a whole could be directed by the principles of least-cost-planning. As a result, investments that increase the amount of products with a high intensity in the use of energy and material will be discouraged while investments in goods which are produced with a constant or even decreasing amount of energy and material input will be encouraged. All this can be achieved with rising profits because profits, which are the difference between earnings and costs, not only can be increased by selling more products but also by reducing input costs. In fact, in a future sustainable economy, we will have to concentrate much more than today on the cost-side of profits, reducing the input of resources and energy.

Recommendations for further research

First, we suggest to develop a detailed criteria catalogue for selective promotion of renewable resources and apply these criteria to concrete examples under ecological and economic considerations with respect to

- a. the existing energy mix and
- b. an increase of the energy efficiency and of energy savings.

An appropriate assessment has been attempted by the "Immissionsausschuss" of the Federal State Brandenburg in Germany. H.C. Binswanger was member to this committee. The assessment was initiated as a result of his initiative. The report (synopsis and three annexes) can be found at www.brandenburg.de/land/mlur/politik/limscha.htm.

Second, it appears promising to undertake research into how a transition to a less energy and resource intensive structure of production and consumption can be brought about. This would include an investigation into how end-of-the-pipe environmental technologies can be replaced by a restructuring of production.

Appendix

1. The numeric example draws on the formula for the sum of a geometric series from which it follows that

$$R = a \cdot [1 + (1+i) + (1+i)^2 + \dots + (1+i)^{n-1}] = a \left[\frac{(1+i)^n - 1}{i} \right]$$

With R = stock of a resource, i = increasing (+i) or decreasing (-i) rate of consumption and a = current consumption level.

For $n \rightarrow \infty$, we have $R = a \frac{1}{|i|}$. In our example $a = 1$.

2. The result is again derived by using a geometric series. See the following table:

	Consumption Level (CL)
t_0	1
t_1	$1 \cdot (1-0.001) = 0.999$
t_2	$1 \cdot (1-0.001)^2 = 0.999^2$
\vdots	\vdots
t_n	$1 \cdot (1-0.001)^n = 0.999^n$

Consumption Level (CL)

For $n = 100$ we have $CL_{100} = 0,999^{100} \cdot CL_0 \approx 0,90$. So the needed reduction on consumption is equal to $CL_0 - CL_{100}$ which is $\approx 1 - 0,90 = 0,10$ or 10%. For $n = 500$ we have $CL_0 - CL_{500}$ which is $\approx 1 - 0,60 = 0,40$ or 40%.

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