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Ecological Economics 58 (2006) 637–649

ECOLOGICAL ECONOMICS

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ANALYSIS

A just and efficient reduction of resource throughput to optimum

Hans P. Aubauer *

Fakultät für Physik der Universität Wien, Alser Straße 12/8, A-1090 Wien, Austria

Received 8 February 2002; received in revised form 19 August 2005; accepted 19 August 2005
Available online 10 October 2005

Abstract

Resource throughput in the economy (e.g., of energy or materials) must be progressively reduced by at least one order of magnitude to achieve an optimal level. Although this would solve the resource distribution conflict between the generations, it would also aggravate the resource distribution conflict between persons of the same generation. It is shown here that a solution to these two conflicts and efficient resource allocation are only possible if resource certificates are distributed to consumers free of charge and traded between them.

This paper builds on and integrates ideas developed in H. Daly's [Daly, H.E., 1992. Allocation, distribution, and scale: towards an economics that is efficient just, and sustainable. Ecological Economics 6, 185–193.] article on allocation, distribution, and scale, adding insights from the ecological footprint concept, to propose a mechanism for facilitating intergenerational equity and drastically reducing resource throughput. Basically the mechanism involves rationing throughput equitably, internalizing environmental and social externalities, and substituting labour for resource use. This can be achieved almost without a drop in prosperity. Both unemployment and dependence on scarce resources decline.

Keywords: Resource throughput; Ecological footprint; Sustainable state; Carrying capacity; Social justice; Intergenerational justice

1. Introduction

Resources (with low entropy) are taken from the sources of nature and pollutants (with high entropy) are returned to nature's sinks. The biophysical scale of this resource throughput is far beyond its optimal value (Daly, 2003; Lawn, 2001) because resources from non-renewable reserves (e.g. fossil, mineral or nuclear) have been intensively exploited over the last two centuries. During this period, resource throughput could be raised by at least an order of magnitude above and beyond the optimal yield of renewable sources and sinks, whereas before this period, this sustainable yield limited the resource throughput of humankind (Appendix A). As soon as average resource throughput exceeds the sustainable yield of renewable resources, this yield drops irreversibly as the underlying natural system collapses. There are positive feedbacks: Global warming may exacerbate global warming as additional greenhouse gases, such

* Tel.: +43 699 11 47 39 34.
E-mail address: hans.peter.aubauer@univie.ac.at.

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doi:10.1016/j.ecolecon.2005.08.012

as water vapour (due to evaporation) or methane (from the sea bed or permafrost), are released into atmosphere due to its heating up. In this way, nature is comparable to a ship that sinks if loaded beyond its plimsoll line (Daly, 1992). This seriously affects future generations because they depend exclusively on the sustainable yield of renewable resources: their resource throughput is irreversibly reduced when the throughput of the living generations is too high. On average, one human being alive today consumes resources at the expense of very many humans living in the future. If sustainable resource yield is irreversibly reduced, very many more humans could be affected in the future than are alive today.

This situation differs fundamentally from the conflicts discussed by Coase (1960). Coase holds that the situations of A and B are comparable if A inflicts harm on B because avoiding the harm on B inflicts harm on A. More serious harm is to be avoided by direct negotiation between A and B (page 2 of Coase (1960)). However, the conflict of resource distribution described above is not between neighbours but between generations. An immense number of human beings are involved and not only a few. Negotiations between the living (As) and the not yet living (Bs) are impossible. Their transaction costs would be too large. Furthermore, the harm A suffers fundamentally differs from that of B: living As suffer inasmuch as they reduce their resource throughput to a sustainable value, but this hardly threatens their prosperity (Sections 3 and 4), let alone their lives. On the other hand, the harm suffered by not yet living Bs consists of denying them of the resource throughput necessary for their survival.

The conflict between living As and not yet living Bs is a macroeconomic one. It cannot be resolved by way of microeconomic negotiations but by changing the macroeconomic structure of the economy. As a consequence of new regulatory framework, the self-regulation of the economy would reduce resource throughput in the proposed world to sustainable levels. As a result, every generation would have the same sustainable yield of renewable sources and sinks at their disposal (Brundtland, 1987). A free economy is regulated by the prices of commodities and services (C/S), but in the world as it is today price differences tend to lead to unemployment and waste of resources (Røpke, 1999; Lawn, 2001) because labour- and knowledge-intensive commodities are too expensive, while resource-intensive commodities are too cheap. The price customers pay for a particular C/S pays only a small fraction of the costs they cause by using that C/S. The unpaid, external share of these costs is shifted onto the community. Internalizing external costs into prices has been discussed in detail (Massarrat, 1997; Rees and Wackernagel, 1999; Aubauer and Bruckmann, 1984; Pigou, 1923; Lawn, 2001; Speck, 1999; Felder and Schleininger, 2002; Bosquet, 2000; Baranzini et al., 2000), yet only a small fraction of external costs have been taken into account, thus only allowing for small reductions in resource throughput (mainly in terms of emissions). Here, on the other hand, the internalization of all the external costs of avoiding externalities and a step-by-step reduction of overall resource throughput by at least one order of magnitude is discussed. Even if the costs of avoiding externalities are considerably lower than the costs of eliminating them, these costs may be extremely significant and either positive or negative. Internalizing the external costs of externality avoidance drastically modifies relative price differences but does not modify the price average, as their sum is zero.

One fundamental cause of externalities and the costs of their avoidance or elimination is the production factor labour/knowledge, which is far too expensive in relation to the production factor soil/resources. Labour costs are too high because they are proportional to income and highly taxed, whereas resource costs are too low because they more or less contain only the labour costs necessary to obtain them. These resource costs ignore both the demands of future generations for non-renewable resources and the costs of repairing the damage resulting from resource use.

External costs can be internalized within prices in the proposed world if the costs of the production factor labour/knowledge are lowered and the costs of the production factor soil/resources are raised in a revenue-neutral way, thus ensuring that neither average real price levels nor taxation levels change. The difference between income and labour costs can be increased using the revenue originating from increased resource costs. Resources become more expensive because their throughput is reduced, in several gradual steps, to a sustainable level. This can either be the result of predetermining the price of the resources (e.g., by means of taxation) so that their throughput adjusts itself or by predetermining their throughput (e.g. with certificates) so that their price adjusts itself. In both cases, the price of the production factor soil/resources increases and very high revenues are raised, which can be used either to reduce labour costs while retaining incomes at their previous levels (Section 3), or to raise incomes while labour costs remain the same (Section 4 and 5). The consequences of these possibilities are investigated in the following model.

2. The effects of prices

The resource throughput R of N citizens living in a territory (a province, nation or several nations) should be reduced, in several gradual steps, to an amount corresponding to the area A of the territory itself (see Appendix A). Let us assume that the throughput of the ith citizen is equal to $r^i (i=1,2\ldots N)$. After an optimal transitional period, the throughput R should not exceed the area A:

$$R = N \cdot \bar{r} \leq A; \qquad \bar{r} = 1/N \cdot \sum_{i=1}^{N} r^i.$$

There are two possible means of achieving this goal: either the average resource throughput of the citizens $\bar{r}$ can be reduced or their number N can be reduced by restricting immigration and/or birth rate (Lawn, 2001). The more the population N grows, the smaller individual resource throughput $\bar{r}$ and prosperity must be to maintain sustainability. Only the reduction of $\bar{r}$ is discussed here. In most cases, citizens put through resources indirectly via the purchase of commodities and services (C/S), but it is assumed here that this is entirely the case and that a number of units K of C/S are available within the territory. The ith citizen buys a number a_1^i of the first C/S, a_2^i of the second C/S and generally a_k^i of the kth C/S. During the production of the kth C/S r_k resources are put through. Thereby r_k is the biologically productive area required to deliver resources from its renewable sources and to absorb them again after use into its renewable sinks (Aubauer, 2004; Wackernagel and Rees, 1996; Wackernagel et al., 1999) (Appendix A). The calculation of area enables contributions to resource throughput (e.g., energy, material, and soil use) to be quantified, converted into one and the same unit, their sum calculated and their total value found. l_k designates the labour required for producing the kth C/S.

Let present conditions be characterized by the unit price of the kth C/S being equal to P_k^0 and the total price of all C/S purchased by the ith citizen being equal to P_0^i:

$$P_k^0 = r_k \cdot P_r + l_k \cdot P_l;$$

$$P_0^i = \sum_{k=1}^{K} a_k^i \cdot P_k^0 = r^i \cdot P_r + l^i \cdot P_l; \qquad r^i = \sum_{k=1}^{K} a_k^i \cdot r_k;$$

$$l^i = \sum_{k=1}^{K} a_k^i \cdot l_k. \tag{1}$$

P_r designates the price of the production factor resources and P_l that of the production factor labour/knowledge. Via his purchase of C/S, the ith citizen consumes r^i resources and indirectly makes use of l^i labour/knowledge. If he uses all his earnings I^i to purchase C/S $(I^i = P_0^i)$, the resources r^i and the labour l^i available to him are limited by the total price P_0^i.

Furthermore, a production function can be assumed that indicates the output Q^i that can be produced with the production factors r^i and l^i (Samuelson and Nordhaus, 1985):

$$Q^i = q \cdot \left(r^i\right)^{\alpha} \cdot \left(l^i\right)^{\beta}; \qquad \alpha \leq 1; \qquad \beta \leq 1. \tag{2}$$

Q^i is proportional to the prosperity the ith citizen indirectly purchases with the resource throughput r^i and the labour l^i for the price P_0^i. The parameter α is proportional to the marginal product of the resources and β proportional to the marginal product of labour (Samuelson and Nordhaus, 1985). Individual prosperity Q^i reaches its maximum level when the marginal product of resources $\partial Q^i/\partial r^i$ to that of labour $\partial Q^i/\partial l^i$ has the same ratio as that of price P_r to P_l (Samuelson and Nordhaus, 1985):

$$\left.\frac{\partial Q^i/\partial r^i}{\partial Q^i/\partial l^i}\right|_{l^i=l_0^i r^i=r_0^i} = \left.\frac{P_r}{P_l}\right|_{l^i=l_0^i r^i=r_0^i}. \tag{3}$$

From Eqs. (1)–(3), the current resource throughput r_0^i, the labour required l_0^i and the maximum prosperity

Q_0^i which the ith citizen is able to purchase with his income I^i due to the prices P_k^0 can be calculated:

$$r_0^i = \left(\alpha \cdot I^i\right)/[(\alpha+\beta)\cdot P_r]; \quad l_0^i = \left(\beta \cdot I^i\right)/[(\alpha+\beta)\cdot P_l];$$
$$Q_0^i = q\cdot\left(r_0^i\right)^{\alpha}\cdot\left(l_0^i\right)^{\beta}. \tag{4}$$

In total, N citizens consume R_0 resources, require R_0 labour and thus gain prosperity to the value of Q_0:

$$R_0 = \sum_{i=0}^{N} r_0^i; \qquad L_0 = \sum_{i=0}^{N} l_0^i; \qquad Q_0 = \sum_{i=0}^{N} Q_0^i. \tag{5}$$

The total resource throughput R_0 is far too high ($R_0 \gg A$) because labour is far too expensive in relation to resources: $P_l \gg P_r$. For this reason, in the following section the resource price P_r is raised and the labour price P_l is reduced in order to reduce R_0.

3. The effect of reducing labour costs

The price P_r of resources can be raised by the amount t by taxation or by auctioning resource certificates. This yields the revenue $R_1 \cdot t$. It can be used to reduce the price or cost of labour P_l by an amount s. This changes the total price P_0^i of Eq. (1) to the following total price P_1^i:

$$I^i = P_1^i = r^i\cdot(P_r+t) + l^i\cdot(P_l - s). \tag{6}$$

The substitution of Eq. (6) in Eqs. (2) and (3) produces the following result:

$$r_1^i = \left(I^i\cdot\alpha\right)/[(\alpha+\beta)\cdot(P_r+t)];$$
$$l_1^i = \left(I^i\cdot\beta\right)/[(\alpha+\beta)\cdot(P_l-s)]; \qquad R_1 = \sum_{i=0}^{N} r_1^i;$$
$$L_1 = \sum_{i=0}^{N} l_1^i; \qquad R_1\cdot t = L_1\cdot s. \tag{7}$$

Resource throughput is reduced by the factor $f_r = R_1/R_0$, while employment increases by the factor $f_1 = L_1/L_0$. From Eq. (7) it follows:

$$f_l = 1 + (\alpha/\beta)\cdot(1-f_r).$$

Resources are substituted by labour due to the change of unit price P_k^0 of the kth C/S of Eq. (1) to $P_k^1 = r_k\cdot(P_r+t) + l_k\cdot(P_1^l - s)$. This change raises the price of resource-intensive C/S and lowers the price of labour-intensive C/S. Differences between the unit prices P_k change significantly, while the price average does not change: $\sum_{i=1}^{N} P_1^i = \sum_{i=1}^{N} P_0^i$.

From Eqs. (2) and (7), current individual prosperity Q_1^i and current total prosperity Q_1 of all citizens can be calculated. Q_1 changes by the factor $f_q = Q_1/Q_0$, if total resource throughput drops by factor f_r:

$$Q_1^i = q\cdot\left(r_1^i\right)^{\alpha}\cdot\left(l_1^i\right)^{\beta}; \quad Q_1 = \sum_{i=1}^{N} Q_1^i = Q_0\cdot(f_r)^{\alpha}\cdot(f_l)^{\beta};$$
$$f_q = (f_r)^{\alpha}\cdot[1+(\alpha/\beta)\cdot(1-f_r)]^{\beta}. \tag{8}$$

Rather than substituting resources with labour in one big step, it is advisable to do this in several smaller stages. Assuming the reduction of resource throughput by factor f_r takes place in m steps by the factor $(f_r)^{\frac{1}{m}}$, then employment changes by the factor f_r^m and current prosperity by the factor f_q^m:

$$f_l^m = \left\{1+(\alpha+\beta)\cdot\left[1-(f_r)^{\frac{1}{m}}\right]\right\}^m;$$
$$f_q^m = (f_r)^{\alpha}\cdot\left\{1+(\alpha/\beta)\cdot\left[1-(f_r)^{\frac{1}{m}}\right]\right\}^{(m\cdot\beta)}. \tag{9}$$

For example, the resource throughput R could be reduced to one-tenth of its original value in twenty stages ($m=20$) if each stage entails an 11% reduction. According to Eq. (9), this very nearly increases the demand for labour and knowledge L by a factor of eight ($f_l^m|_{m=20 f_r=0.1 \alpha=\beta=1} = 7.9$) while prosperity Q drops by 21% ($f_q^m|_{m=20 f_r=0.1 \alpha=\beta=1} = 0.79$). In this case—for simplification purposes—the marginal product α of resources and of labour β were assumed to be equal: $\alpha=\beta=1$.

However, this assumption ignores the fact that resources are very cheap compared to labour ($P_r \ll P_l$). According to Eq. (3), the marginal product α of resources is much less than β, that of labour: $\alpha \ll \beta$. Assuming that $\alpha=0.1$ and $\beta=1$, a step-by-step reduction of resource throughput to one-tenth of initial levels results in increased demand L for labour and knowledge of 24% ($f_l^m|_{m=20 f_r=0,1 \alpha=0.1 \beta=1} = 1.24$. Current prosperity Q drops by only 1.4% ($f_q^m|_{m=20 f_r=0.1 fd>\alpha=0.1 \beta=1} = 0.986$).

At the same time, resource productivity increases from Q_0/R_0 to Q_1^m/R_1. According to Eq. (9), eight (for $\alpha=\beta=1$) to ten times (for $\alpha=0.1$; $\beta=1$) as much prosperity can be obtained from one and the same amount of resources. If this higher resource productivity Q_1^m/R_1 is multiplied by the initial resource throughput R_0, a total prosperity increase $f_q^{m^{\text{total}}}$ by nearly one order of magnitude results:

$$f_q^{m^{\text{total}}} = Q_1^{m^{\text{total}}}/Q_0 = Q_1^m \cdot R_0/Q_0 \cdot R_1 = (f_r)^{\alpha-1} \cdot \left(f_l^m\right)^{\beta};$$
$$f_q^{m^{\text{total}}}|_{m=20 f_r=0.1 \alpha=\beta=1} = 7.9;$$
$$f_q^{m^{\text{total}}}|_{m=20 f_r=0.1 \alpha=0.1 \beta=1} = 9.86$$

This increase in prosperity $\left(Q_1^{m^{\text{total}}} - Q_1^m\right)$ becomes accessible for future generations.

A revenue neutral decrease in labour/knowledge costs and increase in resource costs would solve the resource distribution conflict between the generations, albeit at the expense of the resource distribution conflict between the citizens of one generation. This is because the resource distribution between the citizens r_1^i of Eq. (7) is identical to the initial one R_0^i in Eq. (4). In both cases, individual resource throughput r^i is proportional to individual earnings I^i. If the entire resource throughput R is reduced by an order of magnitude, the individual resource throughput r^i of the poor also drops by one order of magnitude. But this is unfair, as the poor spend a larger fraction of their earnings on resources than the rich (Samuelson and Nordhaus, 1985).

4. The effect of higher incomes

This injustice can be avoided by repaying the resource revenue $R \cdot t$ in Eq. (7) directly to citizens to increase their earnings I^i, instead of using it to lower the price of labour P_1 (Section 3) (VCS, 1985). The revenue $R \cdot t$ could be distributed to citizens equally or unequally. In the latter case, the poor would have to receive more per head than the rich—if not, they would be even more disadvantaged than by the distribution resulting from Eq. (7). However, the revenue $R \cdot t$ to be distributed is so large that favouring the poor in this way would be unfair to the rich. Accordingly, the revenue $R_2 \cdot t$ is to be divided by the number N of citizens and the same amount paid to each one of them (independent of their income I^i) so that this revenue is used to reduce real price levels. This modifies Eqs. (1), (4) and Eqs. (7), (8), respectively, to:

$$I^i = P_2^i = r^i \cdot (P_r + t) + l^i \cdot P_l - \overline{R_2} \cdot t;$$
$$\overline{R_2} = (R_2/N); \qquad r_2^i = \frac{\alpha \cdot \left(I^i + \overline{R_2} \cdot t\right)}{(\alpha+\beta) \cdot (P_r + t)};$$
$$l_2^i = \frac{\beta \cdot \left(I^i + \overline{R_2} \cdot t\right)}{(\alpha+\beta) \cdot P_l}; \qquad R_2 = \sum_{i=1}^{N} r_2^i;$$
$$L_2 = \sum_{i=1}^{N} l_2^i; \quad Q_2^i = q \cdot \left(r_2^i\right)^{\alpha} \cdot \left(l_2^i\right)^{\beta}; \quad Q_2 = \sum_{i=1}^{N} Q_2^i. \tag{10}$$

In this case, the labour L and the prosperity Q of all citizens change, just as in Section 3: $L_2 = L_1$; $Q_2 = Q_1$. However, the individual prosperity Q_2^i of Eq. (10) differs from the result Q_1^i in Eq. (8):

$$Q_2^i = q \cdot \left(\frac{I^i + \overline{R_2} \cdot t}{\alpha+\beta}\right)^{(\alpha+\beta)} \cdot \left(\frac{\alpha}{P_r + t}\right)^{\alpha} \cdot \left(\frac{\beta}{P_l}\right)^{\beta} \neq Q_1^i. \tag{11}$$

According to Eqs. (7) and (8) of Section (3), a citizen without income ($I^{i=1} = 0$) (and without financial help) has no individual prosperity: $Q_1^{i=1} = 0$. He dies. In contrast, a basic supply of resources (even if these are extremely expensive)

$$r_2^{i=1} = \frac{\alpha \cdot \overline{R_2} \cdot t}{(\alpha+\beta) \cdot (P_r + t)}$$

and basic levels of prosperity follow from Eqs. (10) and (11):

$$Q_2^{i=1} = q \cdot \left(\frac{\overline{R_2} \cdot t}{\alpha+\beta}\right)^{(\alpha+\beta)} \cdot \left(\frac{\alpha}{P_r + t}\right)^{\alpha} \cdot \left(\frac{\beta}{P_l}\right)^{\beta}.$$

This fundamentally resolves social conflict.

5. Fair price differences without large-scale redistribution

At the start of resource throughput reduction, existing taxes have to be taken into account. It would be possible to reduce them using resource revenue $R \cdot t$. If taxes on labour (e.g., social security contributions) are reduced, P_l drops, with the results discussed in Section 3. If taxes on income are reduced, I^i grows, with the results discussed in Section 4. For instance, income tax can be reduced and converted to a negative value as soon as it arrives at the value zero—the rich could pay a positive and the poor a negative income tax. However, resource throughput is only reduced by a small amount if all taxes are reduced to zero using the resource revenue $R \cdot t$. To reduce resource throughput by an order of magnitude, a tremendous amount of money has to be withdrawn from the economy and returned to it again. The resulting circulation of money would be many times greater than today and the associated transaction costs would be far too high. But the intended changes of the difference between C/S prices in Eq. (10) can also be achieved without increasing the circulation of money to such a degree.

To this end, the producer of the kth C/S must label the C/S with the biologically productive area r_k, which is the area required to permanently deliver resources for the production of the C/S with its renewable sources and sinks (Aubauer, 2004).

As soon as the resources taken from nature at a certain spot (Appendix A) are labelled with their area demand by a resource agency (Appendix B), the area demand r_k of the kth C/S can be calculated from the resources needed for its production. In so doing, non-renewable resources must be replaced by renewable ones having the same functions (e.g. mechanical or electric properties) or delivering the same services. This labelling of the C/S would be in the interest of the producer: currently, labour is very expensive in comparison to resources and, for this reason, the producer of a C/S calculates the labour necessary for production in order to be able to reduce it and thus to reduce his production costs by means of "rationalization". In the other case of resources becoming very expensive in relation to labour (due to the measures described in Sections 3 or 4), the producer would have to calculate resource throughput in order to reduce it and thus to reduce his production costs. If the resource throughput r_k of the kth C/S is known, it can be labelled with r_k. Once the kth C/S has been labelled with r_k, the individual resource throughput r^i of each citizen can be found according to Eq. (1), permitting resource certificate trading between them.

By a certain point in time, the resource throughput of N citizens should fall below the target amount R^{GOAL}:

$$\sum_{i=1,k=1}^{N,K} a_k^i \cdot r_k \leq R^{GOAL} = N \cdot r^{-GOAL}$$

This can be achieved by distributing resource certificates corresponding to the amount R^{GOAL} to citizens free of charge. In accordance with Section 4, each of the N citizens receives the same amount $r^{-\mathrm{GOAL}}$ of certificates (Barnes, 2001). Every kth C/S is labelled with two numbers—its price P_k^0 in currency units and its resource throughput r_k in area units. The consumer pays for the purchase in money to the value of P_k^0 and with certificates to the value of r_k. In this way, nothing changes for those who indirectly consume through their purchases just as many resources as the goal amount ($r^i = r^{-\mathrm{GOAL}}$) because they would receive a just sufficient number of certificates for all their purchases. On the other hand, those who want to consume more resources than the goal amount ($r^i > r^{-\mathrm{GOAL}}$) have to buy certificates from those who consume less resources than the goal amount ($r^i < r^{-\mathrm{GOAL}}$). During the purchase of the kth C/S, these citizens pay not only the original price P_k^0 of Eq. (1) but also the additional external costs C_k^{total} of avoiding external damage according to Eq. (10):

$$P_k(r_k, r^i, t) = P_k^0 + C_k^{\mathrm{total}}; \qquad P_k^0 = r_k \cdot P_r + l_k \cdot P_l;$$
$$C_k^{\mathrm{total}} = t \cdot r_k \cdot \left[1 - \left(r^{-GOAL}/r^i\right)\right]. \qquad (12)$$

The certificates enable these external costs C_k^{total} to be accounted for both transparently and sepa-

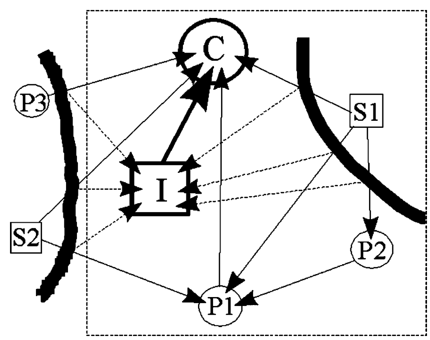

Fig. 1. The resource currency circuit.

rately from the internalized costs P_k^0. The certificates are a tradable currency, a resource currency (Fig. 1). Banks may buy and sell resource currency for a price t at any time under the supervision of the resource agency. Appendix B shows how the circulation of resource currency can be closed.

The external costs C_k^{total} of Eq. (12) include an ecological C_k^{ecol} and a social element C_k^{social}:

$$C_{k,i}^{\text{total}} = C_{k,i}^{\text{ecol}} + C_{k,i}^{\text{social}};$$
$$C_{k,i}^{\text{ecol}} = \left(r_k \cdot t/r^i\right) \cdot \left(\overline{r_0} - r^{-GOAL}\right);$$
$$C_{k,i}^{\text{social}} = r_k \cdot t \cdot \left[1 - \left(\overline{r_0}/r^i\right)\right]; \qquad \overline{r_0} = R_0/N.$$

The ecological element of the costs $C_{k,i}^{\text{ecol}}$—which is always positive—is currently passed on to future generations. Social costs $C_{k,i}^{\text{social}}$ are unloaded from mainly rich resource squanderers onto poor resource savers. Social costs are positive for those who consume more resources than average ($r^i > \overline{r_0}$) and negative for those who consume less than average ($r^i < \overline{r_0}$). Since total external costs $C_{k,i}^{\text{total}}$ are both positive and negative (depending on individual throughput r^i), the overall price level does not change if costs are internalized within prices in accordance with Eqs. (10) and (12). According with $\Sigma_{i=1}^N P_1^i = \Sigma_{i=1}^N P_0^i$ in Section 3 the sum of all external avoiding costs $C_{k,i}^{\text{total}}$ is zero:

$$\sum_{k=1,i=1}^{K,N} a_k^i \cdot P_k^0 = \sum_{k=1,i=1}^{K,N} a_k^i \cdot P_k; \qquad \sum_{k=1,i=1}^{K,N} C_{k,i}^{\text{total}} = 0.$$

Prices are dependent on the individual resource throughput r^i: the individual real price level P^i remains unchanged for those who consume just as many resources as the goal amount ($r^i = r^{-\text{GOAL}}$). Where $r^i = r^{-\text{GOAL}}$ it is the case that $P^i = P_0^i$. For those who consume more ($r^i > r^{-\text{GOAL}}$), the real individual price level increases: $P^i > P_0^i$. From Eqs. (1) and (12) it follows:

$$P_2^i\left(r^i\right) = \sum_{k=1}^{K} a_k^i \cdot P_k$$
$$= P_0^i + t \cdot \left(r^i - r^{-GOAL}\right)|_{r^i >> r^{-GOAL}} \cong P_0^i + t \cdot r^i.$$

In the limiting case of very large throughput $r^i \gg r^{-\text{GOAL}}$ the price P^i grows asymptotically to the value ($P_0^i + t \cdot r^i$). For those who consume less than the goal ($r^i < r^{-\text{GOAL}}$), the individual price level drops. It drops to the value zero in the case of the basic resource throughput r_{BASIC}^i:

$$P_2^i|_{r^i = r^i_{\text{BASIC}}} = 0; \qquad r^i_{\text{BASIC}} = r^{-GOAL} - \left(P_0^i/t\right)$$
$$= r^{-GOAL} - \frac{P_0^i \cdot f_r}{P_r \cdot (1 - f_r)}|_{f_r \ll 1} \cong r^{-GOAL};$$
$$f_r = \frac{R^{GOAL}}{R_0}. \tag{13}$$

Citizens who reduce their individual resource throughput r^i to a value of r_{BASIC}^i do not need to pay anything for their purchases of C/S. Eq. (13) yields a basic supply of C/S goods, made available in return for the service of saving resources and paid for by those who consume more resources than the goal: $r^i > r^{-\text{GOAL}}$. This basic supply r_{BASIC}^i is necessary to maintain the individual resource throughput of the poor (r^i for small i) above subsistence levels if throughput becomes very expensive. Eq. (13) shows that the difference between r_{BASIC}^i and $r^{-\text{GOAL}}$ becomes much less in the limiting case of significant resource reduction: $f_r \ll 1$. In other words, the more resource throughput is reduced, the more it is distributed equally between citizens. Thus, not only is the ecological conflict between generations and between humankind and other species essentially solved but also the social conflict between rich and poor. Present corrections to the socially insensitive pricing system (e.g., social transfer payments and progressive income tax) become superfluous to a great extent. A fair balance between rich and poor is derived from fundamental ethical principles: that the right to resource use of the one ends where the same right of the other begins (Locke, 1690; Kant, 1788).

6. Discussion

There are three independent policy goals for using natural resources: their just distribution between generations (“scale”), between the people within a generation (“distribution”) and their efficient distribution between commodities and services (“allocation”) (Daly, 1992). The policy instrument of the present price system is solely concerned with the goal of allocation. As a result, resource throughput is far higher than its ecologically sustainable maximum—indeed, it is far higher than the even lower ideal economic optimum level (Lawn, 2001). For this reason, it must be reduced at least to the latter level as soon as possible in order to avoid its being reduced to far lower levels following a total breakdown of the natural system. The precise empirical identification of a sustainable level of resource throughput is not required for this purpose. If one jumps from an airplane, it may be nice to have an altimeter, but what one really needs is a parachute (Daly, 2003). The parachute is a policy instrument that reduces aggregate throughput from resource depletion to pollution. The instrument reduces resource throughput, calculated as the demand for biologically productive soil and water area, in relation to the available sustainable supply of biologically productive soil and water area. Thus, the demands made on natural systems in quasi-static equilibrium (e.g. ecosystems, climatic systems and soil equilibriums) fall to levels with which they can cope.

Resource throughput can be reduced by taxation or by certificate auction, producing revenue that can be used to increase the difference between income and labour costs. Either labour costs can be reduced, keeping incomes unchanged (Section 3), or incomes can be raised, keeping labour costs unchanged (Section 4), or both. In every case, resource-intensive commodities become more expensive and are displaced by labour- and knowledge-intensive commodities, which become cheaper. The price difference between the two increases without affecting average price level. The production factor resources is substituted by the production factor labour/knowledge. The third production factor capital is invested in labour and knowledge rather than in the exploitation of resources because the former is more profitable. Resource throughput drops and unemployment rates fall without a decrease in gross national product or prosperity. This is particularly the case if resources are substituted by labour/knowledge in several small stages, as this results in dramatic growth in resource productivity. Thus, a far greater degree of prosperity can be gained from the same amount of resources, prosperity that benefits future generations. In this way, the “scale” goal is attained: every generation receives the same fraction of the resources common to all and, thus, the same natural opportunity to live. Without resources, life is impossible—and the right to life is the most fundamental human right (UNO, 1948). This right is indivisible and cannot be assigned purely to existing generations but must be assigned to future generations in the same way.

The conflict of resource distribution between the generations can only be solved by this resource throughput decrease—but this intensifies the distribution conflict within existing generations. In order to dispel this conflict, the same share of the resources common to all must be assigned not only to every generation but also to every human being within a generation (e.g. citizens within a country), just as every human being has the very same right to life. This can only be implemented if the income of every citizen is raised by the same amount using resource revenue (Section 4) so that resources become more expensive at the same time. This results in real price increases for those individuals who consume more than their share of resources and reduces real prices for those individuals who consume less than their share. Thus, the real price average remains unchanged.

This procedure does have one disadvantage, however: the revenue derived from reducing resource throughput by an order of magnitude is many times larger than GNP. The transaction costs of recycling such a large revenue would be immense. Yet the very same shift in price differences between resource- and labour-intensive commodities can also be achieved without recycling large amounts of money. In this case, neither resources are taxed nor certificates put up for auction and, thus, high revenues are not raised. Instead, certificates pertaining to predetermined resource throughput are distributed. Nevertheless values are assigned to the external avoidance costs by a preset ecological footprint. The certificates are distributed among consumers free of charge—distribution goals cannot be met if certificates are handed out to producers. A system in which some citizens receive more and others less resource certificates cannot be justified because this would reduce the natural life chances of some. Thus it follows that every citizen must receive the same amount of certificates. If a citizen (indirectly through his purchases) consumes more resources than this amount, he has to buy certificates from those he compels—in a manner of speaking—to consume fewer resources than this amount. Selling certificates one received free of charge is profitable. For a certain maximum resource throughput, certificate sale produces as much money as the costs of this throughput. Thus, even the poor are certain to receive a basic supply of resources derived from this certificate sale and paid for by those who consume more than their share, ensuring that the poor can afford vital and possibly expensive resources.

Does certificate trading between citizens consuming resources indirectly by means of consumption correspond to the certificate trade between pollutant-emitting producers, as proposed by Tietenberg (1985)? In the former case, the total resource throughput of the citizens living in a territory should be reduced to a certain amount, whereas in the latter, pollutant emissions from emitters within a territory should be reduced to a certain amount. If an emitter wishes to emit more than a predefined threshold value, he is required to buy certificates from those who he compels—in a manner of speaking—to emit less than this value. Tietenberg shows that certificate trading can significantly increase cost effectiveness: those for whom emission reduction is cheaper sell emission certificates to those for whom emission reduction is more expensive and, as a result, the average cost of emission reduction per unit falls.

Yet this cost effectiveness is far more significant if rights to resource throughput are traded rather than emission rights alone. Firstly total resource throughput is reduced and not only a fraction of it solely in terms of emissions. Secondly throughput is reduced directly at its cause, consumer decision-making, at "point of sale" (Røpke, 1999). Resource-intensive commodities are purchased less, labour- and knowledge-intensive commodities more, as the former become more expensive and the latter cheaper. Changing consumer behaviour in this way (Noormann et al., 1999; Jackson and Marks, 1999) reduces resource throughput without incurring additional costs, while emission reduction on the part of producers incurs additional costs. Thus, the goal of efficient resource allocation between C/S can only be met if resource certificates are traded between consumers and not if emission certificates are traded between producers.

Furthermore, scarce resources can only be fairly distributed between citizens and not between emitters or companies. A citizen consumes resources indirectly via the commodities and services (C/S) he purchases. His resource throughput can only be calculated if the resource throughput of these commodities is known. In order to reduce production costs in view of increasingly expensive resources, it is in the interest of producers to determine the contribution of their production stage to the resource throughput of their C/S. If these contributions are added together, the C/S can be labelled with its resource throughput, which can in turn constitute the basis of certificate trading between consumers. This trade results in all the ecological and social external costs caused by its purchase and use being included in the price of a C/S. The external costs of avoiding externalities have four features: they may be extremely significant; they may be either positive or negative; their sum is zero; and they are related to individual resource throughput. Their internalization within C/S prices significantly modifies price differences while not affecting the price average. Resource-intensive C/S gradually become very expensive; labour- and knowledge-intensive C/S (e.g., science, education, art, and services for old and young people) become extremely cheap. Unemployment drops and wages increase as the demand for labour increases. The average price level increases for those citizens who consume more resources individually than predetermined, while it drops for those who consume less. Not only are C/S traded but also their shares of resource throughput, which is limited for all.

Prices that include all external costs resolve the conflict between the individual interest of the consuming human being with the general interest of humankind living in the present and the future. The tragedy of the commons is removed (Hardin, 1968, 1974). This is a necessary, although not sufficient, condition to achieve the three goals of scale (ecological), distribution (social), and allocation (economic). These goals of sustainable development would not conflict if this pricing system was implemented. By attempting to buy as many commodities as possible with a limited amount of money, the consumer ensures the just distribution of scarce resources between generations and between citizens of one generation and the efficient distribution of resources between C/S, even if this was not his intention.

Adam Smith (1970) credited this process to the operation of an "invisible hand". Smith drew his experiences from the 18th century. At that time, resource prices rapidly increased when resource throughput increased beyond the limits of sustainable supply (see Appendix A). Yet already in those days, prices ignored the limits of individual resource throughput and, as today, the rich put through resources at the expense of the poor.

The advantages of the substitution of resources with labour/knowledge only occur if the territory in which substitution is carried out is suitably integrated with environments in which it is not carried out. For example, C/S produced outside a territory and subsequently imported must be subjected to the same standards as C/S produced within the territory (Appendix B). In view of this, every territory (or state) must be able to determine independently the ecological and social standards of the C/S approved for sale within it. It is easier to realize the substitution of resource throughput with labour/knowledge in a larger territory (e.g. the European Union) than in a smaller one (e.g. a member state of the Union) because the share of cross-border trade is less in the former. On the other hand, the larger the territory, the more difficult it is to agree on the political instruments necessary for substitution.

For example, resource throughput in the member state C of the European Union is to be reduced from its current value R_C^1 to the sustainable one R_C^∞ of its biologically productive area. The C/S offered in C are labelled with their area demand r_k.

At the beginning of the first year a national resource agency of the country C could distribute just as many resource certificates as the current throughput R_C^1 (Appendix B). Their validity would end after a time interval, e.g., of more than a year. Resource throughput would not be limited this way. Nevertheless, it would drop from R_C^1 to R_C^2 by the beginning of the second year because the price P_k of the kth C/S as well as the average price P_2^i/r^i of all the C/S bought by the consumer would drop with his resource throughput r^i in accordance with Eqs. (12) and (10). Similarly, shortly before the beginning of the second year just as many certificates could be distributed as the current resource throughput R_C^2 but less than R_C^1, the throughput of the first year. The periods chosen also could be shorter than a year. This process could be repeated in the following years until the resource throughput arrives at the goal R_C^∞. If this process lasts too long, at the beginning of the yth year less certificates than the current resource throughput R_C^y (say $x \cdot R_C^y$ for $x<1$) could be distributed.

Certificate trading could be carried out by banks under the supervision of a resource agency. For example, certificates could be transferred to consumer accounts (in area units) just like a second national currency, a resource currency as it were. Consumers could withdraw the certificates from their account in normal currency (at the current exchange rate) and could purchase C/S with this currency according to the total price P_k of Eq. (12), which includes all external costs.

In this way, throughput reduction also could be realized in another country D. To enable an inhabitant of one country to purchase C/S in another country, certificates from countries C and D could be exchanged on a one-to-one basis in relation to area ratio.

The method of resource throughput reduction proposed here would enable a country to solve its ecological and social problems with minimal transaction costs and with nearly no loss of prosperity. The use of resources would be replaced by the use of labour/creativity, which in turn would reduce unemployment and dependence on scarce resources. As a result of these advantages, this method of throughput reduction could be copied by other countries and finally become worldwide. No country would use resources at the expense of another one.

7. Conclusion

The three goals of scale, distribution and allocation can only be arrived at if one and the same amount of certificates allocated to total resource throughput is handed out to each and every consumer free of charge and subsequently traded between them. Resource throughput must be progressively reduced by at least one order of magnitude if a breakdown of the natural system is to be avoided which would reduce throughput to a far lower amount. This cannot be achieved by taxation or certificate auction because this requires raising revenues which are many times larger than

GDP and the transaction costs incurred returning this revenue to the economy are far too high. Thus, the only alternative remaining is certificate distribution, free of charge. All three goals can only be met if certificates are handed out to consumers and not to producers. Producers are only able to reduce a fraction of resource throughput, for instance, its end result, pollutant emissions. On the other hand, the consumer can reduce total resource throughput at the point of sale. This can be achieved by labelling commodities and services with resource throughput converted into area units. Moreover, resources can only be distributed in a socially just way among people trading certificates between them and not by means of a certificate trade between producers. In addition, a certificate trade between consumers is considerably more cost effective than one between producers because the consumption shift from resource-intensive commodities to labour- and knowledge-intensive ones does not cost anything at all. Neither GNP nor prosperity is diminished and unemployment disappears.

Appendix A. The goal of resource throughput reduction

Prior to the industrial revolution, humans were dependent on the supply of renewable resources: plant and animal products, the more direct exploitation of solar energy, for example as water or wind power, and the ability of ecosystems to absorb pollution. Renewable resource yield is limited by the biologically productive or fertile ground and water area that support the flora and fauna of ecosystems. This yield has limited population growth and resource use. In the beginning of the 19th century, the earth's fertile surface was sufficient to supply just one billion people permanently because already at that time, for instance, biodiversity was decreasing (Diamond, 1997) and more wood was being extracted from forest areas than was replaced by woodland growth (Sombart, 1922; Hartig, 1811). The limiting of resource throughput by fertile soil area has since been removed as a result of the intensive exploitation of non-renewable resources (fossil, mineral and nuclear resources in particular), which is not limited by fertile soil area because the extraction of non-exhausted mineral oil or ore deposits can be expanded more or less arbitrarily. Yet this cannot endure forever—and to permanently fulfil the functions currently fulfilled by non-renewable resources using renewable ones, many times more than the actual fertile soil area available on earth would be required.

With the removal of this soil area limitation, the number of humans has grown from 1 to 6.5 billion since 1820. Their average individual resource throughput has at least doubled since, for one-fifth of the world population, it has increased by no less than a factor of five (Fischer-Kowalski and Haberl, 1997). In this way, total resource throughput has grown by an order of magnitude.

This statistic is corroborated by a tenfold increase in total energy consumption since that time (Nentwig, 1995) because energy consumption is approximately proportional to total resource throughput (WWF, 2000). Even the very conservative model, the "ecological footprint", reveals a tenfold increase in resource throughput when correctly interpreted (Wackernagel and Rees, 1996; Wackernagel et al., 1999; WWF, 2000). While converting resource throughput into demand for fertile soil, this model made a number of simplifications: for instance, the area necessary for maintaining biodiversity and material supply was ignored and the yield data of non-sustainable intensive industrial agriculture were used and its contributions to loss of biodiversity, soil degradation and the greenhouse effect were ignored. Correcting these assumptions brings even this conservative model into line with the previous two estimates (Aubauer, 2004).

Today more than ten Earth planets would be necessary to permanently satisfy the resource demands of humankind—and the number of planets required continues to grow rapidly, as human populations and their individual resource throughputs grow as well. Notably, fertile soil area decreases if more resources are consumed on average than an area can permanently produce—for instance, due to soil degradation (Brown and Wolfe, 1984; Crosson, 1995), destabilization of the climate (IPCC, 2001), or loss of biodiversity (Pimm et al., 1995; Reid and Miller, 1989). In accordance with the precaution principle, even the probability of soil fertility or ecological carrying capacity decreasing must be ruled out (Cameron and Abouchar, 1991). Within an optimal period, therefore, the resource area demand of humankind must be progressively reduced in a number of stages to the area supplied by planet earth. This optimal period would enable us to minimize the total damage both for the current generation (the As), as well as future generations (the Bs) (Coase, 1960; Hinterberger and Schmidt-Bleek, 1999). This necessitates that the demand for area of a population living in a particular territory be reduced at least to the area of that territory, irrespective of how small that territory might be (in the case of cities, the surrounding countryside should be included), because nowhere the carrying capacity is to be reduced permanently.

Appendix B. The circulation of resource currency

The circulation of resource currency must be suitably closed and overseen by an institution "I", a resource agency (Padilla, 2002). Producers of a C/S use resource currency they receive from the sale of C/S for the purchase of preliminary C/S or resources necessary to assemble their C/S from the agency "I". They buy these preliminary C/S from other producers and buy resources from those who exploit renewable resource sources directly (e.g., mine owners and farmers). The illustration (Fig. 1 in Section 5) shows the boundaries of a territory as a square drawn with a faint dotted line. The consumer "C" is symbolised by a circle within the territory. He buys C/S from a producer "P1" and this flow of C/S is represented by the arrow drawn from P1 to C. Resource currency flows in the opposite direction from C to P1. The producer P1 buys a preliminary C/S from a producer "P2" and resources from the source "S1". Here, the term "source" is used as a synonym for "sink" and "resource", as a synonym for "pollution" (see Appendix A). Resources flow directly from sources within the territory (S1–P1, S1–P2, and S1–C), from sources outside the territory (S2–P1 and S2–C) and indirectly in the case of C/S imports (P3–C) into the territorial economy.

The interfaces between the territorial economy and the natural world are at those points where resources are inputted to the economy (shown as the crossings of the arrows with the thick black lines around S1, P3 and S2). From these interfaces, resource currency flows back into the territorial resource agency "I", shown as a square bordered by a thick black line. The agency "I" distributes resource currency periodically amongst its citizens (represented by the thick black arrow from "I" to "C"). Those who sell resources directly from sources or indirectly from C/S imports deliver the resource currency they receive from their sales to the institution "I". Even resources extracted directly from the natural world are labelled with the fertile area that would be necessary to produce them in a sustainable way with renewable sources. This labelling is carried out by the resource agency "I". In this way, the circulation of resource currency is closed and, thus, "I" safeguards the resource demands of future generations and represents their interests.

The import of resources from a source outside the territory, such as S2, does not differ from their purchase from a source within the territory, such as S1. Resource currency is passed on to the agency "I" in both cases. Imported C/S must be labelled with their resource throughput in the same way as C/S produced within the territory to avoid competition distortion between production outside and inside the territory. Resource currency necessary for the purchase of imported C/S does not flow to the importer or to producer P3 outside the territory but to the agency "I".

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