Assessing Energy Policy:
Should Rebound Count?

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……………………………………..

Abstract

Evaluations of environmental policies to increase technological energy efficiency are investigated for their treatment, or lack thereof, of rebound, the theory of which is presented. As an approximation, until the backfire question is settled, there is enough evidence to justify evaluations' dividing engineering savings by two. It is shown how the environmental energy efficiency strategy relates to other environmental strategies within $I=f(P,A,T)$. Definitions and taxonomies of rebound and of its measurement are analysed. While a broad historical correlation between efficiency increase and consumption increase is attested, establishing causality statistically would require better, perhaps aggregate, metrics for measuring macroeconomic efficiency. There are reasons to prefer physical metrics, especially since the environmental goal is to reduce negative physical impact. While backfire theory posits causality from efficiency to greater input consumption and predicts the correlation, efficiency-strategy theory accepts the real-world correlation but posits causality from efficiency to less input consumption. Ideas of the classical economists that are relevant to rebound are briefly analysed. Theoretical and empirical evidence is not yet sufficient to decide whether rebound is greater or less than unity. If greater, however, the severe consequence is the abandonment of the efficiency strategy, perhaps in favour of quotas.

Glossary

AEEI – autonomous energy efficiency improvements, i.e. business-as-usual cost-cutting ones rather than policy-induced ones

Backfire – rebound greater than 100% of engineering savings

Consumption efficiency – an input-output ratio as influenced not by the technology of a process but by consumer behaviour, e.g. boiling only the amount of water needed or using less lumens by focusing light (e.g. on the page being read)

Efficiency – from the Latin “to do”; here the *ratio* of output to energy input, as opposed to *efficacy* or *effectiveness*, which disregard input; the inverse of *intensity* which is the ratio of energy input to output; greater efficiency is a lower input-output ratio; shorthand for ‘energy efficiency’ and ‘technological efficiency’

Energy – from the Greek “work”; defined ostensively; expressed in joules; loosely, also the material with potential to do work at a certain temperature; subject to First Law of thermodynamics

Engineering savings – the theoretical input savings when processes become more efficient and demand for output is held constant; the quantity *of which* rebound is a percentage

EROI – energy return on (energy) investment, i.e. the ratio of the energy expended to the energy mined or made available, e.g. for oil about 80-93% (Smil 2003, 76)

Exergy – energy in available or useful form to do work; not subject to First Law of thermodynamics, i.e. its quantity can change

Input – presupposes ‘time’, ‘process’ and ‘output’; quantifiable in joules or work-hours, for instance

Input-output ratio: for ‘efficiency’ and ‘intensity’ input is in the nominator; for ‘productivity’ in the denominator

Jevons theory – shorthand for backfire

Organisational efficiency – the ratio of human effort to output; economies of scale, Taylorite factory-floor measures, rule of law, honesty, slim management hierarchy, trade, specialisation or division of labor, information- and population-dense markets, trade, industrial norms, communication, property security, improvements in ‘human capital’, moving closer to work, less crime, and walking in a straight line from A to B

Output – presupposes ‘time’, ‘process’ and ‘input’; quantifiable with difficulty; a ‘product’ or, macroeconomically, all products; loosely, economic size, scale, and consumption; here meant physically rather than economically or in terms of utility

Rebound – consumption or demand *for inputs* caused by income or price effects of efficiency increases; expressed as a percentage of engineering savings

Technological efficiency: the ratio of physical input to physical output (or services: see *Section 6.4*), implying *process;* here usually *energy* efficiency: ratio of conversion of fuel to useful heat or mechanical energy, or to produce things; here often shortened to ‘efficiency’

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Chapter 1 A Paradox

Heightened energy efficiency is a policy tool of governments to achieve the environmental goals of conserving fuel and lowering combustion emissions. Article 2,1 (a) (i) of the Kyoto Protocol to the United Nations Framework Convention on Climate Change, for instance, commits Parties to "implement… policies and measures… in achieving its quantified emission limitation and reduction commitments… [and] in order to promote sustainable development… such as enhancement of energy efficiency in relevant sectors of the national economy." (UNFCCC 1997) Bodansky reports that from the beginning of the Convention negotiations the envisioned legal commitments included not only 'taxes…, cost internalization…, sustainable forest management… and best available technology to limit greenhouse gas emissions, [but also] harmonized efficiency standards [and] promotion of energy efficiency and conservation.' (1993, 508)

Article III-256 1. (c) of the Draft Treaty establishing a Constitution for Europe states that "…with regard for the need to preserve and improve the environment, Union policy on energy shall aim to… promote energy efficiency and energy saving…." (CONV 850/03) The UK Energy Efficiency Commitment (Defra 2002) and Chapter 3 of the UK 'Energy White Paper' foresee efficiency measures in space heating, boilers, appliances, lighting, electric motors, power supplies, etc., to be pursued *inter alia* by legislation, the Carbon Trust, and the Energy Saving Trust (DTI 2003), while the UK Sustainable Energy Act 2003 prescribes efficiency improvement in Sections 2-4. (OPSI 2003; also DoE 2006 [US], BfE/ES 2005 [Switzerland] and Prognos 2004, 4 [Germany])

The various policies mandate, subsidise, or merely encourage technological efficiency gains (*Glossary*) and are familiar: light bulbs, household appliances, vehicles, whole transport systems, electric power installations, buildings, manufacturing, etc., should use less energy input for a given physically measured output. Energy efficiency is universally endorsed by political parties right and left, green as well as industry NGOs, and the press. (Reijnders

1998) Academic ecologists and economists are divided. While some believe that "demand for a scarce resource can be reduced by its more efficient use…" (Jacobs 1991, 91; 105), criticism of higher efficiency's usefulness in lowering pollution and conserving resources has become more widespread since first voiced by Jevons (1865; *Glossary*), Brookes (1978, 1979), Khazzoom (1980) and Saunders (1992) and has led the UK Department of Environment, Food, and Rural Affairs (Defra) to commission academic studies aimed at settling this urgent question (UKERC 2005, 2006; 4CMR 2006; Allan et al. 2006).

This dissertation asks two questions about this environmental energy efficiency strategy. First, should evaluations of efficiency measures correct for *rebound*, i.e. for the increased consumption effected by the lower production costs (including household production) caused by policy-induced technological efficiency improvements? The dissertation answers strongly in the affirmative, but the evaluation documents here surveyed do not do this. Second, are these policies environmentally counter-productive, i.e. do they *backfire*, causing energy consumption higher than it would have been otherwise, without the policies? While the answer is tentatively yes, the dissertation mainly tries to define concepts and questions and establish what counts as evidence.

Chapter 2 examines the methodology of documents evaluating the effectiveness (and cost-effectiveness) of policies, defines the rebound effect and renders it plausible. Chapter 3 embeds the efficiency strategy in the *I=PAT* identity showing environmental Impact to be a function of Population, Affluence, and Technology, and shows that 'dematerialisation' and heightened efficiency are identical. Chapter 4 describes the rebound effect as an *income effect* and tries to improve on the literature's chaotic and non-parsimonious taxonomy of rebound, criticising widely-cited literature. Chapter 5 criticises parts of the theory implicit in the empirical methodology of rebound studies. Chapter 6 draws a correlation between undisputedly rising consumption with rising efficiency but mainly analyses problems of measuring the variables and concludes that since correlation is not causality the debate needs more theoretical work. Chapter 7 briefly describes the arguments and conclusions of classical economists concerning backfire. Chapter 8 discusses open definitional issues and suggests the alternative strategy of energy quotas. Chapter 9 draws conclusions.

No one maintains that increased technological efficiency has succeeded in lowering rates of consumption. Empirical work is universally and perhaps necessarily inconclusive, allowing the two contradictory claims – that efficiency gains at least slow rates of consumption down, or that they speed them up – depending on one's theory. For Jevons the question is a 'paradox' (1865, 141), for Wirl a 'theoretical riddle' (1997, 29), and for Schipper a 'Loch Ness monster' (2000, 351). Since around 1990 rebound literature has burgeoned. No study omits counterfactual assumptions or an "otherwise" clause about the path consumption *would have* taken *without* either the business-as-usual or policy-induced intensity decreases. (Khazzoom 1980, 23, 31; Howarth 1997, 3; Brookes 2000, 356; Schipper & Grubb 2000, 370; Moezzi 2000, 525) The objective of the dissertation is to contribute to the clarification of terms and issues and demonstrate the plausibility of the thesis that changing technological efficiency ratios does not necessarily change the absolute amount of energy consumed.

Chapter 2 Policy Evaluation

2.1 Introduction

Evaluating the environmental effectiveness of energy efficiency policies presupposes quantification of the change in energy consumption or pollutant emissions[1] *caused by* the policies. *Sections 2.2* and *2.3* show how some Swiss and UK assessments do this on the basis of technical product information enabling computation of the average efficiency of the stock of capital goods before, and after, policy enactment. Actual energy consumption over the studied time period can be compared with these potential savings and with hypothetical 'trends' projecting quantities of energy that *would have been* consumed *without* the policies. *Section 2.4* shows that it is plausible in judging policy effectiveness to correct for *rebound* and control for *backfire* (a consumption level even higher than 'trend') that would render efficiency policies counter-productive. *Section 2.5* reviews recent steps to incorporate rebound into evaluation computations.

2.2 Evaluation methodology

2.2.1 Efficiency Changes

The 'bottom-up' method of computing *energy savings* takes "the number of newly influenced agents, realised installations, optimisations, and saved person-km, etc. This number is then extrapolated by an average energy-savings or productions factor" based on engineering data about the product. (ES/INFRAS 2004, 6, 103; also Schipper & Meyers 1992, 65) The extrapolation starts with the average efficiency of pre-existing stock and the number of newly more efficient goods and processes, then computes the greater average efficiency deemed to be caused by policies. The difference in these average ratios of joule-input to output multiplied by the number of *output units* (light bulbs, houses, cars, etc.) in use is called 'savings' or the rate of change of consumption of the input.

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[1] This dissertation analyses consumption, and emissions only implicitly.

Assume the policy measure mandates **kettle** efficiency – joule-input per change of temperature of a litre of water – as evaluated by Defra (2006). All kettles newly taken into use thus have water-boiling efficiency *X*, greater than *Y*, the average efficiency of the existing stock of the capital good *kettle*; the difference in these ratios gives a coefficient of efficiency change. Policy-induced change in joule-input for all kettles is the number of kettles in use times the difference between the before- and after-efficiency coefficients and the number of litres boiled. Assumptions are necessary about the mix of efficiencies among the stock at the two measurement times. (Fouquet & Pearson 2006, 146) Defra gives figures on "standard" and "eco" kettle efficiency, numbers of each in use, number of uses per year, and number of litres boiled per use. This data on the product or output (hotter water) yields data on input: "energy use per kettle per year" times kettle numbers which, taking an efficiency difference of 1.42 and assuming the "whole stock" is now eco kettles, yields "energy saved per year" of 1.27 TWh. (*ibid.*, 4.1) Similar changes for cars, heated rooms, power stations, etc. are routinely tallied.

Since the policy goal is reduction of the *absolute number* of input-joules and not a mere change in *ratios*, the crucial and contentious assumption here concerns the number of kettles/kettle uses by which the efficiency-change coefficient is multiplied. Simply counting kettle-joule consumption at two different times yields no information about the influence of the policies on any measured change, not only because some kettle replacement would happen anyway (*Section 2.2.3*) but also because other causal factors could influence total kettle number. Technical efficiency information – the *engineering* part of evaluation – gives only the dimensionless ratio of input *per unit* of output. To try to determine from these ratios an absolute number one computes ***engineering savings*** by holding output-consumption, e.g. boiled litres, constant. If policies are responsible for doubling the energy efficiency of kettle use, or vehicles, the input-output ratio over some time period *halves*.[2] To

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[2] This unrealistically assumes the homogeneity over time of the outputs e.g. in kettle accessories or car size and weight. (Section 4.7)

derive total consumption of *input* units from this, one must then insert some number of units of consumed output in the denominator and multiply by half the original baseline fraction of 1/1, namely 1/2. Holding this number (e.g. of kettles/kettle uses) constant gives a *theoretical* reduction in input-joules or savings *potential* with constant consumption.[3] This amount is routinely added to *actual* (measured) consumption to arrive at 'trend' or input consumption without policies. (*Section 2.3*)

2.2.2 Real Input Savings

Taking engineering savings as *real savings* assumes that although higher efficiency means lower outlays for energy and freed purchasing power, consumers do not consume more ("*Konstant-Verbrauch"* (CEPE 2003, 39)). A typical document concerning a program for household heating and appliance use takes number of households and *previous demand* for energy services times the fall in the "energy ratio". (Defra 2004b, 29) All investigated[4] regulatory impact assessments (RIA) thus merely substitute lower 'unit energy consumption (UEC)' without altering unit amounts. Prognos similarly assesses Germany's prospects of achieving its emissions-reduction goals, quantifying the variables "policies and technology" (including efficiency), general economic growth, weather, and energy prices (2004, 3); "consumption-reducing efficiency improvements" for car types, for instance, are multiplied by the number of cars in the '*before*' scenario, yielding an alleged 'savings' of 14.7 PJ.[5] (22; INFRAS 2003, 34)

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[3] Were efficiency *decreased,* the theoretical *increase* in consumption would be 'engineering waste'; the discourse of 'wasting' energy is thus dependent on the concept of efficiency. Not every sector becomes continuously more efficient: restaurant eating represents perhaps a decline in the efficiency of 'eating', and aluminium drink containers are perhaps less efficient than glass ones. Efficiency-induced cost reductions in gasoline lead to more kilometers and less efficient vehicles. (Wirl 1997, p. 31)

[4] The sample of documents – all to be found in the bibliography – covers almost all assessments carried out in Switzerland, but only a small number from the UK; no conclusion about the population of all assessment documents is possible.

[5] Prognos also computes tax effects on final consumption (2004, 10), but ignore the eco-tax rebound, i.e. ensuing efficiency increases.

Thus only engineering criteria are used, to the exclusion of the *economic* possibility of changes in input as well as output consumption due to demand stemming from lower per-unit energy expenditures and/or lower prices (*Section 2.4*). A further example is "change in petrol consumption per km specific to car models" – an efficiency-improvement "E-factor" – times e.g. 775 more efficient cars sold to derive fuel litres saved. (ES/Prognos 2004, 10-11, 22; ES/INFRAS 2004, 6, 76) Using this 'bottom-up' methodology DTI estimates 0.6 MtC are saved through boiler efficiency improvements of 5 million boilers (2003, 33-38), while INFRAS takes "Delta r-value" for wall or window insulation times newly improved m^2 to assess heating oil savings. (2000, 3, 16) Paradigmatically, "the empirical basis of the criteria for evaluating the programmes" is only the "amount" (*Mengen*) of more efficient items sold and the "energy-specific effect" (*spezifische Wirkung*) in joules *per unit* (INFRAS 2003, 23). Therefore absolute PJ 'savings' are *exactly proportional* to the changes in relative or 'specific' unit consumption, and when actual energy consumption rises rather than falling by the amount predicted by engineering savings, this is attributed to other 'growth' factors (*Section 2.3*).

2.2.3 Five Measurement Issues

1) Correct calculation of engineering savings includes the 'lifetime' efficiency of the new capital stock compared to that of the old, entailing comparison not only of *operating* energy inputs between less and more efficient equipment, but also of differences in *embodied* energy, and also the costs of 'capital junking' in energy (not monetary) units; i.e. of replacing equipment before wear and tear alone render it depreciated. (Robinson 1954, 91; *Section 5.6*)[6] None of the investigated policy evaluations correct for these.
2) More efficient capital that would have been brought into use anyway cannot be attributed to policies in evaluating their effectiveness. This

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[6] Adding R & D, recycling and waste treatment likewise lowers 'lifetime' efficiency.

Mitnahmeeffekt ('free-riding') is routinely corrected for with some coefficient. (ES/INFRAS 2004, 50-53, 109-113)

3) New more efficient energy-producing installations such as combined heat and power ones are credited with energy savings, new generation being "subtracted from the overall demand for electricity to be met by the generating stations attached to the grid. The use of the electricity from the CHP [combined heat and power] plants shows up as increased energy efficiency…" (Barker et al. 2005, 25) ES/INFRAS speaks of electricity "saved, i.e. substituted". (2004, 4) The assumption that an equivalent number produced by fossil fuels is taken from the grid is however gratuitous.[7]
4) Non-technological *consumption efficiency* (*Glossary*)[8], e.g. a policy educating drivers to drive more fuel-efficiently, is evaluated by multiplying the number of pupils by an "energy savings specific to the course", saving e.g. 150 TJs annually. (ES/INFRAS 2004, 10, 76) The income effect or resulting money savings raises demand, however (*Section 2.4*), and these joules, as well, should not be counted one-to-one as 'saved'.
5) Evaluations universally ignore the possibility that higher operating efficiency can contribute to the emergence of new products (*Section 4.7*).

2.3 Macroeconomic Energy Consumption

The engineering computations predict, *ceteris paribus*, total energy consumption *lower than* a baseline or 'trend' consumption without policies, based on history and adjusted for assumptions about "growth factors" like population and end-product consumption as well as for tax policies, prices, and general "growth effects". ES/PROGNOS for instance, after adjusting for policy effects themselves, observes *actual* energy consumption increases, e.g. of 19.7 PJs for 2002-2003, "…96% of which are explained by the model-supported analysis." (2004, 1-2, 10-11, 20-22) That is, in the face of

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[7] Similarly, new wind energy installations are erroneously said to 'save' about 2,250 tonnes of CO_2 per megawatt.

[8] See Hannon (1975, 96); Etzioni (1998, 630); Prettenthaler & Steiniger (1999); Norgard (2006).

divergence between actual measured levels of demand and engineering computations, not all engineering savings could be realised due to countervailing growth forces: “Human impacts on the environment are a race between economic (and population) growth and efficiency improvements.” (Levett 2004, 1015; Binswanger 2001, 120) The theoretical paradigm sets the trend or reference path based on exogenous growth variables like “population” (Schipper et al. 1996, 188) or a rising background “level of aggregate activity”, *counteracted* by falling “energy intensity” (Schipper & Meyers 1992, 58-60; *Chapter 5*). For Besiot & Noorman, “although… appliances become more and more energy efficient, volume growth… [e.g.] population growth, number of households, household size… still outweighs efficiency gains…” (1999, 375-377)

For instance, SwissEnergy’s assessment of its own “strategy of energy efficiency and renewable forms of energy” first presents the “energy-saving effects” of each policy. (2004, 3, 4, Fig. 10) Then after summing these engineering savings it laments the trend of “increasing traffic volumes and heated surface areas in buildings, and the appearance of ever more and ever larger appliances, equipment and vehicles on the market.” (27) Based on these two independently computed magnitudes, the document concludes that “Without Energy 2000 and SwissEnergy energy consumption in Switzerland would probably be around 6% higher” than actual consumption….” (22, 29, Figs. 12 & 13; ES/Prognos 2004, 25, 27-28) Duchin & Lange use this template to calculate *world* energy consumption. (1994, 48, 92-96, 159-164[9]; Schipper & Grubb 2000, 368; CEPE 2003, 6, 24, 36, 46) This method of “estimating real policy-induced savings” is no longer “bottom-up” but rather “top-down: On the basis of official statistics of actual energy consumption the

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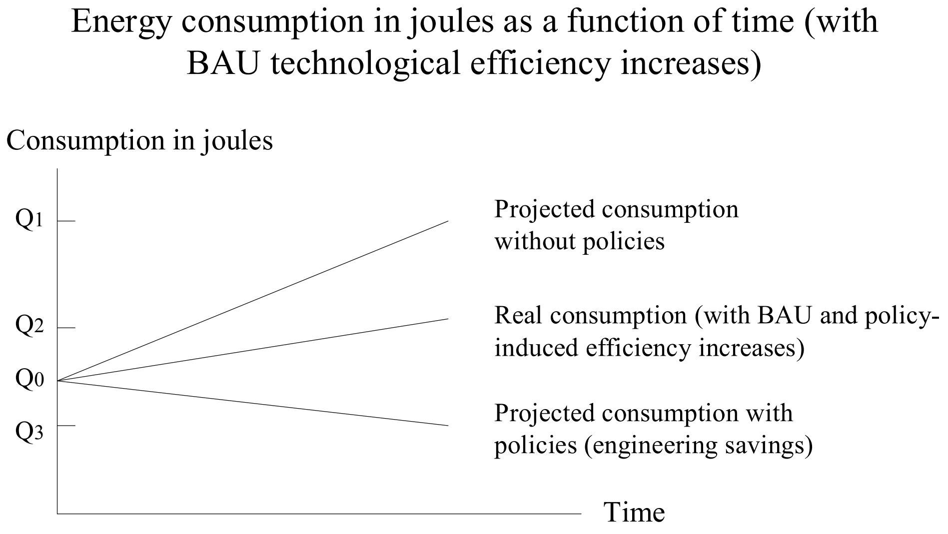
[9] Their study for the transportation sector “…assume[s] that the fuel mix will remain unchanged but that an improvement in the average fuel efficiency of the fleet of 50 % is achieved by 2020… We assume that the number of motor vehicles per capita and the number of miles driven per vehicle in most developed countries remain fairly stable, with an expansion between 16 %… and 450%.. in vehicles per capita in developing countries.” (55)

influence of policies is determined, after deducting a roughly estimated reference scenario." (ES/INFRAS 2004, 6)[10]

Figure 1 shows the effect of efficiency policies on total energy consumption assuming rebound = 0.

Figure 1: Consumption with and without policies



Holding growth drivers unrelated to efficiency constant, Q3 results if rebound = 0. Q2 is actual measured consumption. With various growth drivers Q1 results, a historical trend based on growth factors opposing the alleged shrinkage effects of efficiency.

Only the middle line (the *explicandum*) and engineering savings are real measurable quantities. The top line is the hypothetical or predicted consumption change without government intervention; seen after the fact it is the counterfactual, what consumption would have been without policies. The bottom line is consumption change with efficiency policies but without growth drivers, i.e. with no change in number of products and services demanded. The difference between the bottom and middle lines is explained either by growth forces stronger than efficiency-induced 'savings' or by the opposite thesis, namely that efficiency gains lead to higher input consumption. If

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[10] The "deduction" is of the growth effects from what *would have been* realised with full engineering savings.

engineering savings equal real savings, Q_2 minus Q_3 should equal Q_1 minus Q_2. The middle line could, theoretically, slope downward ($Q_2 < Q_0$).

In terms of kettles, Q_3 results if we hold output-consumption (number of kettles/kettle-uses) constant *after* the change to more efficient kettles. Q_1 results from more kettles and/or more kettle use; if this growth is large enough, even at the new lower input-output ratio input-joule consumption *rises* (Q_2). The top line in effect holds *efficiency* constant while the *number of output units* increases, giving Q_1. The top line, based as it is on historical experience, slopes upward and includes the business-as-usual (BAU) efficiency increases occurring daily as input cost-cutting of firms, governments and individuals (Brookes 1978, 94), but here again this is interpreted by efficiency strategy theory as being in conflict with growth forces; the top line would be even steeper without BAU efficiency gains. In any case, *real savings* is allegedly Q_1 minus Q_2 (SwissEnergy 2004, 22-24), while Jevons' theory holds $Q_2 > Q_1$. Including *BAU efficiency increases* increases the gap between Q_2 and Q_3.

The efficiency strategy's macroeconomic case is strong if *actual* consumption falls over time in comparison to the baseline trend: policy-induced (but not BAU) efficiency increases could be an explanatory variable alongside consumer satiation and structural change (the shift to less energy-intensive sectors (*Section 3.4*)).[11] For instance, SwissEnergy can argue that "…the consumption of combustibles was more or less constant despite an increase in the overall energy-relevant heated surface area by 1.2%, and this points to additional efficiency gains." (2004, 23) If on the other hand real, measured levels of consumption increase, the more so *at an increasing rate*, the efficiency strategy has a more difficult task: the postulated growth forces must be all the stronger the more clearly they win the 'race'. If they decrease or increase at a *decreasing* rate, however, Jevons' theory must counter the suggestion that this is due to greater technological efficiency.

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[11] At the world scale of investigation the structural argument reduces to the saturation one.

Policy evaluation methodology is based on theory. All relevant literature acknowledges this and speculates on what 'would have been' – 'otherwise' – without them. (Alcott 2005, 11, 16) How would consumption have developed in all energy-using sectors without this improvement in the joule/GDP ratio? Evaluations universally assume that efficiency increases of any provenance *ceteris paribus* lower energy input consumption, i.e. register negatively. Jevons' theory observes that Q_2 is higher than Q_0 and takes efficiency increases as one of the causes of this, on the theory that input costs are in aggregate lower, enabling new demand for outputs requiring energy inputs.

2.4 The Economic Effects of Efficiency

Does actual consumption then rise *in spite of* efficiency increases or (partly) *because of* them? The International Energy Agency writes, "Without efficiency gains energy demand would today be half again as high" as some earlier time. (NZZ 2005, 21) A seminal theoretical model including BAU efficiency increases (which are arguably much larger than policy-induced ones) first assumes a "constrained case", scenario 1, with "zero percent autonomous energy efficiency improvement (AEEI)" and then a "high efficiency case… an AEEI of 1.0% per year. By comparison with scenario 1, energy demands in 2050 would be nearly halved…. By definition, no consumption losses are imputed to AEEIs." (Manne & Richels 1990, 72) This dissertation examines Jevons' alternative template, namely that technological efficiency increases, because they cheapen energy inputs, are a *necessary condition* for consumption growth; if this is true, then the methodology of evaluations is based on false assumptions. Is Jevons' model plausible?

If we cease holding the number of consumed products (or their use) constant, input engineering savings and input real savings can no longer be equal. Based not on the macroeconomic correlation between rising efficiency and rising input consumption (*Chapter 6*), but rather on the price consequences of an efficiency-induced fall in demand, one of the two initiators of today's debate wrote:

> Unfortunately, the estimates of energy savings predicted to result from these mandated standards are derived mechanically…[with 'one

> exception’]. When mandated standards raise the appliance efficiency by 1 percent, demand is expected to drop by 1 percent;… Examples of such results are found in reports by the [US] Department of Energy… and by the Staff of the California Energy Commission… These calculations overlook the fact that changes in appliance efficiency have a price content. (Khazzoom 1980, 21-22)

The two questions of this dissertation can now be re-stated:

- Do real savings equal engineering savings? If not, evaluations and the theory underpinning them overestimates the effectiveness of efficiency policies.
- If the technological changes, *ceteris paribus,* cause new consumption of the goods affected by the higher input efficiency (and/or other goods), what is the size of this newly released consumption? Could higher consumption of the newly more efficiently used *input* therefore be even higher than before the efficiency change – a policy “backfire”? (Khazzoom 1980, 23)

While *rebound*, in accordance with the literature, is any consumption caused by efficiency increases, expressed as a percentage of *engineering savings* with 100% sometimes called ‘unity’, rebound greater than unity is *backfire.*

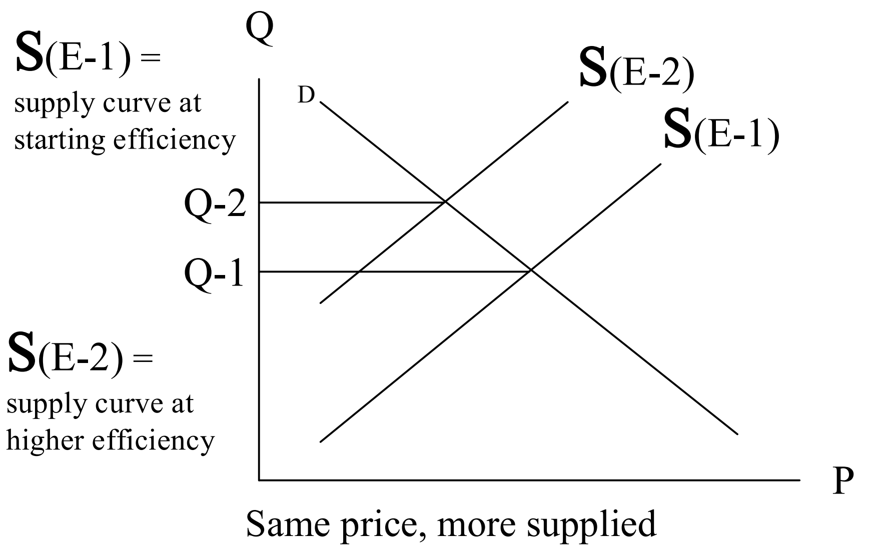
The rigorous argument is presented by Khazzoom (1980, 22-23), Wirl (1997, 31), Birol & Keppler (2000, 460-463), Schipper & Grubb (2000, 369-370), and, below, Binswanger:

> If technological progress makes equipment more energy efficient, less energy is needed to produce the same amount of product or service. However, the amount of product or service usually does not stay the same. Because the equipment becomes more energy efficient, the cost per unit of product or service that is produced with this equipment falls which, in turn, increases the demand for the product or the service. If the energy efficiency of a car is increased by technological innovations, …100 km can be driven with less fuel and, therefore, at lower cost. Consequently, people may drive more and longer distances because mobility… has become cheaper. (2001, 120)

This characterisation describes only *direct rebound* – the greater demand for the product now produced more energy-efficiently (*Section 4.3*) – to the exclusion of further rebound effects which by the same causal mechanism raise demand for related products and by other consumers; in Wirl's words we not only upgrade quality but "the associated increase in the real income allows [us] to raise all kinds of demands including the demand for the service in question." (1997, pp. 41; 20, 26-27, 31) However, computation of total rebound must take into account both new products and worldwide effects. Technically, it must estimate the efficiency elasticities of output price[12] and of energy input price, and then the price elasticities of demand for outputs and energy inputs[13], arriving in the end at the *efficiency elasticity of energy demand* (UKERC 2006, 6-7), formally Δinput / Δinput/output.

Figure 2 shows Khazzoom's depiction of how lower production costs alter the willingness to utilize appliances or cars, even at an unchanged energy-input price.

Figure 2: Lower costs enable a shift in the supply curve



Source: Khazzoom (1980, 24)

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[12] E.g. steel prices fell 80-90% partly due to Bessemer and Siemens-Martin processes and to mechanised labour and factory-floor efficiency. (Landes 1969, 259)

[13] I.e. both supplier and consumer demand functions are needed.

> Q – here unconventionally on the Y axis – is the “utilization rate” of the refrigerator or car; the unit is a change in temperature of a given volume of space requiring embodied and utilisation energy.

Any computation of purported efficiency-induced savings, whether autonomous or policy-induced, *must* assume reference quantities under *frozen technology*. If steam engines were still at their efficiency ratios of 1820, how many steam engines would be made, and how often used, per year today? Any ‘trend’ period could someday also appear relatively *inefficient*, as the period 1820-1825 does to us now, yet total consumption of goods then already existing, plus new things, has since then increased enormously.

The possibility thus emerges that engineering savings must be diminished by some factor or coefficient if we are to take account of increased, rebound demand. A correction formally the same as this is now routinely made in deducting from the estimate of the effectiveness of measures those efficiency improvements of capital which would privately have been made anyway (CEPE 2003, 43), showing that engineering tallies are in principle correctable, in our case for the demand generated by either left-over purchasing power or lower producer cost (input prices) with the ensuing shift of the supply function and price decrease.

INFRAS already does this inadvertently in their evaluation of the *employment* effects of efficiency programmes: “Positive effects on employment result… indirectly from the *newly freed spending power* due to the energy savings… Important assumptions of our model are used to estimate the employment-intensity of the investments that are both triggered and hindered by the programmes.” (2000, 2, 3, emphasis added) This ‘income effect’ (*die infolge der Energieeinsparungen freigewordenen Mittel*; *Chapter 4*) or higher material welfare caused by the efficiency increases is said to increase employment, but by the same logic it increases demand generally. (Schumpeter 1911, 283, 301) Even if higher demand is only for labour, the new wage-earners would demand energy. With an elasticity to be determined, and which in turn will determine whether rebound is greater or smaller than unity, consumption goods embodying and using energy are newly demanded.

2.5 The Rebound Coefficient and Conclusion

Twenty years after Khazzoom's complaint this methodological weakness gained some acknowledgment. Schipper & Grubb wrote:

> The potential feedback between energy efficiency changes and the level of energy-using activities has been proposed to result in a general rebound effect. This postulates that since improving the energy efficiency of end-use technology (e.g. lighting) will lower the cost of the energy service it provides, consumers will tend to increase their demand for that service, offsetting the apparent savings that an engineering calculation would suggest." (2000, 369)

Empirical studies of the 1980s and 1990s established a 20 – 50% "direct" rebound effect, i.e. for the same good or 'service'. (Greening et al. 2000)

One correction for rebound is in the evaluation of UK home-heating efficiency measures, where lower fuel bills allow heating more, a rebound called "comfort taking"[14] in departure from the scientific literature and moreover inaccurate because it applies to home heating only:

> the uptake of such measures may not lead to the equivalent reduction in consumption as householders may reap the benefits as increased comfort. This is accepted and allowed for in the Defra calculations, which allow around 50% rebound in all low income households and 15% elsewhere. Preliminary evidence… indicates that rebound effects may be small in homes which were adequately heated beforehand, irrespective of income." (Defra 2002, 4)

4CMR likewise modifies engineering ("expected") savings by an "exogenously" incorporated *direct* (*Section 4.3*) rebound coefficient ranging from 0 to 75%. (2006, 5, 12, 21, 23, 35, 72-75) Finally, one assessment indirectly acknowledges the principle by remarking, "…calculations [of the Expert Group…] do not include the rebound effect." (EEB 2000, 32)

Similarly, the NRC (2002) in assessing the effectiveness of Corporate Average Fuel Economy standards writes:

> Allowance is made for the 'rebound effect'; that is, there is a small increase in miles driven as fuel economy increases. [The CAFE] policy instruments lead to increases in fuel economy of new vehicles and thus decrease the

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[14] This quaint term departs from the scientific term 'direct rebound' and moreover applies only to home heating. (also 4CMR 2006)

> variable cost per mile of driving. This, in turn, encourages consumers to drive more…. [A] 10-percent increase in fleet economy can be expected to lead to a 1-percent to 2-percent increase in Vehicle Miles Travelled. The net impact would be an 8-percent to 9-percent reduction in fuel use for every 10-percent increase in fuel economy….” (sections 4 – 1 and 5 –24-25)

This corrects engineering savings by 10 to 20%.

In contrast, an assessment of an evaluation [INFRAS 2002] of Swiss efficiency policies takes engineering savings throughout at face value. (CEPE 2003, 6) Two of its assessment criteria are of interest, namely whether the definition of the reference assumptions is adequate, and whether account is taken of suppliers’ hiking up prices to take advantage of subsidies for consumers (*Preismitnahmeeffkete*). (32, 35) As to the first, it accepts as exogenous the usual parameters of space heated, number of new vehicles and appliances, industrial production (44) or “business cycle and structural effects” (56). As to the second, they implicitly acknowledge that while increased purchasing power has resulted, it is appropriated by *suppliers*. Given that by the year 2000 a consensus on the presence of at least some significant direct rebound had been reached, this 2003 study missed an opportunity to note that the reference scenario was *not* necessarily too high and that *some* growth stems from efficiency gain itself.

Statements quantifying energy savings should be taken with a grain of salt. If assumptions are challenged, it must be demonstrated that any savings are achieved at all. At the very least, quantifications of the size of purported savings are overestimates; taking rebound = 0.5 would for instance halve them, with consequences both for judging effectiveness (or distance from policy target) and cost-effectiveness. Whereas Defra in 2005-2006 commissioned studies of the rebound effect, the UK energy department’s Energy Review ignores it, presenting “savings” measures as if technological changes in the average stock of houses, appliances, vehicles, power plants, etc. has no influence on energy prices or consumer demand. (DTI 2006, 36-60, 149)

The debate has led to a consensus that rebound is significant. One new UK study (Allan et al. 2006) concludes that in contrast to the “conventional wisdom” which equates engineering savings and real savings,

> …where substantial across-the-board energy efficiency improvements are being pursued, future evaluation work [should adopt] an approach which allows the system-wide effects of efficiency improvements to be assessed (7, 53)… Our own empirical analysis suggests the likelihood of significant rebound effects in response to system-wide changes in energy efficiency (of the order of 40%) for the UK as a whole…. Our work shows that energy efficiency measures would generally be expected to generate a less than proportionate fall in energy use (rebound), and may actually stimulate its use (backfire). (3, 51)

It is too early to judge whether the policies have an (albeit reduced) effectiveness, or are counter-productive, but a coefficient to adjust engineering savings – perhaps 0.5 – would be far more accurate than not adjusting at all.

Chapter 3 Policy Context

3.1 Introduction

This chapter relates the *technological efficiency strategy* to other environmental policies, using a taxonomy suggested by the identity $I=PAT$: environmental Impact equals Population times Affluence times Technology. After defining these terms it will be shown that the right-side factors are interdependent, i.e. whether any given right-side policy succeeds in lowering environmental impact is contingent upon its not influencing other right-side factors in ways that raise impact. Thus the form $I=f(P,A,T)$ is more accurate. The question of the relevance of *ratios* to *absolute* impact leads into a discussion of the environmental Kuznets curve (EKC). Finally, the assumption of consumer saturation is stated and evaluated.

3.2 The Efficiency Strategy

The *efficiency* policies here examined are just one type of energy policy, namely that serving environmental goals of less pollution and less resource depletion by enabling the same economic benefit[15] with less input. Other environmental measures seek to substitute away from particular pollutants such as carbon dioxide or fine particles, while other strategies employ consumption caps, quotas, ambient standards, subsidies, and taxes to cut consumption or internalise externalities. Non-environmental energy measures can serve supply security or supply sufficiency at politically acceptable prices.

Energy *efficiency* policies seek to lower two types of societal *costs* of energy consumption: ‘source’ costs of depletion of non-renewables, overharvesting of renewables and usurpation of space, and ‘sink’ costs of negative emissions to

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[15] The stipulation that these policies not reduce affluence is explicit in the paradigmatic ‘factor four’ program to double economic welfare while halving resource use. (von Weizsäcker et al. 1997) Indeed, efficiency is arguably a tool to rescue maximum affluence within some ecological limits rather than a tool to remain within those limits.

air, water, soil, and other species.[16] If society's welfare function is such that these outweigh the *benefits* of consumption, at a given *level* of costs, the goal is consumption/emission *reduction* as opposed to correction of negative *externalities* or increasing affluence; the welfare-economics concept of externalities is unnecessary to justify the strategy because even if all costs were efficiently and justly allocated intragenerationally, they could still be too high in terms of a cost/benefit analysis constrained by strong sustainability. These costs are here denoted *negative environmental impact*. A strategy subsumed under *I* would *directly* limit consumption or emissions through source quotas or rationing, while other strategies *indirectly* aim at less harm through energy taxes, substitution of more plentiful or less harmful sources, or (our topic) greater utilisation and embedded-energy efficiency.

3.3 *I = f(P,A,T)*

Microeconomically, lowering the ratio of energy input per unit of output[17] is cost-cutting, but macroeconomically it is a change in the aggregate factor *T* in *I=PAT* (Ehrlich & Holdren 1971; Ekins 1991, 250), an early version of which stated that "resource consumption" equals population times "consumption of goods" (as distinguished from resources) times the technological factor "environmental impact per quantity of goods consumed." (Ehrlich et al. 1973, 206) The authors emphasized the *multiplicative* relations on the right side. In their example of automotive lead between 1946 and 1968, each factor was 1 at the beginning; a population increase of 42% (1.42) multiplied by a per capita consumption increase of 100% (2.00), times a technological worsening (use of lead per kilometer driven) of 81% (1.81) yields an increase of 414% (5.14 minus 1) in Impact. (214)

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[16] Parsimony advises subsuming 'sink' problems under the further 'source' problems of the (over-) *consumption* of clean air and water, good soil, etc. Exceeding 'sink' or 'absorbtion' capacity is then equal to overconsumption of 'sources'.

[17] Unlike most analyses (e.g. Wirl 1997; Binswanger 2001; UKERC 2006), 'output' is defined physically, e.g. as the artificial light in a room rather than either the 'service' of 'lighting' or its monetary value in GDP (*Sections 6.3 & 6.4*).

This taxonomy embeds the efficiency strategy within *T*, the low-affluence 'sufficiency' strategy[18] within *A*, the population strategy within *P*, and the direct 'left-side' strategies of taxes, quotas, and rationing within *I*, the former two being ratios and the latter two absolute (or ambient) numbers. *T* also subsumes *economic* efficiencies (Smith 1776, III.ii.20, IV.i.37-45, IV.ix.17), here termed *organisational* efficiency since its locus is human groups, including "economies of scale, trade, education, legal security, property rights, low transaction costs, Taylorite factory-floor measures, management hierarchies, etc." (Alcott 2005, 10; Solow 1970, 33-34; Greenhalgh 1990, 293; Sanne 2000, 494) Rebound afflicts all types of efficiency as well as sufficiency: by incrementally lowering demand and depressing price, marginal consumers are enabled to take up the slack[19]. (Inhaber 1997, xii)

Impact is the 'bad environmental side-effect of consumption', defined ostensively by Spangenberg & Lorek as climate change, ozone depletion, acidification, eutrophication, biodiversity loss, soil erosion, inland water degradation, waste problems, health risks, and depletion of natural resources. (2002, 133; Turvey 1966, 48-49; Ekins 1991, 244) Energy-use impact is described by Smil. (2003, 105-116, 339-349) Elaborations on *IPAT* include the *STIRPAT* or "stochastic impacts by regression" model measuring "ecological elasticity" which, however, does not "discuss the technology elasticity of impact because there is no single operational measure of *T* that is free of controversy." (York et al. 2003, 355; *Section 6.5*) This and other models are consistent with the model of right-side interdependencies presented here. (Swaney 1991, 504; Durham 1992)[20]

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[18] 'Living sufficiently' instead of luxuriously is different from consumer efficiency (*Section 2.2.3*); instead of boiling only the amount needed in the kettle, one goes without the coffee.

[19] 'Slack' results as the demand function shifts to the left, intersecting the supply function at a lower price and thus causing new demand by *other* consumers.

[20] The 'Kaya Identity' specifically takes Impact as carbon emissions and Technology as primary energy input per GDP unit times carbon content per energy unit. (Nakićenović 1997, 272-273).

Consumption (C) equals $P \times A$, the number of consumers times the amount of consumption *per* consumer, yielding $I = C \times T$, i.e. consumption modified by technology either in terms of *what* gets consumed (e.g. more benign hydrochlorofluorocarbons instead of chlorofluorocarbons (Gardner & Stern 1996, 12-14, 19)), or *how much* gets consumed (per good or process) of an environmentally relevant substance (like fuel) – this dissertation's topic. *Consumption* is physical rather than monetary or 'utilitarian' (*Chapter 6*)[21] yet normatively ambiguous: for example energy is a *good* giving life and affluence, yet the same energy is the *bad* of *impact* (depletion and pollution). As impact, it is the process of "using up" rather than the ambiguous 'use' – in accordance with Princen (1999, 355) and in contrast to Ayres (1978, 57) – and in agreement with its Latin sense of 'taking with' or *destruction*, being something to be minimized (Boulding 1949).[22]

Since this dissertation's *explicandum* is *amounts* of consumption, the terms *size* or *scale* – often 'of the economy' or of 'economic activity' or just GDP – will be used; crucial from an environmental viewpoint is this scale *relative to* the ecosystem (Boulding 1966). In line with Daly's (1992) differentiation between economic issues of allocation, distribution, and size, concern with size replaces the classical, welfare-economics and environmental economics concern with distribution of costs and benefits among economic actors. (Ricardo 1817, § 1 & 2; Pigou 1920) In terms of the ecological footprint metaphor, the motivation for studying the rebound question is that the "ecological footprint" (Wackernagel & Rees 1996) of the world economy is larger than the world (Aubauer 2006).

Figure 3 shows in time series how quantities can be inserted into *I=PAT*. The 'T' column shows that the technology of this economy determines the *efficiency* or ratio of tonnes of coal needed to produce an amount of a

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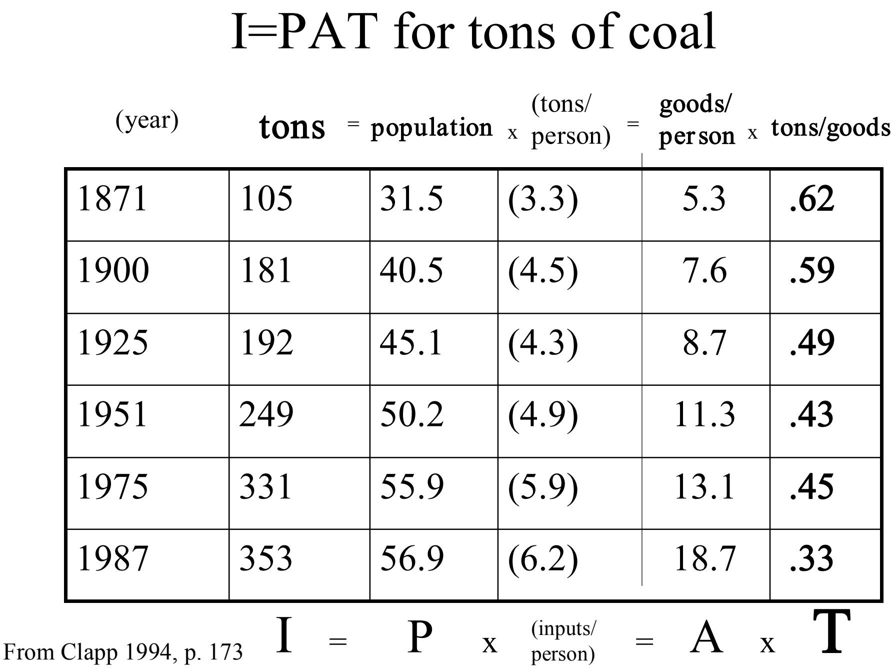
[21] This follows Smith (1776, I.viii.21, I.xi.I, II.i.28), Say (1803, 38, 62), and Malthus (1820, 28).

[22] Since however matter/energy cannot be destroyed, the definition of consumption requires anthropomorphic qualification in terms of availability, usefulness and waste. (Ayres 1978, 43-44, 119-120; Alcott 2004, 6-12)

composite good including cars, driven kilometres, air-conditioned driven kilometres, etc. (also Schurr & Netschert 1960, 64)

Figure 3: Total impact co-determined by the technology determining input by weight per good



I=PAT for tons of coal

(year)	tons =	population x	(tons/ person) =	goods/ person x	tons/goods
1871	105	31.5	(3.3)	5.3	.62
1900	181	40.5	(4.5)	7.6	.59
1925	192	45.1	(4.3)	8.7	.49
1951	249	50.2	(4.9)	11.3	.43
1975	331	55.9	(5.9)	13.1	.45
1987	353	56.9	(6.2)	18.7	.33
From Clapp 1994, p. 173	I =	P x	(inputs/ person) =	A x	T

In reduced form, *I=PAT* is false in implying that right-side changes necessarily change the left side. While this is true *ceteris paribus* as an aggregate, static description, the form *I=f(P,A,T)* describes the dynamic interdependencies resulting from economic behaviour, right-side changes impacting on other right-hand factors, rendering change in impact *contingent*.

[b8]

- an additional inhabitant lowers average consumption: *A=f(P)*
- higher affluence influences desired and possible family size: *P=f(A)*
- as population rises, diminishing returns to ‘land’ lead to more efficient technologies: *T=f(P)*
- as affluence rises, more investment is made in research and development: *T=f(A)*
- technology in agriculture, sanitation, medicine and energy efficiency – all regarded as exogenous – enable a higher population: *P=f(T)*
- technologies using electricity enable higher affluence: *A=f(T)*

E.g. if farm efficiency (*T*) causes population (*P*) to rise, affluence (*A*) and impact (*I*) may well stay the same. The term 'enable' indicates that in all examples something *hitherto impossible* becomes possible, and is used rather than 'cause' because the bivariate changes are also *contingent*.

This dissertation treats the last two interdependencies: How do technological efficiency increases affect affluence and population? (Reijnders 1998, 17) What is the magnitude in physcial, i.e. environmentally relevant terms, of the rise in consumption (*A x P*) enabled by falling energy intensity and the concurrent fall in energy price, resp. increase in purchasing power? In the words of Pigou, for whom "national dividend" signified total consumption or economic scale: "All developments of this [efficiency-raising] kind, since they enable something to be produced which was not being produced at all before, or enable something which was being produced before to be produced more easily, must increase the national dividend." (1920, 671)

3.4 Ratios

The targets of the efficiency strategy, such as less electricity per light bulb or lumen, are *ratios* symbolised by T_E. Numerators or inputs[23] are to be lowered *relative to* denominators or output, whose size is free to grow or shrink. But because efficiency is a **ratio**, it "doesn't save energy except under conditions that also limit increases in production." (Moezzi 2000, 525) *Total* quantities are thus untouched by the policies, which alter only either less input (here *fuel*) for the same output, the same input for more output, or more input but even more output. While lower numerators diminish T_E (as the sufficiency strategy diminishes *A* in aggregate average terms), so also do *higher* denominators – in the case of *T* more produced goods and in the case of *A* more consumers. There is therefore no necessary link between improved

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[23] I have chosen the numerator for input in order to remain consistent with 1) the phrase 'input/output', which is *intensity*, the inverse of *efficiency* (see *Chapter 6*) and 2) the term *T* in $I = f(P,A,T)$ wherein raising efficiency is hoped to be a lowering of *T*.

efficiency or lower affluence to lower consumption or impact. (Dahmus & Gutowski 2005, 2-3; Lantz & Feng 2006) Just as falling affluence leaves impact unchanged if population accordingly rises (Malthus 1798, 79, 119)[24], falling energy intensity leaves impact unchanged if consumption proportionately rises. Dividing *T* by 2 does not *ipso facto* halve *I*. Analogously, policies requiring electricity producers to use renewables in some *percent* of total output say nothing about the number of joules generated by fossil fuels. (*Section 2.2.3*)[25]

Khazzoom's analysis assumed *any* positive price elasticity of demand, however small. (1980, 22) The slopes of these functions determine whether rebound is less than or greater than one, but we cannot *derive* slopes from other ratios. While *some* rebound is a theoretical certainty, its size is a difficult empirical question. An "efficiency shock" changes physically expressed input-output ratios (Allan et al. 2006, 5), and two other ratios stand between this and final input-consumption change: that of efficiency change to price changes (of either the products comprising output or of energy inputs themselves), and that of price changes to demand change. That is, we seek the *efficiency elasticity of demand*. (UKERC 2006, 5) How do these intensive, dimensionless quantities transform into the extensive quantities of environmental interest?[26] The next section examines a similar relationship between the ratio of income per capita and (absolute) environmental impact, namely the claim that while engineering 'savings' *can* be eradicated by

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[24] Correlations between *P* and the left-hand factor have been computed, e.g. Shi's (2003) finding that a 1% rise in *P* causes a 1.42% rise in global carbon dioxide emissions. (also Raskin 1995)

[25] Classical economists similarly worked on 'getting from' the wage *rate* (ratio) to absolute quantities of hours worked, population size, and consumption. (McKinley 1960, 92-96) A later challenge is the relationship between labour productivity and the size of the economy. (Rosenberg 1982, 23, 55)

[26] Malthus castigated Ricardo: "But, to estimate rent and wages by the *proportion* which they bear to the whole produce, must, in an inquiry into the nature and causes of the wealth of nations, lead to perpetual confusion and error." (1820, 164; 170, 175, 211)

greater consumption, the extent of their eradication depends on income levels.

3.5 Saturation of Demand

The environmental Kuznets curve (EKC: an inverted U-shaped curve with GDP per nation or per capita on the X axis and environmental impact on the Y axis) is relevant because 1) the problem of deriving absolute quantities from ratio changes is the same in both discussions and 2) one condition for low rebound is consumer saturation, and the EKC hypothesis posits either consumer saturation (declining marginal utility) or structural change to less material intensity as a function of income above a level that may or may not be sustainable. If the marginal consumption triggered by the price or income effects of efficiency (*Section 4.3*) is somehow less energy intensive, the efficiency elasticity of input demand is lowered. The results of EKC studies are here ignored[27] in favour of this conceptual question and the methodological problems of the axes' metrics.

Again, if the independent variable is per-person or country-average purchasing power and if the dependent variable is an amount such as total tonnes of carbon dioxide in the atmosphere, causal influence is contingent on the size of the denominator, in this case number of persons. The further problem is that often the dependent variable is *not* calibrated as an absolute number using a measure such as volume or weight, or an ambient measure such as weight or parts per m^3 but rather as pollutant or 'impact' *per capita* or *per unit of output* (often GDP); some studies use both. When the former[28], some 'indicators' of environmental degradation show the inverted-U shape (usually in rich countries rather than the world) whereas others rise monotonically. When the latter[29], practically all show this shape. This

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[27] Studies of UK 'energy intensity' routinely ignore air travel! (Fawcett 2004, 1080)

[28] Absolute metrics are *inter alia* in parts of Shafik & Bandyopadhyay (1992), Selden & Song (1994), Shafik (1994), and Grossman (1995).

[29] Relative metrics are *inter alia* in parts of Hettige (1992), Panayotou (1993), Selden & Song (1994, 148, 151, 157), Shafik (1994), Grossman (1995), and Holtz-Eakin & Selden (1995).

ambiguity is fatal to clear discussion of affluence's effect on total impact and, since efficiency influences affluence, to our question of efficiency's effect on total consumption.

Moreover, imprecise metrics abound, such as 'environmental impact', 'some measures of environmental quality', 'some environmental indicators', or 'pollution levels'. (e.g. Birol & Keppler 2000, 458-459) Efforts at clarity are Jänicke et al.'s differentiation between "absolute [and] relative structural improvements" (1989, 30, 32)[30] and Opschoor's (1995) and de Bruyn & Opschoor's (1997) distinction between "weak" and "strong" dematerialisation, the former denoting merely *per unit* decrease as of a certain empirically determined level of purchasing power. Honouring this distinction definitely weakens the broad hypothesis that at high average incomes absolute or ambient impact falls. (266) In any case, studies with ambiguous or relative Y axes are thus *misleading* because many indicators of pollution and depletion rise absolutely while falling relatively (Herman et al. 1989, 50), a further instance of the lack of logical connection between ratios and extensive quantities.

Radetzki & Tilton, whose "intensity of use" hypothesis that *metal* consumption can be predicted from per capita income (1990, 26-29) was the 1970s forerunner of the EKC, thus doubt the EKC hypothesis:

> Material substitution, new technology, and other factors, may also influence intensity of use…. [and] are discrete events that occur at regular intervals. Their number, speed of adoption, and ultimate impact on metal use [consumption] in specific applications vary greatly in response to a variety of factors, including the opportunities they provide for reducing costs and *expanding markets*…. The development of the aluminum beverage can, for example, increased the intensity of aluminum use in the United States." (28, emphasis added)

Also applied to energy, such 'structural change' isn't necessarily dematerialisation. "All production requires matter and energy, including the

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[30] Also in Grossman (1995, 34), Holtz-Eakin & Selden (1995, 98), Torras & Boyce (1998, 149, 167), Johnson (2001, 742).

production of labour and capital." (Young 1991, 172) Yet this is assumed for instance in the seminal contribution to the rebound literature of Schipper & Meyers, who held the "structure" of economic activity sectors (agriculture, industry, service) to be one of three major determinants of energy consumption. (1992, 58-59) The concept of structure here however reduces to the concept of "energy intensity": a *sector's* energy intensity – a dimensionless number – is said to determine total consumption. However, this chapter has tried to show that for this chain of reasoning to hold – for marginal consumption to necessarily be less energy intensive in aggregate – *saturation* (i.e. one explanation of the EKC hypothesis) must hold, under the debatable premise that, like Adam Smith's stomach (1776, I.xi.c.7), a human life can handle only so much energy throughput.[31] Structural change is irrelevant, especially if e.g. energy consumption remains constant or even grows a bit while further income and expenditure raises utility to higher and higher levels: the issue is *saturation*. Efficiency improvements thus lower consumption marginally only if material saturation obtains, and this can be established, if at all, only empirically.

The relatively strong case of the EKC hypothesis *against* high rebound/backfire thus identifies two kinds of consumer saturation: 1) The nature of utility functions could be such that marginal expenditure is less energy intensive – marginal "consumption desires" are satisfied with lower energy inputs. 2) After consuming more efficiently, we can do absolutely nothing, i.e. choose leisure or non-consumption. (*Section 4.3*)[32] However, the EKC concept of (the ratio of) 'dematerialisation' is ambiguous: while it is, in one sense, identical to resource efficiency increase as understood in the debate over technological efficiency gains, it is here the dependent variable. In the strictly technological sense, though, it is the independent variable. Thus the claim that rebound is low because of structural change to greater efficiency (Schipper & Meyers 1992, 59-60; Berkhout et al. 2000, 425) begs

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[31] A large literature doubts this. (Alcott 2004)

[32] Worldwide saturation seems best ignored for the next century or so given the human tendency for display consumption and the poverty of over 3 billion humans.

our question. Finally, the argument that efficiency-induced *structural* change lowers consumption is reducible to a claim about consumer *saturation* (*Section 4.3*).

3.6 Conclusion

Comparing *I=PAT* and *I=f(P,A,T)* sheds light on why this issue is called 'Jevons' *paradox*'. As a static description the former holds: a system with lower *T* (greater efficiency of any sort) also has lower *I*. If we respect the consumer, i.e. Jevons' "natural laws which govern… consumption" (1865, 25), we conclude that production functions alone settle nothing. Including consumer behaviour brings in dynamics and psychology; the economic version contradicts the engineering computation, which is therefore insufficient to guide policy. A broader formal lesson for the rebound discussion is that dimensionless numbers say nothing about absolute quantities of environmental interest, because ratio reductions enable both less or more consumption. The EKC hypothesis' statement that economy-wide, as income per person grows, resource consumption falls – either absolute or per person – seems to not only lack inferrential power but to beg questions of consumer demand as a function of small-scale efficiency changes.

Chapter 4 Microeconomic Methodology

4.1 Introduction

Empirical rebound studies start with the event of a technological efficiency increase, then investigate change in demand for the newly more efficiently provided good or service. Then, with efficiency coefficients for any input, input demand is derived for this good or service *only*, yielding *direct rebound.* This chapter attempts clearer definitions and taxonomies of rebound effects, relying on Khazzoom's description of a shift in the supply function for the utilisation of newly more efficient household appliances. It identifies the system boundary problem of investigating only certain sectors and countries to the neglect of other extant sectors, new products or sectors, and the global economy, ending with a criticism of Greening et al.'s influential survey of empirical studies.

The backfire debate to date lacks clear terminology and taxonomy of the effects of efficiency increases. For the microeconomic concept of 'engineering savings', for instance, although precisely defined, other terms abound like 'technical energy conservation potential', 'benchmarking', 'energy efficiency improvement potential', 'calculated savings', 'changes from an engineering point of view', 'gross saving', 'technical computations', 'initial benefit', 'potential dematerialisation', and even – begging the question – 'energy conservation'.

For the quite clear term 'rebound' one encounters 'comfort taking', 'takeback', and 'feedback', and for rebound greater than 100% of engineering savings not only 'backfire' but also 'boomerang', 'very large rebound' and "'rebound effect" writ large" (Ayres & van den Bergh 2005, 100). Rebound taxonomies include the categories 'direct', 'indirect', 'own', 'primary', 'conventional', 'secondary', 'respending', 'narrowly defined', 'producer side', 'substitution', 'structural', 'transformational', 'income', 'direct price', 'price', 'composition', 'output', 'sectoral', 'first-order', 'first-cost', 'Jevons', 'general equilibrium', 'overall', 'long-term', 'short-term', 'economy-wide', 'aggregate' and ‘activity’ effects. Approaches are termed ‘micro’, ‘macro’, ‘bottom-up’, and ‘top-down’.

4.2 The Income Effect

Khazzoom’s analysis (1980; *Section 2.4*) showed that lower fuel input requirements for a unit of fuel-requiring output, holding prices constant, mean cheaper unit output prices: with a more efficient car, a consumer can drive the same number of kilometres for less outlay. Previous budgets are not used up, i.e. purchasing power is newly created. In effect, the *whole economy* has cut energy costs without raising others, an economy-wide *income effect*. To the extent that this purchasing power is availed of, new demand appears for further output which itself requires some fuel or other energy. The new input demand is *rebound* and is some percentage of the demand reduction that would obtain were none of the new purchasing power availed of (i.e. engineering savings). Economy-wide, output in terms of goods (or ‘services’, but not necessarily money or GDP; *Sections 6.3-6.5*) has risen. Consumption – some combination of population and affluence – is higher. But since input per unit of output fell, consumption of fuel or energy input *could* end up lower (rebound < 1), or higher (backfire).

It is equally true that if smelting becomes more coal-efficient and the amount of metal produced remains constant, demand for coal and its price drop. However, with the higher profits, and assuming competition among smelters, metal prices drop through “underselling” (Mill 1848, 133-134), stimulating demand for metal and indirectly for coal. The “gains of increased productivity have been distributed to consumers by means of price changes.” (Salter 1966, 10; Malthus 1820, 52, 55; Jevons 1865, 8, 141, 156; Berkhout et al. 2000, 426) But even if the new demand raises coal prices to a new equilibrium level equaling the old (Saunders 1992, 135), metal consumption – and perhaps coal-input consumption – is higher than at the abstract point in time just after the technological efficiency increase, again implying some coal consumption greater than engineering savings. That is, once again, society is richer in terms of output. With the same inputs – labour and matter/energy – it has more output. (Birol & Keppler 2000, 461) Purchasing power is once again newly created.

From Brookes' perspective:

> The market for more productive fuel is greater than for less productive fuel, or alternatively… for a resource to find itself in a world of more efficient use is for it to enjoy a reduction in its implicit price with the obvious [sic.] implications for demand. (2000, 355)

In the terms of classical economics, the exchange value of a unit falls but that of the "whole mass" rises. (Malthus 1820, 134-135, 288) (Schumpeter 1911, 283, 304; Rosenberg 1982, 106) Because efficiency is a *ratio* a subtlety arises: Jevons writes, "*Economy* multiplies the *value* and *efficiency* of our chief material." (1865, 156) I take "value" as 'use-value' or the 'whole mass' of the coal *input*, if expressed monetarily not necessarily per unit but as total units times price per unit; "economy" refers to lowering input *per unit* of output, but "efficiency" is closer to "efficacy" as in the Latin *efficare*, to make or to do: the lower ratio means that more can be produced.

One conclusion is that efficiency increases always increase total wealth[33], i.e. entail not only no net cost to society but a profit. (Say 1803, 71, 101, 295) Whether they also reduce input consumption is still an open question. A second conclusion is that while real price reductions of energy inputs could occur, both with or without them purchasing power increases and an income effect ensues, raising demand. Similarly, in the aftermath of *labour-input* efficiency and lower production costs in textiles Malthus observed that "…the whole value of the cottons produced in this country has been prodigiously increased, notwithstanding the great fall in price." (1820, 314; 49) For labour as well as fuel inputs then, some amount of rebound ensues, which in Malthus' view is indeed greater than the labour savings due to efficiency:

> When a machine is invented, which, by saving labour, will bring goods into the market at a much cheaper rate than before, the most usual effect is such an extension of the demand for the commodity, by its being brought within the power of a much greater number of purchasers, that the value of the whole mass of goods made by the new machinery greatly exceeds

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[33] I.e. some combination of population size and affluence.

> their former value; and, notwithstanding the saving of labour, more hands, instead of fewer, are required in manufacture. (281; 192, 287)[34]

The question now arises whether all *efficiency* rebounds are subsumable under the term *income effect,* enabling a more parsimonious taxonomy.

4.3 Rebound Taxonomy

The following taxonomy contains five different ways this freed or created purchasing power (income effect) can be used:

- by the same consumer for the same product
- by the same consumer for a different product
- by a different consumer for the same product
- by a different consumer for a different product
- for leisure, i.e. *all* consumers reduce their purchasing power to a degree proportional to engineering savings.

The first and third categories are the well-investigated 'own' rebound of the product or service, usually called *direct rebound* but often confused with 'rebound', i.e. the generic term. Perhaps deserving of a sixth category is a "substitution" effect, when energy as the now cheaper factor of production (also in home-production functions) is purchased 1) *instead of* other factors and 2) when the other factors are by some definition less 'energy intensive' than that newly purchased. (*Section 4.7*)

Where the 'same' consumer decides either to lower his purchasing power by earning less, thus demanding no more goods than previously, or purchases a good containing or implying less embodied or operating energy, price falls enable 'different' or marginal consumers to demand more, at no cost to themselves. Rebound study must also include 'different' products for cases where demand for the product or process now more efficiently and cheaply available is relatively saturated or price inelastic. Even in the case where engineering savings are fully realised, i.e. even if at lower fuel or car prices nobody drives more, untapped purchasing power (greater income)

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[34] See *Chapter 7* for the classical economists' conclusion that labour-input efficiency clearly resulted in backfire, i.e. greater employment.

remains for other extant or newly invented products. Even with *direct* rebound of 100%[35], if the efficiency elasticity of price is sufficiently large consumers may retain untapped purchasing power. But certainly with direct rebound less than 100%, potential demand for other goods, or the same or other goods by other consumers, becomes effective demand.

Measuring *direct rebound alone* is of little value. Yet Schipper & Meyers seem to advocate just this:

> ...one should examine the energy efficiency of well-defined sectors or end uses,… For refrigerators and freezers there is little, if any, scope for increased utilization. For clothes washers and dryers it seems doubtful that households would use a more efficient device more frequently than an average one. (1992, 55)

The sector is so well-defined that it ignores even larger or more refrigerators and freezers; Greening et al. thus enter for "white goods" a "potential rebound" of zero! (2000, 398) Another aspect is that a non-consumer can become a consumer: If due to efficiency gains razor blades become cheaper and/or better, as happened in the mid-19th century, people shave who did not before. With even cheaper blades, one uses throw-away double-blade razors. And if electricity becomes more efficiently provided and therefore ever more cheaply available, people switch to less energy-efficient electric shavers. Finally, as energy becomes generally cheaper – either per unit (price effect) or using up less of one's budget (income effect) – other things besides shaving can be done.

Taxonomy faces the difficult task of incorporating two criteria. *Who* consumes *what*? One influential study classifies only categories 2 and 4 as "re-spending in general" or "income" effect (which they deem "small"), i.e. excluding what I am calling direct rebound. (Schipper & Grubb 2000, 384) Grubb calls this dimension the "joker… of new demands, rather than the efficiency of meeting existing ones" and sees "increasingly profligate and wasteful attitudes to energy as consumers become richer." (1990a, 239)

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[35] Glomsrød & Taoyuan (2005) and Dahmus & Gutowski (2005) found *direct*-rebound backfire in some sectors, as had Malthus for the cotton industry. (1820, 314)

Categories 2 and 4 are here called ‘indirect’. One similar taxonomy distinguishes sufficiently between “direct” and “indirect” rebound effects, but somewhat vaguely between “indirect” and “economy-wide” effects (which together comprise “macroeconomic rebound”): While the former are said to consist of income and price effects for “other goods and services”[36], the latter are, less precisely, “cumulative impact of numerous energy efficiency improvements throughout the economy.” (4CMR 2006, 4, 9, 51)

Category 5 is a limiting case where our wishes, in aggregate, are satisfied, and we react to lower prices/greater income by working and earning less, taking the efficiency ‘dividend’ as non-consuming leisure. In the search for environmental solutions this emotionally powerful vision has spawned a large literature. (Schor 1992, 1999; Princen 1999, 354; Røpke 1999; Alcott 2004, 776-778) Were this case (zero price elasticity of demand) really to obtain, it would eliminate the interdependency in $I=f(P,A,T)$ between T and A: Lower T leads to higher A only under the *ceteris paribus* assumption of latent consumer demand. (Jevons 1865, 25)

While category 5 excludes marginal consumers by definition, some studies exclude them – and thereby categories 3 and 4 – for methodological reasons that do not imply an assumption of full saturation. Wirl for instance “… excluded marginal consumers… [although] many important energy services are at present consumed by a minority, or a fraction of the households. However, as the efficiency of… an appliance improves, more consumers can now afford the now cheaper service and thus acquires the corresponding appliance.” (1997, 32)[37] Schumpeter captured this process with the doctrine that entrepreneurs’ profits from “new combinations” of productive factors are over time transferred to all members of society. (1911, 297, 301-302, 306)

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[36] It is moreoever claimed without argument that “The indirect effects from individual energy efficiency improvements may be relatively small.” (4CMR 2006, 9)

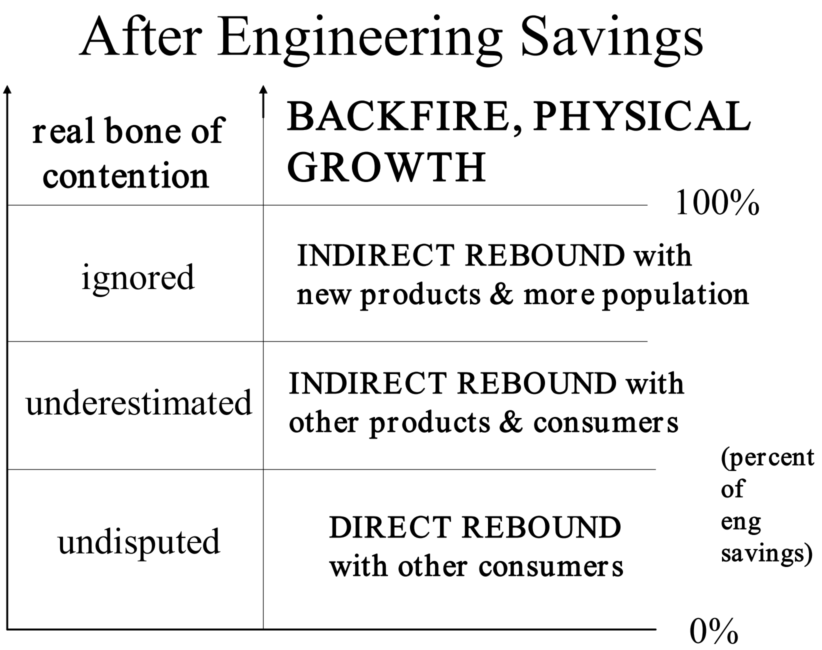
[37] Wirl remarks that this gets around the “conservation [or] energy paradox”, i.e. leads to serious underestimation of rebound. (1997, 19-32, 36, 112)

Thus, the more so because the energy market is global, measuring the first two categories alone is likewise of little value.

4.4 Products, Sectors, Consumers

This dissertation suggests the term *income effect* as a replacement for many of the literature's ptolemaic array of rebound effects including often vague 'macroeconomic' or 'general equilibrium' effects (but see *Section 4.7*). It denotes an economy-wide enlargement of "consumer surplus". (UKERC 2006, 13) Subcategories are direct, indirect (including new products, *Section 4.5*), and leisure effects (category 5). Figure 4 shows how the literature almost universally limits study scope, or 'system boundaries', thus "neglecting openness" (Allan et al. 2006, 18), and underestimating rebound. Research begins at the bottom with efficiency change in a particular process, e.g. kettles boiling water more cheaply.

Figure 4: The task of measuring all (not only direct) rebound effects



The analysis of Owen for instance details "savings due to better insulation and heating efficiency 1995" which "helped counteract" the exogenous growth "of… comfort standards and… number of households", but does not stray from this sector. (2000, 561) That of de Haan et al. (2006) examines rebounds of car-kilometres and second-car ownership among new owners of fuel-efficient cars, but not other parts of demand stemming from the implicitly increased income of those who can now spend less on fuel, for the same amount of mobility, but perhaps more heating their swimming pools. Binswanger therefore conservatively claims that “single-service model[s]… can be misleading.” (2001, 121) The consequences of efficiency show no respect for sectoral boundaries such as those of the International Standard Industrial Classication (ISIC).

Many like Roy attest the difficulty of measuring indirect effects, i.e. “…a whole range of behavioral responses of the end-users that follow any technical efficiency improvement all of which may, however, not be traced empirically.” (2000, 433) Grubb sees after “literally hundreds of scenario studies” the “hopeless complexity” even of comparing “end-use efficiency of hundreds of different processes” (1990a, 235, 195; *Chapter 6*)[38] For Khazzoom the problem is that “price elasticity estimates are not detailed enough to allow us to pinpoint for all end-uses where an improvement in appliance efficiency will result in a net increase in energy demand and where it will result in energy saving.” (1980, 32) But unless all consumer reactions are investigated, we cannot answer our question – and DTI can conclude counterfactually that “Over the last 30 years the economy’s energy intensity… has improved by around 1.8% each year. Without this, home heating, for example, would use more than twice the energy it uses today.” (2003, 32) Did for instance energy intensity have no influence on the number of homes built during those 30 years?

Other income effects result from *organisational* efficiency gains (*Section 3.3*), usually subsumed under ‘Pareto-optimal’ improvements, or from increases in human skill, sometimes regarded as greater human capital

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[38] Howarth calls the “sorting out of the empirical dimensions of the Khazzoom-Brookes hypothesis [an] ambitious task.” (1997, 4) Greening et al. write that “only a general equilibrium analysis can predict the ultimate result of these changes.” (2000, 396; Brookes 2000, 360, 362; Binswanger 2001, 122-126)

efficiency. Similar in effect to discovering higher-quality or more ‘available’ natural resources, these are of net benefit to society economically and universally seen to be growth drivers in physical as well as utility or monetary units – as opposed to technological efficiency gains, which are sometimes said to reduce growth in the physical, material sense.

4.5 Output Quality and New Products

Technological efficiency improvements are easily measured if the *output* stays the same in all respects, aside from input requirements – e.g. an *automobile kilometre* holding weight and other qualities of the car constant. However, car weights, sizes, etc. do change.[39] When cutting-tools change from steel to ceramics to carbide (diamonds), are these new products or just more efficient cutting tools? (Rosenberg 1982, 65) Surely completely new products emerge: the first kettle was perhaps a more efficient version of an open pan, but the first pan, and the first electric current generator, were simply new.

This affects rebound bookkeeping and taxonomy when 1) new products represent new, *additional* demand for some combination of output and energy input and 2) efficiency improvement was a necessary condition for the new product. This is difficult because

> …an innovation from outside will [often] not merely reduce the price of the product in the receiving industry but will make possible wholly new or drastically improved products or processes. In such circumstances it becomes extremely difficult even to suggest reasonable measures of the payoffs [rebound, growth] to the triggering innovation, because such innovations, in effect, open the door for entirely new economic opportunities and become the basis for extensive industrial expansion elsewhere. (Rosenberg 1982, 75)

Therefore attempts to measure more than direct rebound must judge efficiency gains’ contribution to the invention of new things like synthetic fibres or lasers. Early on, Rae observed that invention and wealth reinforced each other: “improvement” in steam pumps suggested new areas of application,

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[39] Sometimes at the cost of greater fuel input, as with heavier or air-conditioned cars, or other material input as when greater boiler efficiency itself requires thicker walls.

namely transportation and milling, while printing efficiency enabled applications for not only reading but for playing cards and coin minting as well as huge numbers of Bibles. (1834, 245-248) But to my knowledge Jevons is the only author to incorporate such efficiency effects into a theory of rebound (Alcott 2005, 13-15), and this area of indirect rebound seems to be outside the remit of current UK studies (*Chapter 1*).

Can examples make this category plausible? Rosenberg gives several: Neilson's hot blast smelting process enabled the use of anthracite coal, turning this fossil fuel into a resource in the first place and causing its consumption. (1982, 23) Henry Maudsley's slide rest for turning resulted in better locks at lower cost, expanding demand for locks and their material-energy inputs. (47) "The compound steam engine had to await cheap, high-quality steel", i.e. smelting efficiency enabled pumps, steamships, and railroads and thus higher demand for steel [and coal]. (61, 157, 187; 1994, 166) More efficient production of fertilisers and subsequent price decline led to an increase of fertiliser and land use as well as food. (75) Balzhiser attests a correlation between declining electricity intensity and a "…continuing stream of new industrial applications [and] new uses for electricity and a continued growth in… commercial sectors…" (Balzhiser 1989, 99; Price 1998, 78-79)

Thus, some of the "…knowledge that makes it possible to produce (1) a greater volume of output or (2) a qualitatively superior output from a given amount of resources" is knowledge of more efficient processes. (Rosenberg 1982, 3-4; Schumpeter 1911, 287-288) On the other hand, while the puddling steelmaking technique turned previously unused impure or scrap iron into (useful) resources, "enlarging the resource base" (87) and causing even more fuel use, is puddling more *fuel-efficient* than earlier techniques? Is the greater fuel efficiency of aircraft engines not offset by their greater thrust, lowering efficiency's contribution to increased fuel consumption entailed by increased air travel? (127-128) Efficiency gain surely lowered input costs, but not all of the new demand for air travel is attributable to such a rebound effect, stemming perhaps instead from changed tastes.[40] Finally, new products are also crucial to any rebound beyond direct rebound because they can shift preferences away from leisure and non-consumption. In sum, while the environmental energy policies here examined define themselves in terms of *existing* products and/or processes, in the longer term new products and activities appear. What new uses are developing at this moment as the result of prior efficiency gains?

Taking energy consumption as the dependent variable, it is difficult to isolate the role of input efficiency, *ceteris paribus*. If we expand the system boundary backwards to mining, we see that lower costs of obtaining usable energy constitute an efficiency increase with effects in every economic sector.[41] And were there no qualitatively changed or new products which have efficiency gain as a precondition, consumer saturation would be considerably nearer. Moreover, efficiency and invention reinforce each other. The conclusion of Rosenberg becomes a *hypothesis* for rebound study, viz., that "new technologies that improved energy efficiency have often led to a significant increase, not to a reduction, in fuel consumption;… improved energy efficiency may itself stimulate new uses of energy that are difficult to anticipate." (1994, 165, 166)

4.6 Countries or World

Investigations of only certain countries exhibit two problems:

- Marginal or 'different' consumers in other countries are ignored. But if efficiency lowers fuel prices internationally, and fuel is traded, the income effect can be enjoyed by anyone. Moreover, not only does poverty assure little saturation, but some suggest that marginal energy intensities could be higher in developing countries. (Binswanger 2001, 126; Shi 2003, 32, 38-39) Therefore Schipper & Grubb correctly note that their findings "cannot be extended readily to developing countries"

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[40] Capital junking or economic obsolescence in connection with new products raises consumption further. (Babbage 1832, 231-233; Rosenberg 1994, 34, 51)

[41] But EROI also falls ('diminishing returns') as more available sources are exhausted.

(2000, 387), but how useful is their conclusion "that feedback [rebound] effects are small in mature sectors of mature economies…"? (368; Ayres 2000; Opschoor 2000)

- Due to energy that is *embodied* in traded goods, studies of countries or groups thereof should always correct for trade. (Cleveland & Ruth 1998, 44-45) While data especially on embodied energy imports are hard to compile, there is evidence that goods imported to the often-investigated OECD countries are from countries with relatively energy-intensive technology. (Greenhalgh 1990, 298; Hinchliffe 1995, 94; Saunders 2000a, 439) The methodology for computing relative 'ecological footprints', though, using material flows and input-output analysis, is well-known. (Wackernagel & Rees 1996; van den Bergh & Verbruggen 1999) Furthermore, evidence that declining rates of increase in total OECD consumption is at least compensated for by 'developing country' consumption is empirically collected on a regular basis. (e.g. Brown 1998, 114) This hardens the thesis that both EKCs and the gap between trend projections and actual consumption in evaluation analyses (*Section 2.3*) to some extent result from marginal, non-OECD consumers and imported embodied energy.

Nevertheless most rebound studies do not systematically integrate these cross-boundary movements into calculations either of consumption or of "energy intensity of production". (Sebold & Fox 1985; Schmidt-Bleeck 1999, 24; Greening et al. 2000) But surely 'structural' change from agriculture to industry to services in rich economies (Jänicke et al. 1989, 24-26) depends partly on imports of agricultural and industrial goods. One recent study acknowledges such imports, in consequence of the income effect, noting that "the rebound effect defined for UK consumption is thereby reduced"; but it seems to ignore them due to measurement difficulties. (4CMR 2006, 24, 52-53) Outside the rebound literature, however, Dahlström & Ekins (2006) for instance in their study of the steel industry integrate flows of energy into and out of the UK. And Weisz et al. explicitly conceptualise the problem that since the "nation state as a unit of analysis for… material final consumption… and the nation state as a territory where certain materials are extracted and transformed into products are drifting more and more apart", cross-boundary analysis is essential. (2006, 694)[42] To measure this, one comparison of "trade between Japan (an Annex I country) and South Korea…" uses the "bilateral balance of emissions embodied in trade (BEET)." (Rhee & Chung 2006)

For our question, country studies seem of little value in the absence of a methodology to include international effects. The assumption of one study that UK efficiency policies – conceded to lower costs and prices *nationally* – have no effect on international prices seems moreover unlikely. (4CMR 2006, 9) For a wide range of environmental issues, the concept of the country or 'economy' indeed could be largely obsolete. (Saint-Paul 1995)

4.7 'Substitution' and Time Effects

Conceptual difficulties in rebound taxonomy remain. Schipper & Grubb's category of "micro-rebound" includes a "substitution" rebound, "another variety of the micro-rebound [which] could occur if higher efficiency through lowering the cost of using energy leads to substitution of more energy for other factors of production." (2000, 368) Burniaux et al. write:

> There is a link between technical progress, output prices and real income… [T]he rise in energy productivity tends to lower the relative price of energy, thereby generating a substitution effect from non-energy towards energy goods. In the aggregate the increase in autonomous energy efficiency also generates a real income gain that leads to higher consumption of both energy and nonenergy goods. The net result is that emissions do not decrease in the same proportion as the AEE increase because the energy conservation effect is partly compensated by the relative price and income effects. (1995, 246)[43]

Jevons' explanation of greater coal consumption similarly included the fact that coal costs had remained nearly stable in seventy years, while "the price of labour and all materials was doubled." (1865, 118)

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[42] The daunting task of computing this for all pairs of countries is prescribed in the monitoring procedures foreseen by the Kyoto Protocol. (UNFCCC, Art.5.2)

[43] Here again is a 'race' between efficiency and emissions; moreover, it is not clear how the authors measure AEE change (*Chapter 6*).

Perhaps the substitution effect *strengthens* each category in *Section 4.3*. On the other hand, does it matter to rebound's size whether the newly cheaper energy is bought *instead of* something else, e.g. labour, or *in addition to* it? Consider a two-product model. If they are perfect substitutes, consumption of the newly cheaper one, X, entails a one-to-one decrease in consumption of the other, Y. Expenditure on X rises, but this is more than compensated within his budget by the decrease in his expenditure on Y – because Y is (remains) more expensive. The result is that the consumer has the same amount of product (or utility) with purchasing power left over (income effect). On the other hand, if a potential increase in consumption of X cannot substitute for Y and consumption of units of X do not increase, then because X is cheaper purchasing power again remains, potentially for Z.

Often 'substitution' effects are taxed as 'price' effects because the more efficiently used input becomes cheaper. However, 'price' effect often refers instead to the price *elasticity* of the relevant output. When this is low, then *direct* rebound is low: When Lovins assumes that the "price" effect is greater than the "income" effect, he can only be measuring direct or 'own' rebound. (1988, 158) One can in any case concur with Cleveland & Ruth's description:

> Energy efficiency gains look to the consumer a lot like price reductions, spurring increased demand for energy either directly through price elasticity effects (e.g. people buying more gasoline when its price drops) or indirectly through released purchasing power redirected to energy-using goods and services. (1998, 44)

The alternative purchases are on average more energy intensive. Of course, not only is income *redirected*; *new income* is created.

Another type of effect that is difficult to categorize is identified by Cogoy: "If technical progress improves the time-efficiency of enjoyment processes, room for enlarging existing types of consumption activities or for introducing new ones is opened." (1999, 388) This has been called a rebound effect with respect to time. (Binswanger 2001, 127ff) Like EROI increases, this would seem to pervade all sectors and marginal consumers. The relationship between material and time efficiency deserves much more attention: freed time is also the precondition for taking efficiency gains as leisure.[44]

4.8 Berkout et al. 2000 and Greening et al. 2000

This section criticises two of the most widely-cited papers in the literature, illustrating problems of the microeconomic approach. First, both between the papers and within each, definitions are either lacking or contradictory.[45] Berkhout et al.'s (2000) taxonomy of effects includes at least 13 classes, inconsistently used. When results are shown of "rebound" between, say, 0 and 60%, one cannot tell which definition is operative: "direct" rebound and the overall, broader "rebound effect, RE" are not clearly distinguished. Therefore their main conclusion – "There is agreement that the RE is small" (431) – is *misleading*. While the evidence they offer shows that direct or "lower-order" rebound is well less than unity, they switch to the general category "RE" for the conclusion. As in much literature, the term 'rebound' is in effect co-opted to mean 'direct rebound'.

Second, while the authors acknowledge that non-direct rebound is "difficult to assess"[46], and note that the "reduced energy bill enlarges purchasing power", they nevertheless cite and endorse the results of a "long-term macroeconomic" study concluding that "[p]robably, the second-order effects will be smaller than the first-order effects – like a stone in the pond" (425-427). Finally, one could argue with their use of *price* elasticity of energy demand as the proxy for the (rebound-determining) *efficiency* elasticity of demand. (428-430)

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[44] Jevons remained true to form in noting that although coal was substituted for wood, wood's use also rose. (1865, 249) Was coal 'substituted' for wood?

[45] A detailed document proving this is available from the author.

[46] de Haan et al. maintain that even some *direct* rebounds are too difficult to measure, namely the number of rebound vehicle kilometres consumed by purchasers of fuel-efficient Prius cars; they therefore restrict themselves to car weight, and number of cars per household. (2006, 596, 603)

Greening et al. (2000) likewise on the one hand “return to a narrower use of the term rebound or takeback and employ other terms for the economy-wide phenomenon”, yet on the other hand “extend [their] typology beyond its origins in the microeconomics literature to include secondary and economy-wide sources.” (390)[47] They likewise shift without explanation from direct to total rebound. First they give secondary evidence from 74 studies that “a *given* fuel-using activity” reveals low rebound and attest “satiation for a *given* service”. (390, emphasis added) [48] They then state the nonsequitur that “increases in efficiency, although partially offset by increases in consumption, will result in an overall reduction in energy consumption.” (392) They call the “low to moderate” estimates of *direct* rebound estimates of “rebound” as such. (399) Moreover, no proof is offered that “secondary effects” are “probably insignificant” or “relatively minor”. (391) In sum, their evidence is about direct rebound, yet their conclusions are about “total fuel consumption” (392)

Greening et al. identify

> of market response to changes in fuel efficiency…: (1) direct rebound effects, (2) secondary fuel use effects, (3) market-clearing price and quantity adjustments (especially in fuel four categories markets) or economy-wide effects, and (4) transformational effects… (390)

They however regard the last two effects too difficult to investigate, and the second as insignificant. Thus, exactly twenty years after Khazzoom’s original contribution, we are left with direct rebound only; but direct rebound cannot ‘speak for’ the whole rebound effect as the basis for policy recommendations. The epistemology of these studies is inadequate for the badly needed clarification of the debate.

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[47] Including (exogenous) “fuel markets” extends the typology too far, because rebound measures only consumer response to *efficiency* change.

[48] For “space cooling” nine studies report direct rebound from 0 –50%; the result for “long-run aggregate impacts” is given as “<100-0%; for appliances, although the studies were “inconclusive in results” and “indirect effects in terms of the purchase of larger units with more features were reported,” their figure for “potential size of the rebound” is a straightforward 0%.

4.9 Conclusion

Estimating rebound presupposes definitions, taxonomy, and transparency about exactly *what part* of new consumption in the economy is meant; when these are unclear descriptions of backfire such as the following are difficult:

> If saving energy is to lead to greater, not less energy use *than otherwise*, then either energy intensities after energy saving must somehow wind up greater than before energy saving, or the activities and output for which the savings were made must increase by more than the savings decreased energy use, or the overall mix of output must evolve in a way towards greater, not lower energy uses [sic.] than otherwise. (Schipper & Grubb 2000, 383)[49]

Heightened demand for the "activities… for which the savings were made" corresponds to my categories 1 and 3, while the "overall mix" covers either 2 and 4 or all four (*Section 4.3*), the evolution of which the writings of backfire theorists from Jevons through Saunders have tried to describe. It is hoped that the taxonomy proposed in this chapter, and the identification of misleading sectoral and country boundaries in rebound studies, contribute to bringing some light into the 'black box' of the macroeconomic effects.

Schipper & Grubb write:

> Overall, our analysis of disaggregated sectoral and subsectoral energy-use and activity trends in a variety of IEA economies suggests that any feedback effect is small compared to both the effects on energy use of changes in energy intensities and overall economic growth. (2000, 367)

We have shown the severe limitedness of sectoral and country studies. *Section 5.3* questions treating "overall economic growth" only as an independent variable. However, the most doubtful element of this conclusion regards "changes in energy intensities": Since "energy intensities" *are* technological efficiency, the "feedback effect" is part of the change-in-energy-intensity effect and cannot be "compared" with it. These intensity changes are the independent variable causing the rebound effect. Empirical work seems to need a better toolkit of definitions. Once ill-defined, the taxonomy of 'rebound' is as a rule unparsimonious and contradictory.

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[49] The phrases "saving energy" and "energy saving" beg our question.

Chapter 5 Methological Problems

5.1 Introduction

The contentious backfire question involves acerbic exchanges (Lovins 1988; Khazzoom 1989; Grubb 1990b; Brookes 1992; Grubb 1992) Perhaps because of ambiguous definitions and non-rigorous taxonomies and because study scope is limited to sectors and countries, estimates of 'rebound' ('direct rebound'?), range from "insignificant" (Lovins 1988, 156-157) or "small" (Schipper & Grubb 2000, 367-368, 384-386) to greater than 100% (Jevons 1865; Brookes *passim*; Saunders *passim*). This chapter continues to try to clarify "a number of definitional and methodological issues that are inadequately discussed in the literature" (UKERC 2006, 3), both to explain this variation and to question some assumptions behind rebound measurement. It critically examines five concepts for their relevance to the measurement of rebound and their employment in arguments for low rebound: *population, economic growth, energy's proportion of GDP, market failure, and the costs of efficiency*.

'Growth of efficiency-induced energy input consumption' is our dependent variable. We distinguish between this and the vague term '*economic* growth', which can use monetary, utility or 'service' or physical metrics. When for instance Birol & Keppler write that "It is the rebound effect that translates technological efficiency improvements into economic growth" (2000, 462), they are not endorsing backfire because their metric is monetary and thus inclusive of non-physical service measures. Two premises of the chapter are that e*nvironmental* energy policy measures only the physical scale of energy consumption, and that r*ebound* is calibrated only as a percent of theoretical input savings due to technological efficiency changes.

5.2 Population

Population increase is often said to cause a larger size of the economy; a "population effect" expanding consumption (Schipper et al. 1996 174) is seen to ‘race’ (*Section 2.2.3*) against efficiency gains which are shrinking it (net of some rebound). Lantz & Feng for instance compare elasticities between CO_2 emissions and the three drivers population, GDP per capita and technology, the former two increasing, the latter decreasing, emissions; however, if population is not wholly exogenous, but itself influenced by more efficient technology, its coefficient (0.8 compared to 0.1 for technology) is probably overstated. (2006, 235) Howarth’s model of energy consumption similarly contains the exogenous factor “constant rate of population growth”. (1997, 4)

But what causes population increase? The claim here is that while population times affluence *is* consumption, neither is purely exogenous but rather determined partly by institutions and organisational and technological efficiencies, the latter our independent variable. Greater production per hectare, per work hour, per machine and per unit of material input supports a greater population, a position of classical economists who thus played down the explanatory importance of merely settling new land or working harder. (Malthus 1798, 74-75, 206; Jones 1831, 196) More recently Cipolla (1962, 49-53, 94-95, 105), Clapp (1994), Johnson (2000) and others[50], using historical methodology, argue that without efficiency increases in producing food, warmth, clothing, transportation, metals and fuel, neither affluence nor population could be of today’s magnitude. This efficiency/population connection is put by Giampietro in terms of “Malthusian instability”, “Jevons’ Paradox” and the “desire for greater affluence” – a “ratchet effect” showing that, like land availability, productivity *enables* more people to live healthy lives; the *tendencies* of human reproductive behaviour (Malthus 1798, 52, 70) add to this necessary condition to yield sufficient conditions for population growth. (1994, 680-681) Hannon’s argument is formally similar, that vegetarianism doesn’t necessarily lower impact because of “a reaction that people… seem to have to eating lower on the food chain in the face of land scarcity: produce more people per family…. These gains in efficiency allow for larger populations…” (1998, 215)

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[50] Also Pimentel (1994), Bartlett (1994), Giampietro & Mayumi (2000).

What is the relative size of an endogenous, as opposed to an exogenous component of population? And of the endogenous part, how much is explained by *technological* efficiency gain? Whatever the proportions, this contribution of efficiency to energy consumption, through enabling larger population, must be booked under rebound, unlike the part stemming from biology and sexual or parental emotions. Failing to do this leads to underestimating rebound, as when Schipper & Grubb, for instance, although they "normalise… observations of absolute quantities to either population or GDP", see none of this "significant" population growth as "stimulated by the increases in energy efficiency". (2000, 368)

5.3 Endogenous Growth

The greatest part of rebound literature thus explains growth in the number of joules consumed with three variables: economic growth, population growth and – pulling in the other direction and thus begging our question – energy efficiency increases. When considering a trend holding technological efficiency constant, for instance, Schipper & Grubb write:

> Of course, the scale of the system keeps increasing with population, household formation, and the climb of incomes and sectoral output… [O]ver the time it takes to implement techniques that save energy, the entire system is growing. (2000, 368, 370)

Alternatively, population can be subsumed under 'growth' and an additional factor added, as when Schipper & Meyers use the three impact factors "level of aggregate *activity*,… the *structure* of activities, and… the *energy intensities* of specific types of activities" (1992, 58), or when Manne & Richels' three exogenous, mutually independent parameters are "potential GNP growth, elasticity of price induced substitution between capital-labour and energy[51], and the rate of autonomous energy efficiency improvements…" (1990, 51)

This paradigm of the 'race' thus enables the statement that "[e]conomy-wide fuel demand can increase in the face of fuel conservation simply because economies grow." (Saunders 2000a, 442; Fouquet & Pearson 2006, 172) But

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[51] The more so since efficiency increases lower prices, treating prices as solely exogenous likewise begs many questions.

why do incomes, output and population increase? Schipper & Grubb further speculate that “[w]e still may find that… energy use has increased even if energy efficiency has improved, because population or GDP grew significantly, growth not significantly stimulated by the increases in energy efficiency.’ (2000, 368) This seems to concede, in agreement with the analysis here, that efficiency stimulates GDP, but that this is “not significant”. But instead of merely lending ‘economic growth’ itself autonomous causal power, we should ask what *does* then cause this growth.

It seems correct for the rebound and EKC literature to partly explain the size of the economy endogenously in terms of economies of scale or of population and infrastructure density (Petty 1675, 255) or (begging our question) in terms of more research and development for efficiency increases. Difficulties of circularity notwithstanding, growth itself is in this sense *explicans*. But to the extent that productivity ‘leads to’ greater consumption – if this is conceded – also *explicandum*. Schmookler, for instance, in conceptualising “technology” and “economic growth” as both independent and dependent variables, emphasies that “the amount of invention is governed by the extent of the market.” (1966, 104-106; Rosenberg 1982, 141) But he ignores the reverse causality attested by the classical economists and Solow, namely that the “extension of the market” is itself a function of technology. (Say 1803, 86-87, 295-301; Malthus 1820, 53-56; Mill 1848, 87-89; Solow 1957; 1970)

If we are to avoid begging our question, then in addition to undisputed forces like organisational efficiency or population (to its exogenous extent), engineering innovations should no longer be assumed at one and the same time to raise ‘economic growth’ but lower growth in energy consumption. When, however, in explaining energy use the scale of the economy is taken as wholly exogenous, efficiency of energy use is ruled out as a cause of growth of energy use. If ‘economic growth’ causes greater energy consumption, as in the ‘trend’ scenarios of evaluation studies, yet efficiency *cannot* cause ‘economic growth’, then rebound is by assumption underestimated. If on the other hand greater efficiency *can* cause ‘economic growth’, but this is defined in terms of GDP or utility, the difficult questions of the decoupling of growth from physical matter and energy once again arise. (*Section 3.5*)

In other words, Jevons' paradox once more arises, due to the all-important implicit distinction between growth of *output* and growth of *inputs* like energy. Efficiency-induced income effects – an economy-wide increase in absolute purchasing power – are on the one hand universally conceded to cause *some* increase in demand for inputs compared with engineering savings; otherwise rebound equals zero. On the other hand they are said themselves to lower absolute consumption levels of energy inputs, and actual measured rises in energy consumption are then attributed to the exogenous drivers like population and GDP. Only the ambiguity in the term 'growth' can explain this. Only if growth of output or 'economic activity' is conceptually decoupled from growth of physical throughput[52] can efficiency increase raise one while lowering the other. Whereas if a higher output/input ratio *is* energy efficiency increase, our question is begged.

In any case, one contribution to the literature within this paradigm thus (self-contradictorily) concludes:

> [I]ncreased growth should, all else equal, lead to increased energy demand. If this growth effect is large enough, it might counter the direct effects of reductions in energy-output coefficients so that improved energy efficiency actually gives rise to increased energy use. (Howarth 1997, 2)

Again, not only is the "growth effect" fully exogenous, but it is unclear what the role of "improved energy efficiency" is. Howarth calls "the ratio of energy use to gross national product a crude but frequently employed indicator of energy efficiency" (2)[53], but "energy efficiency" denotes exactly this ratio in addition to, ambiguously, more narrow technological, physical process changes.

Pertaining directly to rebound measurement, Howarth then calculates that for the years 1929-1970, "[t]o accept the Khazzoom-Brookes [backfire]

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[52] Throughput is input of matter/energy into the economic system *plus* output of good products *and* waste.

[53] See *Section 6.3*.

hypothesis… one… must assert that improvements in energy efficiency were responsible for a full 29% of the increase in gross national product that occurred during this period"; he opposes this to Denison's finding that "productivity improvements and capital investment account for some 54% of the increase in national income between 1929 and 1982." (4) First, again, this leaves out of consideration that labour or total factor productivity could result partly from energy productivity. (Schurr 1982) Second, Howarth then dismisses the 29% figure above: "Claims of this sort, however, seem palpably implausible." (4) They are "empirically implausible" (7), but plausibility is not defined. In the absence of clear terminology he appeals only to "casual observations" (3) and the "intuitions of technology analysts" (2) in arguing for low rebound. Schipper & Grubb similarly assert:

> It is *fanciful* to suppose that the 20% energy savings, together with the restraining effect of structural changes, would boost GDP by 33%." (2000, 384, emphasis added)

Such argumentation, however, is unscientific.

Howarth further states that "[g]rowth accountants have not identified energy efficiency as an essential aspect of their calculations…" (4) This *ad hominem* argument seems to ignore, however, a large body of literature including Solow's calculation that technological progress is stronger than organisational progress (1970, 33-35, 38), and that together they account for 87.5% of growth (1957, 320). Thus, a problem for the paradigm that *a priori* denies the growth effects of efficiency is that the factors which then *do* cause the growth must be Promethean. They must not only compensate for, but overcome, the consumption-shrinking effects of efficiency.

5.4 Small Shares

A common argument for 'small' rebound is that energy's *share* of GDP is 'small'. In his attempted rebuttal of Brookes (1990), for instance, Grubb argues against the significance of a "re-spending effect [where] purchasing power is released for other energy-containing services"; he asserts that because "total energy costs are generally a few percent of GDP… this… effect will, even if one assumes a linear energy-GDP relationship, be of this order." (1990, 784) Greening et al. similarly claim that "Since energy is a relatively minor share of an individual consumer's total expenditures, the secondary effects are probably insignificant" (2000, 391), while Sorrell holds that "Indirect rebound effects may be small because… energy typically makes up a minor share of total consumer expenditure." (2005, 2.2; Schipper 2000, 353)

Howarth substitutes "services" for GDP and sees *two* small ratios:

> Since energy costs are typically a small component of the total cost of owning and operating energy-using equipment, large improvements in energy efficiency may generate comparatively small reductions in the cost of energy services… [and] energy costs are a small component in the cost of energy services, so that large changes in energy intensities are accompanied by modest changes in decision-makers' incentives. (1997, 3, 2)

If energy/energy *service* and energy service/GDP are both small, rebound melts. Even some researchers who measure more than just direct rebound, and thus deem it relatively large, seem to measure rebound not against engineering savings but GDP: "It is true that the significance of [the broad income effect] is moderated by… energy's share in the relevant scale variable (e.g. GDP in a KLE value-added production function), which is typically of modest scale." (Allan et al. 2006, 18-19)

But whether 'small' is 0.5% or 6% (Howarth 1997, 7), the argument misunderstands the concept of rebound. Rebound does not depend on the percentage of GDP of engineering savings, but of the percentage of engineering savings of new consumption enabled by lower production costs and mediated by the efficiency elasticity of demand. This consumption, resp. the potential energy savings, could be a tiny part of GDP or total energy consumption and still be greater than engineering savings. This issue is purely conceptual: rebound is not a claim about everything else going on in the economy which might increase energy consumption.

5.5 Market failure

Another common argument claims that rebound is lower than usual in areas of the economy dominated by market failure:

> The sharpening energy efficiency debate has revived claims that the apparent savings from using more efficient technologies would be largely offset by the macroeconomic response – the tendency to use more energy services because they are made cheaper. When energy price or availability constrains demand this is correct. In more normal circumstances, it may be true for efficiency changes which occur as part of general economic trends, but not for policy-driven measures aimed at bringing more efficient technologies into imperfect markets. In such cases there will usually be real net energy savings only slightly smaller than those suggested by a simple engineering analysis, and clear economic benefits…. Conservation policies can choose to focus upon… areas, including those dominated by market failures, where the implicit price falls from increased efficiency have little impact on activity levels. (Grubb 1990b, 783)

First, when is energy price or availability *not* a constraint on demand? Second, while conceding that higher BAU efficiency causes enough consumption growth to "largely offset" the lowering effect of "more efficient technologies", Grubb claims the opposite for non-BAU changes, i.e. those forced by policy. But why, in these areas, does the income effect not obtain? He suggests seven states of affairs of "market failure" including lack of knowledge and skills, "separation of expenditure and benefit", and "rapid payback requirements", but no detailed argument. (1990b, 784-785)

Perhaps the technical change is not carried out in the first place. Or low price elasticity of demand brakes the effects of price falls, or prices do not fall due to lack of competition. Concerning the first (that 'market failure' leaves actual efficiency below technologically possible efficiency), this is not relevant to measurement of rebound, but only to engineering savings, against which rebound would be measured, were there any. Indeed, the issue of market failure seems relevant only if one *assumes* efficiency to be environmentally efficate: "Grubb and Lovins argue that energy efficiency policies primarily address market failures/barriers which prevent currently most energy efficient technology or systems being used." (4CMR 2006, 5, 14)[54] This argument from 'market failure' begs our question.

To my knowledge no one denies that once efficiency increases are made, an income or price effect ensues. Thus, if the argument is that in these "areas" price elasticities of demand are low, there is still indirect rebound, i.e. effective demand for other consumption. Malthus addressed this, noting that "the increase of wealth" was perhaps less when "the commodity to which machinery is applied is not of such a nature that its consumption can extend with its cheapness"; but he saw that thus "a portion" of the now idle circulating capital is "set free for the purchase of fresh commodities" creating new demand and new employment. (1820, 282) Grubb's list of market failures thus has relevance for *direct* rebound, but not for the "re-spending" or "macroeconomic" rebound here under debate.

Alternatively, in some (monopoly) areas the entire increased purchasing power could accrue to producers as profits. But even then lower demand by suppliers can cause a fall in energy prices, opening the market to marginal consumers. Furthermore, the higher profits would generate demand through investment spending, distributed dividends, or political clamour for privatisation of the profitable sector. (Malthus, *ibid.*; Schumpeter 1911; Grubb 1992, 393) Finally, it is not clear why rebound's size should depend on whether the efficiency gain is BAU or policy-induced. That BAU ones are cheaper is considered in *Section 5.6*, but at first glance engineering savings depend only on physical changes, not their motivation. Using more efficient light bulbs leaves purchasing power in any setting.

The literature, not to mention the evaluation documents review in *Chapter 2*, often conflates welfare economics concepts like market failure with environmental ones. Brookes' challenge to the efficiency strategy itself stated

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[54] If efficiency policies backfire, however, they are environmentally damaging. And to the extent that *economic* efficiency (e.g. lower transaction costs or free competition) furthers economic growth, it too mitigates, *ceteris paribus*, against environmental goals.

that “Reductions in energy intensity that are not damaging to the economy are associated with increases, not decreases, in energy demand at the macroeconomic level.” (1990, 199) Schipper & Meyers argued that “Narrowing…the difference between the average energy efficiency in the market… and the level of efficiency that would be economically beneficial from a societal point of view, is an important role for public policy.” (1992, 305) Grubb similarly writes that “market imperfections make efficiency improvements economically attractive.”[55] (1992, 393) Jevons argued that indeed all efficiencies raise affluence, but we are here investigating the *environmental* impact of levels of consumption influenced by rebound.

5.6 Costs of efficiency increases

Engineering savings computations include the energy necessary to produce the more efficient equipment (embodied energy and R&D and junking costs in terms of joules): if the more efficient capital costs more or is installed earlier, the overall efficiency increase is smaller. Computing rebound then proceeds as usual. Yet some argue that “…capital costs form an important part of the total cost of providing energy services and… the higher cost of energy efficient conversion devices will reduce the magnitude of the rebound in many instances”; capital costs influence the “efficiency elasticity of energy demand.” (UKERC 2006, 11-12) The argument seems to be that high capital costs hinder the purchase of more efficient equipment, resulting in lower average technical efficiency. (Besen & Johnson 1982, 111) Capital and maintenance costs and opportunity costs of space and time taken together can lead to the decision not to change to equipment with lower operating costs. But again in this case, there is no engineering savings and thus no rebound. Or is it again being assumed that efficiency increases, *ceteris paribus*, lower consumption? Efficiency’s cost seems relevant to engineering savings and *overall* energy consumption, but not specifically to rebound.

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[55] These ideologically crucial questions concerning possible conflict between welfare and environmental goals deserve study. (see Pigou 1920, 134, 183-196)

Economists have long known that “[t]he efficiency of the instruments produced must... be generated by greater cost... [in labour and material]” (Rae, 111-116, 100-102; Rood et al. 2003) In today’s debate, however, there is disagreement on the relative capital costs of more, and less, efficient equipment. (Khazzoom 1982) What seems clear, though, is that capital costs relative to lower future operating input savings could theoretically be so high that no income effect remains; i.e. there is an efficiency *loss*. (Brookes 1990) But assuming no market failure, all *economically* beneficial efficiency increases would be made. Additional policy-induced ones would lower ‘lifetime’ efficiency in the mandated areas. The paradoxical question then again arises: If this also lowers affluence, are environmental and economic goals in fundamental conflict?

5.7 Conclusion

Radetzki & Tilton’s intensity of use (IU) methodology to predict *metal* demand is the same as those discussed above to determine energy demand, and raises two of the same difficulties. “Consumption (demand) of the metal” depends on “the output in physical units of the *i*th final good,… the amount of the metal consumed directly and indirectly in the *i*th good, and… the number of final goods produced throughout the economy”; the amount of output is then related to “national income” [GDP], yielding the familiar result that “changes in metal demand over time are the result of three causal factors – the overall level of national income…, the material composition of products…, and the product composition of income….” (1990, 25-26) Again, in taking GDP growth as an independent variable it neglects the important question of what causes growth, and while knowing the *share* of the economy paid for metals might help compute physical metal demand, it would not help compute metal *rebound*.

Some of the problems perceived in this chapter are evident in the top-down policy-evaluation methodology of 4CMR (2006). First, the two exogenous factors seem to be *direct* rebound (taken from empirical studies) and “energy saving… projected from energy-engineering studies for the policies….” (35, 52, 23) Second, two counterfactual scenarios for energy consumption are compared, one with and one without the efficiency policies, both assuming an exogenous GDP growth factor (about 2.65%). (6, 36) Various types of rebound are then computed "allowing for the direct rebound effect." (23, 52) The scenario with policies includes "the sectoral effects on energy use by assumption..." (32) and predicts less energy use than the scenario without policies (56, *passim*).

Three questions that arise are: First, even if the figure for "direct rebound" (15%) were correct, what indirect rebounds were either left out or underestimated? Second, what if backfire, at least in many sectors, is true, and therefore some of the GDP growth must also be attributed to AEE or policy-induced increases? Third, the "assumption" of the computation of the difference between the two scenarios seems to be that rebound is (well) below 100% - the very question that backfire (and rebound) studies are trying to answer. The study concludes that the policies are effective, saving about "8% of the energy which otherwise would have been used by 2010." (6; *Sections 2.2 & 2.3*)

We do confront a paradox. The arguments tying rebound, or at least energy consumption, to population, exogenous growth in general, energy's share of GDP, market failures, and the capital costs of efficiency gains are all searching for an explanation of why, in the face of more or less well-documented energy efficiency increases, energy consumption goes up and up. A parsimonious and perhaps naïve answer is that technological and other efficiency increases *cause* greater physical consumption. While parsimony does not establish truth, it recommends Jevons' theory for further investigation.

Chapter 6 The Macro Empirical Approach

6.1 Introduction

This chapter no longer starts with the concepts of engineering savings, rebound and backfire but with the scale of the world economy – more precisely of energy consumption and changes thereof. Population times affluence in *I=PAT,* modified by technology either downwards (according to efficiency strategy theory) or upwards (according to Jevons) determines aggregate *consumption* of fossil fuel, the growth of which over recent history is assumed without documentation. We need therefore the determinants of population and affluence. Is there a correlation between level of consumption of natural resources and level of technological efficiency? Determining the latter requires a metric, perhaps an aggregate one. While the input *numerator* (joules) is unproblematic[56], monetary, 'service', and physical *denominators* are not.[57] Each is explored in turn, the conclusion being that the least problematic are physical: if left relatively unaggregated, one can perhaps average specific sectors, each with their own metric.

While a consensus attests correlation between resource use and the efficiency of resource use[58], causation is disputed. The hypothesis is stated that efficiency increases do raise overall consumption, alongside the conventional factors of organisational efficiency, the efficiency of human capital, appropriation of space, hours worked, and population and economic scale to their exogenous extent.[59] To enhance the *plausibility* of this

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[56] This ignores distinctions between primary and secondary energy, and exergy.

[57] Sometimes Δtechnology is simply *time* on the independent-variable axis. (Lantz & Feng 2006, 233)

[58] This dissertation regards the terms 'resource efficiency' and 'resource productivity' as virtually synonymous, although while the latter term usually measures output in terms of money or utility, the former – here in any case – is measured over against physical outcomes only.

[59] It is speculated that quantity and efficiency of capital is reducible to these.

hypothesis, secondary literature from the interface of economics and engineering is consulted. Highly aggregated empirical work, with whatever metric, has to date yielded only weak evidence. If the hypothesis is true, however, the consequence for environmental policy would be the abandonment of efficiency policies as counterproductive.

6.2 Change in Efficiency

Measuring macroeconomic efficiency is challenging. That inputs of matter and energy *per consumption unit* (physical commodities, services, or Gross World Product) have indeed fallen since Adam Smith's day is claimed by many (Jevons 1865, 145-146, 388; Cipolla 1962, 49, 99; Schurr 1982, 5; Cleveland et al. 1984; Kaufmann 1992, 52; 2004, 63-64; Inhaber & Saunders 1994, 21; Clapp 1995, 161-171; Giampietro & Mayumi 1998, 20-24; Vringer & Blok 2000) However, how can we compare efficiency over twenty-three decades, if not with the denominator 'average human life'? The capital goods and processes subject to efficiency variation have after all changed (*Section 4.5*), rendering the denominator a 'moving target'. However, measuring input against 'a human life' or the total of human *utility* would not be measuring the *technological* ratios that are the tools of environmental policy. Therefore we must somehow measure goods, artifacts, transformed material.

Technological efficiency is here defined as a ratio adhering ontologically to the production-consumption *process*, preanalyzed into outputs and inputs and done by man-made *capital* units. (Rudin 2000, 539; Rood et al. 2003, 492) The literature similarly uses terms like 'transformation', 'transfer', 'throughput', and the term 'production' itself. For Enos, "process [is] a unit of enquiry for the study of improvements… [in] technology plus its application, i.e. the physical and chemical relationships governing the transmutation of elements…." (1994, 2; Barker et al. 2005, 5, 17) The process of converting energy to lumens via the capital good 'light bulb' is an example of a target of efficiency policies. Van den Bergh's statement that "[t]he production process may be envisioned as a transformation by agents of material inputs into goods and waste outputs" (1999, 555) reminds us not only that we can efficiently produce *waste*, but that the metric for *negative impact* is necessarily physical.

Capital, labour, and (sometimes) energy/material (*KLEM*) are common determinants of production quantity. The last chapter tried to show that population and the physical scale of the economy are partly endogenous, i.e. explicable by efficiency changes either upward or downward. The hoary concept of capital is here used broadly in the classical sense of "circulating" as well as "fixed" capital (Smith 1776, II.i.4 & 5; Malthus 1820, 192; Mill 1848, 751) or Rae's "instruments" (1834, 86-89, 170-171). This concurs with Boulding's inventory of artifacts (1949; 1966, 9-10; Daly 1974, 15) or Solow's "capital in natural units" (1970, 35). Following Schumpeter (1911, 20-21, 37, 210-211) and many classical economists[60] capital is treated endogenously, i.e. reducible to 'land and labour'.

Capital also 'augments' material and labour. (Smith IV.ix.34; Mill 60, 63, 92, 100-115; Saunders 1992) In disentangling labour- from capital-productivity used the homely example of "an improvement in the design of a typewriter that gives one secretary the strength of 1.04 secretaries after a year has gone by"; this yields, using the 'strength' metaphor, the concept of "efficiency units" to measure the augmentation of "*both* labour and capital". (1970, 34-35) Capital's reason for being is to improve efficiency – important for the rebound question because while backfire is thus not guaranteed (*Section 4.3*), it is *enabled*.[61]

Although controlled experiment is impossible, the fortuitous case of two societies differing only in level of technological efficiency is not ruled out. Yet statistics seems the most likely method of testing the hypothesis that increased efficiency, *ceteris paribus*, causes an increase in consumption of

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[60] E.g. Smith (1776, II.iii.25, 33-34); Say (1803, 293); Mill (1848, 100, 182).

[61] While removing capital from the production function is perhaps not pertinent, it is hoped that bringing matter/energy back into it helps focus attention on the natural resources at the centre of environmental questions.

the more efficiently used input. The problem of metrics is therefore unavoidable. Solow's pioneering work in establishing "technical progress" rather than *quantities* of labour and capital (and their ratios) as the strongest causes of growth had no rigorous metric but included both technological and organisational changes. (Rosenberg 1982, 24) This large residual[62] was arrived at more by a process of elimination than by explicit testing. The classical economists likewise attested the contribution of process efficiency to the amount of a nation's wealth, more on the basis of theory. Lauderdale's examples of the spade, plough and stocking-making machine (1804, 162-168), further analysed by Schumpeter (1911, 280-284), or Say's of the flourmill (1820, 133-134, 140), show productivity increases to increase aggregate production and sustenance *as well as employment*. Jevons showed empirical correlations between coal and iron consumption and increasing efficiency of steam engines and smelters. (1865, 113, 119, 155, 262-265, 387-388)

But even if efficiency almost surely contributes to 'economic growth' and affluence, does it contribute to *input* growth?[63] Solow's conceptualisation of change in *physical* capital is a motto for this chapter:

> Obviously much, perhaps nearly all, innovation must be embodied in new plant and equipment to be realized at all. One could imagine this process taking place without net capital formation as old-fashioned capital goods are replaced by the latest models, so that the capital-labor ratio need not change systematically. But this raises problems of definition and measurement even more formidable than the ones already blithely ignored. (1957, 316-317)

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[62] Domar's "historical play about growth models" featured "a whole group of actors" alongside capital and labor, including technical progress, which he calls "Measure of Our Ignorance" and his own hero, "the Residual." (1961, 709)

[63] Saunders quotes Solow that "it's hard to break the habit,... 'factor-augmenting' does *not* mean 'factor saving'." (1992, 131) Jevons warned of confusion between coal "saved" and coal "spared". (1865, 13)

6.3 The Monetary Denominator

In measuring "eco-efficiency" Reijnders names five denominators: "a product (such as the automobile), a service (e.g., transport over a certain distance at a specified speed), an area of need (e.g., clothing), a sector of the economy (e.g., energy supply and demand), or the economy as a whole." (1998, 14) The metric for the last is monetary, relying on the System of National Account's concept of income or GDP. Justifications of this denominator are its convenience and the availability of data (Radetzki & Tilton 1990, 28) plus the idea that it is a good proxy for output in some sense meaningful in studying physical environmental impact. (Moezzi 2000, 528) What are the problems of this denominator?

Typical statements use "joules per unit of GNP or economic activity" or per "relevant measure of activity or output" (Schipper & Grubb 2000, 369), e.g.:

> Over the last 30 years the economy's energy intensity (total energy consumption divided by total GDP [as] Mtoe/$USbn)… has improved by around 1.8% each year. (DTI/Defra 2003, 3.3)

GDP and the ubiquitous but amorphous 'economic activity' are synonymous. Greening et al. note a widespread vagueness about *what* "end-use activity" within GNP is being measured (2000, 392), both concepts being fully *abstract.* Many doubt GDP's viability. For Smil GDP, if "used simply as [an] absolute measure for categorical comparisons of economic and energetic efficiencies... [is] grossly misleading." (2003, 66, 81; Manne & Richels 1992, 40) Specifically for environmental research Jänicke et al. hold that "[r]esource consumption by the national economy and the process of environmentally significant structural change are not appropriately described by the production values used in the national accounts…." (1989, 25) Often GDP is first cogently criticised, e.g. as "…not really an aggregate measure of all activities that use energy, but rather and attempt to measure the exchange value of economic activities" – but then relied upon for analysis. (Schipper & Meyers 1992, 54)

A set of problems in using GDP outside the realm of fiscal bookkeeping includes its *not* measuring resource depletion, unpaid labour or bartered products (Daly & Cobb 1990, 401-455; El Serafy 1991; Smil 2003, 73-74), all of which are relevant to the study of environmentally problematic consumption. Moreover, monetary indexes yield *lower* ratios of energy intensity whenever ‘value-added’ rises for reasons having nothing to do with material efficiency or energy’s share in intermediate products. Lower *material* intensity results similarly when physical inputs of goods like air, water, and space, lacking a price, are not deducted as intermediate expenditures – in effect lowering the numerator. GDP thus seems to measure something other than the aggregate output consumption which concerns environmental policies.

That is, GWP measures *prices*. But, as shown by the hoary water and diamonds paradox (Smith 1776, I.iv.13), these bear no necessary connection to physical attributes contributing to environmental impact. Applied to *metals* Cleveland & Ruth likewise note that monetary units for the “intensity of use” ratio include “forces unrelated to quality, such as cartels, regulation, and labor and capital costs, [that] can affect the price or value of metals.” (1998, 35) Radetzki & Tilton point out that “The price of metal… may rise over time even though quality remains unchanged” (1990, 21), while Robinson notes that the “measuring rod of money” misleads by the mere fact of sales and advertising costs (1954, 18).

A further case of GDP’s autonomous rise is that “the fuel/GDP ratio can decrease simply because fuel prices rise. Yet this is not evidence of fuel conservation.” (Saunders 2000a, 442) And even if there is backfire, i.e. the elasticity of fuel consumption over against efficiency is greater than unity, if GDP for any reason grows *even faster*, a lower fuel/GDP ratio masks the fact that real consumption has risen.[64] Finally, Kaufmann showed that the efficiency ratio with a monetary denominator cannot tell the difference between a ratio decrease of energy to unit of GDP caused by 1) lower input for a *given quality* of service and 2) the same input for a *lower quality* of service. (1992, 54; Cleveland et al. 1984, 893; Wackernagel & Rees 1997, 17).

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[64] This could be the normal case. (Kolstad 2002)

Moreover, insofar as efficiency increase lowers the price of energy, and energy prices comprise part of the GDP denominator, they *raise* energy intensity by *lowering* the denominator. Yet because usually *growth* in the monetary denominator – for whatever reason – registers as an increase in all productive factors (not only energy), it tells us little about the relative strength of the factors. Schurr's "counterintuitive" results were that "total factor productivity" rises more rapidly than "the increase in energy consumption associated with production" in absolute terms; the "paradox" was that "favorable energy supply conditions" led to our "getting more from energy". (1982, 7-10) Could this be clarified by adopting a physical instead of monetary metric?

Finally, Smil's "deconstruction" of the monetary concept of energy intensity (2003, 71-78) emphasises the difficulty of computing purchasing power parity in international comparisons, and of aggregating his six variables determining differences in nations' energy intensity into an overall index, an index of limited interest to the technological ratios sought here, as shown by his example of the USA and Canada, which have *high* energy/GDP ratios but also "the most technically efficient machinery and equipment sector…" (77). Thus, it seems gratuitous to assume that GDP's advantages and disadvantages somehow "balance out" (Reijnders 1998, 14). Bartelmus may be right that physical metrics evidence problems of "arbitrary weighting and indicator selection" (1997, 334), but the monetary metric fares no better.

6.4 The Service Denominator

Do 'services' – used pervasively in the rebound debate – serve the denominator better? Reijnders' second category (*Section 6.3*) was "a service (e.g., transport over a certain distance at a specified speed)." Similar definitions are "thermal comfort, lighting and cooking" (Foxon 2000, 590) and "the output from a 'home-production-function' requiring (market) commodities and time [such as] mobility (passenger kilometers), lighting (lumen hours), washing (kg clothes), etc." (Wirl 1997, 14). That is, the chosen unit is "passenger kilometre" instead of the physical "tonne kilometre". (UKERC 2006, 4; Binswanger 2001, 120-121) These are two different perspectives on one and the same phenomenon.

'Service' is not without ideological freight. Advocates of low rebound insist on the concept, arguing for instance for the significance of the fact that physical energy costs are only a small part of the costs of energy *services* (Howarth 1997, 3; *Section 5.4*); Foxon claims that "increasing resource efficiency follows *naturally* from the perspective of considering resource and material flows needed to satisfy end-use service demands" (588, my italics). Saunders on the other hand claims that his backfire model does not suffer from the distinction (2000b). The "material input per service unit" (MIPS) concept is also used to advocate the vision that we can keep or double our *utility* (affluence) with less resource consumption, i.e. an efficiency strategy with both welfare and environmental goals. (Schmidt-Bleeck 1994; Hinterberger et al. 1997; von Weizsäcker et al. 1997) The service concept forms moreover a bridge to the EKC discussion (*Section 3.5*) and *consumer* efficiency: Perhaps if we carpool, we move closer to absolute satiation without consuming more; but we also free purchasing power to consume more.[65]

The approach here, however, asks more dryly whether the concept of service is *needed* to answer our question. What facts about efficiency change and ensuing consumption change might render it useful? However fruitful an analysis of the ambiguous phrase 'goods and services' would be[66], the main problem with 'services' is that technological efficiency would by definition increase when two persons, rather than one, ride in a car. 'Passenger kilometer' times two yields doubled efficiency without, however, any technological or engineering change whatsoever. The ratio of paper and ink inputs to the 'service' output of a journal rises with each additional reader. The

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[65] The *consumer efficiency* strategy is distinct from both the efficiency strategy and the sufficiency strategy (whereby in order to lower consumption we do without some utiltiy). All three rebound due to price effects.

[66] Robinson wrote ironically of "the mass of solid goods and useful services". (1954, 19)

analogy with GDP is clear. A whole economy's efficiency can vary depending not on technology but solely on behavioural change which, to be sure, likewise does not guarantee lower energy consumption. The difference is captured by Grubb's conceptualisation of the "anomaly" of "efficient production and inefficient use" (1990, 198; Cogoy 1999, 388, 397).

If efficiency can be fully described in physical terms – a light bulb of a given strength and input – what is gained by calling this a lighting *service*? The new analytical paradigm holds that "[c]onsumers are assumed to derive utility (*U*) from consuming these [energy] services[67], rather than from consuming energy commodities and other market goods directly." (UKERC 2006, 3; Foxon 2000, 589) But while utility is perhaps derived from 'service', service is necessarily derived from energy.[68] Shove likewise insists that "…people do not really 'consume' energy. Instead, they consume the services – heating, lighting, showering, cooking, television watching, computer interaction – that infrastructures of gas, electricity and water make possible." (2004, 1054) But this undefended redefinition of consumption (and infrastructure) results in the incorrect assertion that *energy is not consumed*! What new term is proposed, then, to describe the human activity that results in ever more depletion and pollution?

Perhaps the claim is that defining efficiency change in terms of services lowers the efficiency elasticity of price or demand. However, even assuming that we derive the same service from carpooling and driving alone, offering an energy 'saving', this again represents a violation of the *ceteris paribus* condition of our question: In looking for change in consumer demand after efficiency gain and price fall, this would *not* hold the factor *consumption efficiency* constant.[69] That is, adopting services as the basic concept (UKERC 2006) opens up the danger of analysing *two changes* at once, and it is a

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[67] 'Consuming a service' jibes badly with ordinary language.

[68] Does this paradigm fail the test of Occam's razor?

[69] If behavioural change is a function of efficiency change, it is probable that more efficiently provided products are used *less* consumer-efficiently.

conflation of physical and service denominators to write that "*technical efficiency*" measures the conversion in an "economic system" of "basic resource inputs – notably available energy – into a given fixed set of goods and services for consumers." (Ayres & Miller 1980, 359)

A further problem is that, especially if we correctly include transportation energy and embodied energy in the analysis, *all* services are energy services just as they are all 'labour' services. That is, something is said to be an 'energy service' *as opposed to* what other kind of service? Is the difficult concept of the energy 'content' of an expenditure unit needed? Finally, we ultimately need a ratio whose denominator directly affects environmental quality. Again, and metaphorically, the environment does not 'care' how many people get how much utility out of consuming it. Only physical amounts matter. (Jacobs 1991, 25) The concept however seems to shift the ontological locus of a service from the environmentally relevant goods and processes to the *relation* between humans and a service-yielding stock of artifacts.[70] Parsimony often seems lacking: Berkhout et al. suggest that "the consumer can be regarded as a *producer* of useful services [sic.] using energy as an input" (2000, 427, emphasis added), while Dimitropoulos & Sorrell devleop a complex production function with "demand for energy (*E*)..., demand for energy services (*ES*)...", the "utility" derived from services (*U*) and a "feature" of services called "useful work (*S*)" as well as "broader attributes (*A*)" of services (UKERC 2006, 3-4).

The concept of services dominates the rebound discussion, yet I know of no demonstration that the efficiency-induced demand for capital goods and the energy to use them is in some way crucially different from the efficiency-induced demand for the *services* that these goods and energy provide. In any case, it is difficult to approach our question physically and at the same time accommodate the concept. Ayres, whose taxonomy of production processes

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[70] One definition even redefines the term 'commodity': "Energy services refer to the commodity, which is actually used or demanded, i.e. refrigeration, hot water, and process heat." (Greening et al. 2000, 389)

and "resource/commodity definitions" are throughout physical, fails in his attempt to distinguish "production of goods" from "production of services". (1978, 53-54) Extraction, conversion, and manufacturing are indeed "transformations" producing goods requiring "consumption of material goods and energy"; but since this is exactly his definition of "production of services", there is no difference. (54) He also attempts to "map" these transformations, first "from *factors of production* to *goods and services* and thence to *utility or welfare*", and then "from *exhaustible or renewable natural resources* to *finished materials and forms of energy*, and then to material *products* and *structures*, then to (abstract) *services*, and finally to *utility*". (67) Yet no difference emerges between services, structures and utility. He abandons this attempt to accomodate welfare economics, deciding that "Production of pure services such as transportation is omitted from further consideration for conceptual reasons." (1978, 66)

Returning to the normative role of the concept, Ayres writes:

> [A] technological escape hatch to the 'limits' [and general impact] bind still remains open, however. It is that final services (as 'consumed') may not have an irreducible minimum material or energy content. In other words, it may be technologically possible to increase the 'service content' of a given unit of materials or energy effectively without limit. Since service content is nonmaterial, the second law constraints against unlimited creation of negentropy does not apply in this case. (1978, 50)

He then confesses his lack of "a conclusive argument against" this escape hatch, and indeed, the study of the use of the service concept would require an interdisciplinarity beyond the scope of this dissertation.

6.5 Physical Denominators

Recall that the first of Reijnders' possibilities for a metric of output is "a product (such as the automobile)". (1998, 14) Assuming some taxonomy for 'products', sectoral efficiency changes seem in fact amenable to measurement of engineering savings. (Ausubel 1989; Dahmus & Gutowski 2005) For instance, Ayres' material-flow framework covers elements, compounds, energy, transformations and final goods in terms of stocks and flows (1978, 53-66) and can calculate efficiencies for all processes (53; Ayres

& van den Bergh 2005, 102-103). Certainly, integrating “physical principles” or “physical-chemical classification” into the “micro-structure of the economy” or “commodity-based classification system” encounters problems of aggregation; and both taxonomies, for instance, “freely aggregate toxic and nontoxic materials”. (57) These problems are, however, less severe if only material-efficiency and not toxicity is considered, and further if one settles for less than total aggregation.

World physical energy depletion and pollution, again, is our relatively easily measured dependent variable to be related to changes in world technical efficiency, *average* across sectors. This section briefly surveys some candidates for a physical metric, relying on literature by the cited authors Ausubel, Ayres, Cleveland, Enos, Jevons, Landes, Rosenberg, and Sieferle. In Rosenberg’s opinion:

> Not only is it difficult to sort out the contribution of technical progress… to economic growth… from other related contributions – capital formation, education, resource allocation – but there are no unambiguous measures of output over time periods long enough to permit large changes in both prices and the relative importance of each component of output (the index number problem). (1982, 23; 55)

If physical energy consumption rather than ‘economic growth’ is the *explicandum*, and energy efficiency rather than the broader ‘technical progress’ the hypothesised *explicans*, can we find an appropriate physical metric?

Such a metric could be vehicle miles, tonne kilometres, lumen hours, or “kWh/year for a given refrigerator of a given size and features).” (Schipper & Grubb 2000, 369). While weight, volume, energy content, and chemical (table of elements) content are units applicable to all process outcomes (fully aggregate), vehicles and refrigerators are not. Still, they comprise Reijnders’ first category of ‘products’, as opposed to his other groups: services, sectors, areas of need and the economy as a whole. (1998, 14) These products, as objects from which more aggregate units are abstracted, should not be ignored. As ‘objects’, these products include ‘producer’ and ‘consumer’ goods (i.e. fixed and circulating capital including food), but also products like a ‘lighted space’ or ‘heated space’; excluded from ‘capital’ here are natural resources, which are inputs only, and human beings – the *L* and *M* in production functions.

An example of a capital object is a poorly-insulated house containing an open wood-burning fireplace. It can be made with more, or less, input or *embodied energy.* The second sort of product is neither an object nor a service, but rather the heated volume of the house, definable in terms of temperature and m^3, made with more or less *operating* or *utilisation* energy. Changes in both the house (insulation) and the firing place (enclosure with a ceramic stove) reduce the input requirements for the resulting ‘heated space’. These processes and ratios are subject to research independent of the motivation for them, i.e. the heated house constitutes an environmentally relevant state of affairs whether or not anyone is in it.

The example of rotating axles and rods shows moreover that capital efficiency improvements can change several ratios and several qualities (*Section 4.5*):

1) As hardwood was replaced by metal rings – which were replaced by ball bearings and then roller bearings – each different capital object brought more operating efficiency, i.e. lowered the ratio of energy input to useful (the desired) work.
2) Each type of capital object functioned longer, i.e. lowered the ratio of embodied energy to output spread over the good’s ‘lifetime’.[71]
3) If the new machine part contains more embodied energy, this *lowers* the work-efficiency ratio.
4) A qualitative change in the output itself can take place, in this case the quality of the rotations – e.g. faster or smoother. This point again raises the problem of efficiency measurement that the *characteristics* of output often change. This ‘moving target’ problem (*Section 6.2*) besets *all* denominators, monetary and service ones as well.

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[71] Durability, recycling, and embodied energy – usually within the questionable metaphor of ‘life cycle analysis’ – are here subsumed under efficiency. (Ayres & van den Bergh 2005, 101)

Ayres & van den Bergh tentatively suggest a *matter/matter* "measure of the technical efficiency of the production process" in terms of *mass* instead of energy – "the ratio of mass inputs embodied in the physical output (finished products) to the gross mass of material extracted from the environment." (2005, 103) But if we keep joules as the input metric, we can still take "mass embodied in output" as denominator. Such physical metrics for an aggregate efficiency index are then in units of weight[72], differentiated by chemical composition. Metrics of mass or weight however, have the weakness of not distinguishing between different chemical compositions of inputs. Taking a *bad* in the denominator, the joule ratios of natural gas to CO_2 mass differ from those of petroleum.

In their discussion of the methodology for studying consumption in the *metal* sector, Radetzki & Tilton (1990, 19-21) consider solving the problem of incommensurability of outputs by "weighting" the weights of each of twelve steel-product types in the denominator by an abstract coefficient. They also attest important product differences that are often not physical, as when copper of multiplexing quality enabled the same amount of wire to carry more conversations. But for reasons of such complexities and data limitations, and because monetary metrics raise even more difficulties, they advocate a simple tonnage metric. However, a more complete physical metric than ones using mass would have to include temperature, light, and perhaps even space.

Cleveland & Ruth also see the "serious flaw [of] aggregation by weight or volume" as ignoring "material quality,… *the marginal amount of economic output generated per mass unit of material input*" and therefore similarly "weight" mass units with "its relative economic usefulness." (1998, 35) The concept of "economic usefulness" is clearly no longer a purely physical metric, especially if it is "relative". Birol & Keppler propose the similar idea of "efficiency units" of fuel: one and the same litre of petrol would count as more efficiency units as it becomes more productive of useful work. (2000, 461)

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[72] 'Pound' and 'peso' are both monetary and physical units.

However, since usefulness and productivity are themselves ratios, these systems place beneath the joule numerator a joule/work, joule/tonne or joule/unit-of-GDP denominator. For instance, efficiency would be the ratio of joules to *the ratio of* joules/dollar; but then to define these aggregated ratios – now in the denominator – entails the original problems discussed above.

Can one solve aggregation problems by using joules in the *denominator as well as numerator*? What then distinguishes the input-joule from the output one? For instance, Ayres suggests a ratio of exergy to exergy – "available work of inputs" to "available work of final outputs" (1978, 52) – that offers no adequate distinguishing criterion; relying on the Second Law of thermodynamics' concept of entropy, this metric includes the *quality* (availability) of the joules rather than their mere *quantity*. He also proposes a "'first law' of energy efficiency" ("η"), the ratio of "energy transfer (of a desired kind) to total energy input" (44). Under this law, output joules are more *desired* or *economically* more valuable. In thermodynamic terms, this "transfer" could also be described as the *conversion* of energy with potential to *forms* which are actually useful. However, since the "energy input" must also have potential to do work, i.e. low entropy, it would be more accurate here to speak of *exergy* inputs.[73]

Enos likewise seeks a metric going beyond comparison of "products… in physical terms": for instance, when petroleum cracking increases gasoline's efficiency at the expense of fuel oil's, we don't know which is "better" [more useful]. (1958, 180, 183) Other attempts to overcome the disadvantages of joules, kilograms, and space (in ecological footprint metric) are made by van den Bergh, who proposes 'weighting' physical quantities by *economic* value (1999, 551, 559) and Dahlström & Ekins, whose "value chain analysis" technique attaches monetary flows to the traditional material flow analysis (MFA: Ayres 1978, 1998; Duchin & Lange 1994) categories of added

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[73] Can all output (our denominator) be reduced to work? Because physical objects are surely also 'output', one must at least integrate the concept of 'embedded energy [or exergy]'.

chemical elements, weight, waste, shape, and recycled tonnage. (2006, 509, 515, 518, 517; also Enos 1994)

Two issues arise from these attempts. First, the changes we seek to measure do not rely on the concepts of "desired" or "better". Second, having different *types* of joules in numerator and denominator can reveal important cases where input is higher than output, as when a number of fossil fuel joules yield a much lower number of maize ones. (Martinez-Alier 1987, Ch. 2) Such processes with intensities greater than unity are obviously sometimes economically desirable. EROI is another such a ratio, measuring joule investment over against joule 'return', the lowering of which, by making energy cheaper, is perhaps the cause of a special, economy-wide rebound.[74] If they are the same, a joule is like a seed which produces 100 seeds.[75]

Joan Robinson (1954) sought a non-monetary metric for technical progress, choosing the capital/labour ratio with capital physically measured as the "value of a stock of goods in terms of commodities" or "equipment, work-in-progress [and] materials" and labour measured in terms of time. (122, 65) She concluded, however, that "index-number ambiguities" are insoluble (64-65, 115): "Economics is the scientific study of wealth [our denominator], and yet we cannot measure wealth." (24; Victor 1991, 204-206)

However, is aggregation necessary? Can we not average physical ratios in different units over all sectors to arrive at a macroeconomic index? A recent computation of "domestic material consumption" in the EU-15 for instance, rejects metrics of weight, weight adjusted by life cycle analysis (LCA), and exergy, choosing instead a less aggregated MFA using fossil fuels, industrial minerals and ores, construction minerals and biomass. (Wiesz et al. 2006,

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[74] Rising EROI has caused falling real oil prices. (Smil 2003, 94, 76)

[75] Ayres & van den Bergh insist on counting high-entropy "process waste", the difference between "work done by the economic system [and] the exergy of all inputs". (2005, 103) Exergy is energy available for useful work or economic activity and unlike energy can be destroyed. (Ayres 1978, 52) This is consistent with older analyses of the conservation and transformation of matter to create utility. (Say 1803, 62, 387-388; Rae 1834, 29, 82, 99-100)

681) While the authors conclude that MFA is beset by the usual problems of incommensurability, change over time and “finding a common denominator for cross-country comparisons” (693), less aggregation suggests a solution.

In spite of the problems, if limited to particular sectors, many writers deem change over time to be physically measurable. Rosenberg traces the following:

1) efficiency in coke use for steel, which a century after Jevons was still rising from 1,900 pounds per ton of pig iron in 1949 to 1,200 pounds in 1968, and
2) efficiency increase in lamps rising between 1882 and 1945 enough to enable an 80-fold reduction in lighting price. (1982, 61, 65; Saunders 2000a, 445) According to Smil, “In 1900 efficiencies of thermal electricity generation… were as low as 5%. Today’s best thermal plants… have conversion efficiencies of just over 40% but cogeneration can raise this rate to almost 60%.” (2003, 22-23; Schurr 1982, 5) Two studies outside the OECD using physical measurements of average efficiency for certain types of capital are Roy (2000) and Glomsrod & Taoyuan (2005).

Jevons’ empirical measurements of efficiency increases were made explicitly in support of his backfire theory. (Alcott 2005, 17-18) Further, some recent authors find empirical evidence for rebound greater than unity, based on correlations of rising input-energy consumption and rising efficiency. Ausubel shows efficiency increases over roughly 200 years for:

> prime movers [steam engines], lamps, and ammonia production… measured as machines or processes for energy transformation [from coal to work or electricity to lumens] according to the second law of thermodynamics…. [I]t is clear that many engineering systems… tend to follow steady trajectories over long periods of time toward higher efficiency. (1989, 83-84)

Greenhalgh shows engineering efficiency gains of over 20% for household appliances in Denmark between 1977 and 1986, alongside rising electricity consumption. (1990, 297) Rudin does the same for U.S. energy use in commercial buildings (8% more efficient from 1979 to 1995) and cars (30%

from 1967 to 1997). (2000, 542-543) Smil likewise covers efficiency change and energy consumption. (2003, 6-14, 34, 41) Dahmus & Gutowski have undertaken the most systematic attempt to date to regress overall physical consumption upon efficiency gains in seven industrial sectors: globally and in joules/kilograms for pig iron, aluminium and nitrogen fertilisers and in the US e.g. for refrigerators and airplane travel (albeit in *passenger* kilometres). (2005)

Adding a third parameter to the efficiency-consumption equation, namely *prices,* reveals the dynamic relationship that higher material-input prices raise efficiency, but efficiency lowers material-input prices. (Smil 2003, 82-88, 149-161) Fouquet & Pearson (2006) show for the UK efficiency increases in lumens per watt (150) and strong correlations between such efficiency gains, lighting prices and lumen consumption (158-166). Their data shows that the price of a lumen-hour in 2000 was one three-thousandth of that in 1800, while the number of consumed lumen-hours rose twenty-five thousand times, yielding a theoretical price elasticity of demand. (173-174) One cannot, however, then correct this by a factor 'joule intensity of a lumen-hour' because the prices are also in terms of lumen-hours, not joules. However, especially since prices should not be treated fully exogenously, to interpret such correlations requires causal theory: even if the historical elasticities are precisely recorded between efficiencies, prices, and both inputs and outputs, one can always say that "*otherwise*" input consumption would have been *even higher*! (Schipper & Grubb 2000, 370)

6.6 Conclusion

1) A correlation, much less causation, between energy consumption and energy efficiency cannot be shown until the latter is clearly defined, the precondition for which is a clear and appropriate denominator.
2) Monetary denominators are convenient but inappropriate.
3) Methodology should start with demand for energy; it has not been shown that demand for energy *services* is necessary to study consumer

reaction to *technological* efficiency change; therefore service denominators are not appropriate.

4) Relatively unaggregated physical denominators have yet to be developed.
5) No metric for technological efficiency is sufficiently clear and appropriate for macroeconomic empirical work.
6) Studies conflating the three metrics are unfruitful.
7) In the literature, 'output' is used *ambiguously* to mean both specific products, processes, or sectors, and the whole economy.

Ten methodological problems of studying both *energy consumption* and rebound, conceptualised in the last three chapters, are evidenced by Schipper & Meyers' (1992) paradigmatic study:

- Population is uninfluenced by technology.
- Growth is only negatively influenced by technology.
- The GDP denominator is adopted in spite of its weaknesses.
- Technological and consumer ("operational") efficiency are conflated.
- Entire sectors and countries are excluded due to lack of data.
- Indirect (including international) rebound is largely ignored.
- Cost-effectiveness and effectiveness are conflated.
- Ratios of energy to service, service to sector, and sector to economy are used uncritically.
- While it is assumed that an aggregate metric is needed, none is achieved.
- The denominator changes from sector to sector as a "middle way".

The evidence for this chapter's conclusion that energy efficiency has indeed risen worldwide over decades relies only on a small sample of secondary engineering and economics literature. A physical efficiency metric would, however, aid in testing variables with standard statistical methods comparing countries (corrected for trade of embodied energy), comparing time periods within countries, and following changes in *rates of* change in efficiency and energy consumption.[76]

This chapter attempted to look at the forest in addition to the trees of the microeconomic tracing of rebound through all sectors and consumers. Yet even insofar as the variable *technological efficiency* is measurable at the world scale, this correlation establishes no causality: because technology only *enables* more output consumption – whatever the consequences for input consumption – both Jevons' theory and efficiency strategy theory must make explicit assumptions about consumer preferences for more consumption as opposed to reaping leisure and permanent input cuts from technology gains. That is, disagreement reigns over the counterfactual. While Jevons' theory indeed predicts the correlation, the efficiency strategy assumes that without efficiency increases (*"otherwise"*) consumption would have been *even higher*, i.e. to predict the correlation, it must explain rising consumption with further, Promethean factors. At the present, given the state of existing theory, further empirical research at the less-than-world scale seems unfruitful, yet a model including all sectors and all consumers does not yet exist.

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[76] Perhaps the literature on the price elasticity of technological efficiency when prices exogenously *rise* can illuminate elasticities when they *fall*. (Smil 2003, 82-88, 149-161)

Chapter 7 The Classical Economists

7.1 Introduction

The simultaneous growth of technical progress and wealth in 19th-century Europe was by all accounts visible and was attested by all classical economists. David Ricardo for example wrote:

> By the invention of machinery, by improvements in skill, by a better division of labour,… a million of men may produce double, or treble the amount of riches, of ‘necessaries, conveniences, and amusements,’ in one state of society, that they could produce in another. (1817, 273)

More specifically, William Stanley Jevons presented empirical data showing that steam engine and smelting efficiency rose alongside coal and iron consumption. (1865, 154, 261-271, 387-388) Jean-Baptiste Say went further, claiming causality between productivity and production:

> But whence is derived this… larger supply of wealth, that nobody pays for? From the increased command acquired by human intelligence over the productive powers and agents presented gratuitously by nature…. A power… before known and available is directed with superior skill and effect, as in the case of every improvement in mechanism, whereby human or animal power is assisted or expanded. (1803, 101; *Section 4.2*)

This chapter very briefly surveys the major writings of these authors and John Stuart Mill, John Rae, Thomas Robert Malthus and Adam Smith, in order to discover their arguments and conclusions concerning several themes relevant to the rebound debate:

- what efficiency, productivity, or ‘improvement’ is;
- the economic process of lower production costs and falling prices;
- the large societal income effect, i.e. increase in total output;
- the contribution of organisational efficiency and the consumer’s propensities;
- the possibility of causality and even backfire;
- the evidence that labour-saving improvements saved no labour;
- the possibility of satiation, leisure, and non-consumption; and
- that growth without technical progress is impossible.

7.2 From Efficiency to 'the Consumer'

The term 'arts' denoted science, technology and invention. It was clear that knowledge of nature led to 'improvement' of land and machine capital. In Rae's view invention and improvement

> …cause the same returns to be produced from a less expenditure, or greater returns, from the same expenditure….It is the intention of the inventive faculty, when it applies itself to the arts… [to] render the labor of the members of the society in which it operates more effective, and enable them from the same outlay to produce greater returns, or from less outlay to produce the same returns. (1834, 131, 258-259)

The concept of an improved input-output or expenditure-return ratio is similarly clear in Mill's statement that "any progress in those arts, any improved application of the objects or powers of nature to industrial uses, enables the same quantity and intensity of labour to raise a greater produce." (1848, 130) Smith had already distinguished productivity from increase in sheer *quantities* of inputs: To "…augment… the real revenue, the annual produce of the land and labour of… any society", one needed either *more* labour, or greater "improvement in… productive powers", depending on the ability of the worker and "upon the machinery with which he works." (1776, IV.ix.34-35)

The result of the enhancement of productive '*powers*' was seen to be lower prices. To illustrate lowered commodity prices, Ricardo employed the well-worn example of stockings, which, when efficiently produced, "would inevitable fall in [exchange-]value". (1817, 25) Malthus likewise observed that "…after very great improvements have been made in the machinery used in producing them," stockings "…can be made at half the price" without losing any use-value (1820, 241-242); "[I]mproved machinery" lowers costs and [w]e all allow that when the cost of production diminishes, a fall of price is the consequence" (60; 233). Charles Babbage described such engineering-economic processes in detail, for instance in the case of lowered costs in making tanks. (1832, 100) For Mill "expensive machinery… producing up to the full powers of the machine" lowered production costs such that the owner gained the "power of permanently underselling" previous suppliers. (1848, 133-134) For him the "productiveness of industry" causes "diminishing proportional [marginal] cost." (180-182).[77]

These lower prices meant a general income effect. Smith introduced the concept of the "agricultural surplus" resulting from reductions in "the real price of… manufactured produce". (1776, I.xi.o.4; also Mill 1848, 12-13, 411) Say's interpretation was that

> [e]very saving in the charges of production, that is to say, every saving in the productive agency exerted to raise the same product, is an increase of the revenue of the community to an equal extent. (1803, 295)

By "productive agency" he means land as well as labour; efficiency raises the total product or "revenue"; when a "new machine" lowers "charges of its production,… the revenue of the consumers is benefited." (87)

In Malthus' words, "[A] large mass of manufactured articles can be obtained with much greater facility than before… [and] the value of the whole mass of goods made by the new machinery greatly exceeds their former value." (1820, 49, 281) Rae's example of an "improvement in the art of baking bread" illustrates the point that "it would not benefit the bakers exclusively, but would be felt equally over the whole society…" (1834, 259; 118, 173) Mill identified a production function or "law of the increase of production", a consequence of both more "elements" or "requisites of production" and their greater "productiveness". (1848, 154)

These writers were describing the purchasing power that was freed or, more exactly, created:

> Invention is the only power on earth that can be said to create… It enters as an essential element into the process of the increase of national wealth, because that process is a creation, not an acquisition." (Rae 1834, 15)

An "acquisition" is taken from someone else, while the benefits of greater efficiency accrue to all – an aggregate income effect. Malthus claimed that

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[77] These observations constitute Khazzoom's "price element" in the relationship between input efficiency and input consumption. (1980, 22)

even if there were saturation in some area, "there would be a portion of revenue set free for the purchase of fresh commodities." (1820, 281)[78]

The new productivity, of course, being a ratio, only *enabled* greater production (and consumption). Say noted that "the productive agency thus released *may* be directed to the increase of production" (1803, 295, emphasis added), and Malthus added that we could choose "leisure" or "indolence" instead of the more cheaply available goods. (1820, 170, 268) Mill likewise insisted that the rise in consumption was contingent upon our not taking "leisure". (1848, 130, 133) In fact, after establishing that one purpose of "industrial improvement" is "abridging labour", he ironically claims that "[h]itherto it is questionable if all the mechanical inventions yet made have lightened the day's toil of any human being." (756-757)[79]

Rae also emphasized that all "instruments… possess a capacity for supplying the wants, or saving the labor of man." (1834, 166, 171) However, in the face of "invention" and increasing "total wealth of the community" he asked:

> What do we find to have been the most prominent accompaniment of this change [in improvement]? Is it a diminished expenditure – an increased parsimony – a frugality before unknown? I believe not. Any great diminution of the expenditure of a whole community, it will be found difficult to trace…(23)

We *mustn't* consume more, but, because of efficiency gains, we can, and usually do. Saturation is a change in people's tastes, not an efficiency change.

7.3 The Labour Analogy and Frozen Technology

Rae's and Jevons' analysis also included efficiency's role in opening up entirely new uses (*Section 4.5*), technological interdependencies recounted in

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[78] Not only Smith, but all these writers attributed wealth's increase to organisational efficiency as well as mechanical efficiency. (e.g. Rae 1834, 29, 95, 165, 314 and Mill 1848, 130-135, 184-189, 706-707).

[79] Veblen in his 400-page book broke his rule against citations exactly once, quoting this passage from Mill. (1899, 111)

detail by Babbage (1832). But do these income and invention effects add up to what we are calling backfire? Not having asked this question (until Jevons), there is of course no straightforward answer. But certainly much greater production ensued, *implying* more use of resources. Malthus summed up the chain of events by writing that if an article were to

> …vary in the difficulty of its production,… the cost of producing [it] were greatly diminished, the fall of price would… be occasioned by an increased abundance of supply, either actual or contingent. In almost all practical cases it would be an actual and permanent increase; because the competition of the sellers would lower the price, and it very rarely happens that a fall of price does not occasion an increased consumption…. It is known that facilities of production have the strongest tendency to open markets. (1820, 53-56, 287; 281)

Depending on what definition of "circulating capital" is taken – perhaps whatever is not 'fixed' – then Mill is perhaps describing resource use when attesting that

> transformations of capital are of the nature of improvements in production, which, instead of ultimately diminishing circulating capital, are the necessary conditions of its increase… [T]here is hardly any creation of fixed capital which, when it proves successful, does not cheapen the articles on which wages are habitually expended….[and] almost all improvents in machinery cheapen the labourer's clothing or lodging… (1848, 751)

Rae's speaks more directly to our question of material input consumption. For instance:

> The various agricultural improvements… with which invention enriched that art in Britain…, occasioned a great amount of material to be wrought up, which before lay dormant…. Sometimes a very small improvement may put a large range of materials within reach of the accumulative principle…" (1834, 261-262)

Furthermore,

> A multiplication of instruments is of no avail, unless something additional be given on which they may operate. When invention succeeds in discovering these additional riches, the mere view is sufficient, in every well regulated community, to induce its members to form the new instruments, necessary to draw these riches forth. (29)

Rae seems to be asserting that both outputs (end-products) and natural resource inputs experience greater demand.

But it was only on the topic of inputs of *labour* that the classical economists reached a consensus that higher productivity meant more, rather than less, employment than 'otherwise'. Malthus was particularly adamant on this point, which was sometimes doubted by Ricardo (Sraffa 1951, in Ricardo 1817, lvii-lx), tracing with the example of cotton machinery and manufactures the redundancy of workers in the short term but overall, longer term, the need for "more hands"; concerning employment, there was "little reason to apprehend any permanent evil from the increase of machinery." (1820, 281, 287)

Say (1820) delivered a scathing and detailed refutation of Sismondi on this score, always arguing that the *increased produce* at cheap prices was more than enough to re-employ workers no longer needed in the newly more efficient sectors. For reasons of space, this topic of the net effects on 'saving' more efficiently-used *labour* inputs cannot be pursued; however, the arguments are of great relevance to today's energy-efficiency rebound debate. By Jevons' time, in any case, economists had concluded that 'labour-saving' processes saved no labour; especially taking into account population increase, they raised employment levels. (Jevons 1865, 140)[80]

Similar to Jevons, who argued that the population and affluence of mid-19th-century Britain is unimaginable at the efficiency level of Savery's steam engine (1865, 143, 118; Alcott 2005, 15-16), Say asks us to assume the opposite, namely an efficiency decline:

> By the rule of contraries, as a real advance of price must always proceed from a deficiency in the product raised by equal productive means, it is attended by a diminution in the general stock of wealth. (302)

We ask after the consequences of technological efficiency increases, but Say challenges us to assume the opposite and see if this could conceivably lead to higher input consumption. Are today's levels of consumption possible under the assumption of technology frozen at some earlier historical level?

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[80] See also Smith, IV.ix.34; Say, 86-90; Jones 1831, 249-250; Mill, 63, 66, 92, 100-115; Greenberg 1990.

An *anonymous* writer similarly took the argument at its word that labour efficiency gains led to less population and affluence:

> If the use of machinery is calculated to diminish the fund out of which labourers are supported, then by giving up the use of the plough and the harrow and returning to the pastoral state, or by scratching the earth with our nails, the produce of the soil would be adequate to the maintenance of a much greater number of labourers. There are many labourers now in England, and the gradations of ingenuity and skill in machinery are numerous; but as the number of labourers and the funds for their support would be gradually increased in proportion as we fell back upon the less perfect machinery, so, at last, when we deprived ourselves entirely of its assistance, the produce and hence the population of England would be increased beyond what has ever been exhibited in any country upon the surface of the globe.... (Anon. 1826, 102)[81]

The efficiency strategy theory holds that higher efficiency causes less resource consumption; turned around, lower efficiency would then raise consumption.

Say, as well, adds this *obverse* argument:

> A country is rich and plentiful, in proportion as the price of commodities is low. For argument's sake, I will put the matter in the most favourable light for those who dispute this maxim, and suppose them to urge an extreme case, namely, that, by successive economical reductions, the charges of production are at length reduced to nothing;… What then?… Every object of human want would stand in the same predicament as the air or the water [Smith 1776, I.iv.13; Lauderdale 1804, 43-45], which are consumed without the necessity of being either produced or purchased. In like manner as every one is rich enough to provide himself with air, so would he be to provide himself with every other imaginable product. (303-304)

That is, if efficiency causes price and cost-of-production decrease, raising demand, imagine the situation if production costs fell to zero. According to this *reductio ad absurdum,* to the extent that consumption entails emissions and human appropriation of space, at lower efficiency population and environmental impact would be astronomical. This reasoning must be countered by today's efficiency strategists.

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[81] Anon. then chides Ricardo for entertaining the anti-machine position.

7.4 Conclusion

The first and to date most exhaustive treatment of our question is Jevons' *The Coal Question* (1865), whose arguments the author has elsewhere analysed (Alcott 2005). Jevons' predecessors commented on the eight topics listed at this chapter's beginning, and only indirectly on the resource-consumption rebound question. However, their interpretations of the palpable correlation between a growing economy and greater productivity is closer to the backfire position of Jevons than the 'savings' position of energy efficiency strategists. Deeper analysis of these thinkers seems advisable. In particular, an exact analysis of the 19th-century debate over rebound and backfire concerning *labour* inputs might reveal that today's debate over material and energy inputs is re-inventing the wheel.

Chapter 8 Discussion

8.1 Concepts

Estimates of total rebound range at least from 26% (4CMR 2006, 6) to significantly over 100% (Jevons 1865; Brookes *passim.*; Saunders *passim.*) This fact suggests that there are issues of definition, taxonomy, scope of study, and assumptions in baseline scenarios that are unresolved. Until this kind of groundwork is done, this variation will continue to prevent useful policy advice, the more so because the two extremes recommend contradictory policies. The concepts of energy 'services', 'useful' work,[82] and 'economic activity', for instance, are perhaps superfluous, and blur distinctions concerning *what* consumption is being measured in rebound study. The cacaphonous array of types of rebound, furthermore, confuse discussion.

For example, is the term 'energy' for joules (a measure for energy as well as work), or 'useful' work? Is the distinction between exergy and energy useful? When we purportedly consume services, are these, for example, 'car kilometres', 'passenger kilometres', or even the pure utility of the act? The most damaging ambiguity, however, concerns 'output', 'production', 'economic activity' and 'growth': Are these physical, monetary, or welfare units? If the last, then it is true that 'economic growth and stable or declining resource consumption are compatible. If the first, this is (tautologically) false. The conceptual difficulty about 'declining energy content of consumption', 'structural' change and 'dematerialisation' or *decoupling* is: *From what* are the inputs decoupled? If from 'service' or 'utility' or 'welfare', then it must be shown that the concept is relevant for the study of environmental impact and more specifically rebound. If from physical output, though, then this *is* technological efficiency increase, and any claim that it weakens rebound effects *begs the question*.

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[82] The anthropocentricity of the concept of useful work is illustrated by the case of the 'waste' heat from nuclear power plants at the ocean's edge: if technology exists to use this for desalination of water, the same type (form) and amount of energy has become 'useful'.

8.2 Policy Alternatives

'Efficiency' is positively connotated (Moezzi 2000; Sanne 2002); do we sense that it is no threat to material welfare?[83] The 'factor four' political-economic vision seeks after all to cut resource consumption in half *and double affluence*. The rare political unanimity in favour of efficiency policies – encompassing Greens and Conservatives, George Bush and Gordon Brown – is even predicted by backfire theory, as Jevons intimated. (1865, 136, 460) The rival quota strategy – caps and permits – faces ecological limits more clearly and dethrones the goal of maintaining material affluence as one which *must* be fulfilled. It is not only the principle of the Kyoto Protocol (also Bodansky 1993, 509), but receives academic attention (Daly 1974, 19-20; Hannon 1975, 101; Greenhalgh 1990, 296-297; Victor 1991, 209; Jacobs 1991, 123; Starkey & Anderson 2004; Simms 2005; Aubauer 2006, 644-646). Quotas are, with good reason, not positively connotated; i.e. if we want to conserve, or lower impact, "[i]t would be more straightforward to direct that there should be reductions in 'world economic activity', of specific emissions, or seek worldwide agreement to placing heavy taxes on the offending fuels." (Brookes 1990, 201)

There is a parallel to more local problems; Owens & Cowell observe that because it is so difficult to reduce

> the rate of traffic growth… a view that policy should focus on reducing pollution and congestion, rather than the volume of traffic *per se,* has prevailed, conveniently shifting attention towards vehicle performance, traffic management and selected improvements in the road network. (2002, 97)

Just as economic growth weakens concern for distributional justice problems, focussing attention on efficiency, something that is relative, familiar, and 'positive', takes attention *away from* the necessity for absolute global limits to consumption and pollution. Yet "the presence of backfire… does imply that environmental benefits cannot be guaranteed by such policies alone." (Allan

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[83] Glomsrød & Taoyuan "bring attention to the possibility that [more efficiency resulting from] coal cleaning is a case for economic efficiency more than energy saving and climate policy." (2005, 536)

et al. 2006, 51) If our main criterion is *effectiveness,* however, limits must be "established by prior [exomarket] law". (Stewart 2000, 212-214)

Decisions about population, affluence, and efficiency would then take care of themselves:

> Under carbon rationing, the rationing scheme itself should provide all the incentive that individuals would need to search out the lower carbon energy supplies, lower energy using products and services and so on…. No longer would it be necessary to have separate government policies and programmes to promote everything from cycling strategies to efficient refrigerators. (Fawcett 2004, 1078, 1077)

Thus, quotas are probably more *cost-effective* as well.

It seems that many if not most economists, starting with Smith, regard efficiency as a cause of larger economic size, physically as well as in terms of welfare. Efficiency of all sorts is usually seen as a means toward affluence. Thus the view must be contradicted that "Periodically, claims [of backfire] surface…" (Schipper & Grubb 2000, 367); instead, efficiency's harnessing for environmental purposes seems to be the exception, happening during the coal supply worries of the mid-19th century and the depletion and pollution crisis starting in the 1960s.

8.3 Frozen Technology

Malthus believed that *lower* efficiency causes lower material welfare in the sense of lower input consumption, in this *case agricultural land*:

> Even in our agriculture, if the fixed capital of horses, which from the quantity of produce they consume, is the most disadvantageous description of fixed capital, were disused [an efficiency loss], it is probably, that a great part of the land which now bears corn would be thrown out of cultivation. Land of a poor quality would never yield sufficient to pay the labour of cultivating with the spade, of bringing manure to distant fields in barrows, and of carrying the products of the earth to distant markets by the same sort of conveyance. (1820, 192)

Efficiency-strategy theory, on the other hand, must maintain the opposite: if more efficiency causes less total input use, then less efficiency must cause more use. This leads us again to the thought experiment of holding technological efficiency *frozen.* Again, Jevons' insight: Savery's engine *“consumed no coal, because its rate of consumption was too high.”* (1865, 118, 143) Even at Watt’s highest efficiency levels, would we have been *able* in terms of time, population, distances travelled, and machine capital to consume as much as humans do today? This seems *implausible*; we would for instance probably have no railroads, cement, or irrigation pumps.

Or, following Say (*Section 7.3*): Holding technological efficiency change (increase) as it has in fact been since, for instance, 1781, what must the efficiency-strategy (anti-backfire) theory predict about today’s levels of consumption (population times affluence)? It must predict that these have *fallen*. However, this scenario seems not only counter-factual but unimaginable. The theory has it that we consume more things without their being offered more efficiently than when they are offered more efficiently – and without thereby having freed time. Inputs are no longer ‘normal goods’. *As inputs become more costly, we consume more of them.*

This reasoning is behind Wirl’s suggesting the policy possibility that “highly uneconomical [light]bulbs are prescribed,” which would result in a “reversal of... rebound”. (1997, 39) Hotelling likewise noted:

> The method ordinarily proposed to stop the wholesale devastation of irreplaceable natural resources, or of natural resources replaceable only with difficulty and long delay, is to forbid production at certain times and in certain regions or to hamper production by insisting that obsolete and inefficient methods be continued. (1931, 137)

The rebound discussion should open itself to this corollary of efficiency strategy theory, just as Jevons’ theory must explain any real-world decreases in consumption rates – and even decreases in rates of increase.

Finally, perhaps we should ignore the concepts of engineering savings and rebound and use growth theory ‘positively’ to explain the consumed amounts of inputs – of energy as well as any other material, land, labour, and time. Baseline trends would no longer have a ‘technology’ factor lowering input consumption, and the backfire question would be open. World studies using physical denominators for ‘efficiency’ seem the most promising path upon which to do this. Still, we have a paradox: perhaps demand for ‘output’ does not imply proportional demand for ‘input’.

Chapter 9 Conclusions

9.1 By Chapter

ONE *Chapter 1* identified the energy-efficiency environmental strategy, its popularity, and Jevons' challenge to it. The topic remains a *paradox*: Given ratio decreases of energy intensity for a given product or process, how can aggregate energy consumption continue to increase *because of* this (or is it *in spite of* this)?

TWO For rebound study a clear concept of *engineering savings* is indispensable, of which rebound is a percentage; *rebound* is only that consumption enabled by efficiency increases. The mechanism enabling more consumption is at once lower production costs and prices, enhanced purchasing power, and substitution for other production factors. Although rebound's existence is indubitable, practically all evaluations of efficiency policies' effectiveness ignore it in computing '*energy savings*' and in quantifying consumption trends without policies. Correction of engineering savings (or potential savings) by a factor of perhaps 0.5 is justifiable.

THREE Like organisational efficiency and consumption efficiency, technological efficiency influences the size of the ratio T in $I=PAT$. Since however the size of this ratio influences P and A there is no necessary effect on I. We thus cannot assume, as does the efficiency strategy, that lower T means lower I, and thus $I=f(P,A,T)$ is accurate: any change on the right side can change the other two factors. Deducing an absolute quantity for I is in any case not possible from the ratio T. I.e. dynamic economic facts complicate the static engineering facts used in evaluations. Lower T causally reduces I only to the degree that consumers are materially, or energetically, *satiated*. Testing the EKC hypothesis – that this is a function of rising income – requires clarity about whether the quantities in the dependent variable are absolute, or are themselves ratios.

FOUR While the newly created or 'freed' purchasing power *can* be availed of, it does not *have to* be, i.e. previously impossible engineering savings do become potential. It is availed of *for* the same or other goods *by* the same or other, ‘marginal’ consumers, yielding a suggested taxonomy to replace the plethora of terms in the literature. The new relative cheapness and productiveness of energy can mean, through a substitution effect, that the newly demanded goods have a relatively high energy ‘content’, perhaps countervailing any saturation effect purported to result from the higher income (EKC hypothesis).

Policy advice based only on direct rebound, rather than total rebound, is not useful. Academic studies should take only total rebound as their ultimate study object, using direct rebound information only as a starting point and specifying the role of direct rebound study in total rebound study. Moreover, because of trade and the global nature of many impacts, country studies are misleading. Finally, much influential literature suffers from unclear definitions and inconsistent application of taxonomy.

FIVE If efficiency increases raise the purchasing power of more people, for more goods, then part of rises in population and production must be counted as rebound. That is, levels of population and ‘economic activity’ are not determined totally exogenously as assumed in most models. Rebound is by definition only that consumption caused by greater production efficiency, not all growth forces. In making counterfactual claims about real energy savings, assumptions of the real-savings effects of efficiency beg the question.

Because rebound is nothing more than a percentage of potential savings, energy’s share of total GDP is not relevant to its measurement. Similarly, the costs of efficiency increases influence the size of engineering savings, but not of rebound. Finally, it has not been shown that when sectors characterised by market failure experience efficiency improvements, income or price effects are lower than in situations of greater competition, information, or motivation. Whether ‘barriers’ to efficiency increases are *environmentally* good or bad depends on the backfire issue, but in any case rebound science should cease to conflate goals of lower impact and greater *economic* efficiency.

SIX Defining efficiency for narrowly defined products or sectors is possible, despite problems with new products and/or changing characteristics of similar products; computations based on these definitions, after all, yield the key quantity ‘engineering savings’. However, if we investigate the forest instead of the trees, defining and calibrating technological efficiency for the world economy is difficult. Do we need fully aggregate numerators and denominators? Do we define denominators in terms of money, ‘services’ or physical units like space, weight, or chemical elements? The problems of GDP are severe, and ‘service’ has not been shown to be relevant to rebound study, leading to the conclusion that physical metrics should be sought, perhaps averaging efficiency increases, in percentages, over differently-measured sectors.

Nevertheless consensus reigns on a broad correlation – over time and national economies – between lower energy input *per* unit of each of the above denominators and rising consumption of energy. If this is mere correlation rather than causality, other causes must explain the observed rise in consumption. If rising efficiency causes *lower* input consumption, the forces that do explain consumption’s rise must moreover be strong enough to overcome this ‘shrinkage effect’ of greater efficiency. Empirical statistical methods to answer the backfire question, presupposing an answer to the vexing question of denominators, must study world, total rebound. Yet the opinion that rebound is ‘only an empirical question’ is incorrect because designing such research presupposes some theory.

SEVEN Jevons deemed his paradox easily solved. Perhaps this was because his predecessors Smith, Say, Ricardo, Malthus, Babbage, Rae, Hearn and Mill had constructed plausible accounts of economic growth – in rough agreement with the later results of Solow – which explained the size of the economy, the amount of ‘wealth’, in terms of organisational and technological efficiencies concerning labour and, less specifically, material/energy inputs. These writers attested efficiency-induced price falls, purchasing power effects, expanding markets, and increasing numbers of non-satiated consumers – as well as what we now call backfire with regard to employment inputs.

9.2 General

The answer to the dissertation’s title question is that assessments of energy efficiency policy should take rebound into account. Whether *backfire* should be taken into account is still debatable. While backfire theory predicts the rise of some combination of population and affluence alongside greater energy consumption, this is not proof. In particular, any theory must make assumptions about consumer saturation – the only force that lowers rebound. Increase in the efficiency of any input frees that input, but this only *enables* us to thereafter use more of it at no cost; efficiency gain is only a *necessary* condition of greater consumption of that input, just as it is a necessary condition of more leisure and non-consumption. The *sufficient* condition for higher consumption depends on the world demand function.[84] That is, the price and income elasticity of demand is necessary to determine the efficiency elasticity of demand. Yet policy must make assumptions about consumer behaviour based on less than full empirical knowledge, necessitating some theory of consumer psychology. Efficiency enables backfire, and not just rebound up to unity; it expands the production *possibility* frontier. Therefore, if worldwide latent demand is judged to be great, there is danger that forcing efficiency is environmentally counter-productive.

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[84] Malthus' "population principle" was the identical argument: neither increased subsistence nor our "tendency" to reproduce were *sufficient* for population growth. (1798, 19, 33, 76-78, 115)

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