

Historical Overview of the Jevons Paradox in the Literature

by Blake Alcott

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Epigraph

[In] a stationary condition of capital and population... the industrial arts might be as earnestly and successfully cultivated, with this sole difference, that instead of serving no purpose but the increase of wealth, industrial improvements would produce their legitimate effect, that of abridging labour. Hitherto it is questionable if all the mechanical inventions yet made have lightened the day's toil of any human being. They have enabled a greater population to live the same life of drudgery and imprisonment, and an increased number of manufacturers and others to make fortunes.

– John Stuart Mill (1848), *Principles of Political Economy*, pp756-757

Introduction

For William Stanley Jevons's immediate predecessor Mill, according to the above epigraph, the legitimate effect of 'industrial improvements' such as efficiency increases would be less work per capita. This is, after all, *enabled by* labour-efficiency increases at the same level of affluence. In the same manner, today's environmental strategy of technological efficiency holds that the legitimate effect of *energy*-efficiency improvements is less energy consumption at the same or an even higher level of affluence. Jevons asked, and to his satisfaction answered, the question of whether energy efficiency by itself leads to this hoped-for result or whether it leads to the same or even a higher rate of energy-resource consumption. He titled the seventh chapter of his 1865 book *The Coal Question* 'Of the Economy of Fuel', which confronts us with the 'paradox' that less fuel consumption per unit of equipment causes greater total consumption (p141). Fuel can be 'saved' per unit while not at all being 'spared' for posterity's use (p155).

The fuel in question was the coal to which Britain owed its affluence, power and civilization; the worry was that supplies, especially easily-mined ones, were dwindling fast. Some experts advised not to worry because coal's use in steam-

engines, smelting and so forth was becoming more and more efficient, a view to which Jevons objected by means of his 460-page argument that 'it is the very economy of its use which leads to its extensive consumption' (p141). And while today's fuel worries concern pollution somewhat more than depletion, the paradox remains. Why otherwise would virtually all governmental bodies, green lobby groups and the greater part of public opinion favour efficiency increases to reduce our rate of overall consumption?

Yet many academics take Jevons's part in doubting this.

To his brief statement of his thesis Jevons cheekily added,

Nor is it difficult to see how this paradox arises... It needs but little reflection to see that the whole of our present vast industrial system, and its consequent consumption of coal, has chiefly arisen from successive measures of economy. (pp141-142)

Today however the *solution* of the paradox is requiring a great deal of reflection, of which the present book is a part. The revival of Jevons's argument by Leonard Brookes (1978 and 1979) and Daniel Khazzoom (1980), both of whom doubted the environmental efficacy of the efficiency standards for cars, refrigerators, houses and light bulbs that were being enacted in the decade that saw the Club of Rome report¹ and OPEC fuel price hikes, opened a heated debate. In Khazzoom's words,

changes in appliance efficiency have a price content... [W]ith increased productivity comes a decline in the effective price of commodities, and... demand does not remain constant... but tends to increase. (1980, pp22-23)

While this new/old insight that efficiency increases trigger *some* additional input consumption – known by the cute technical term *rebound* – was readily acknowledged by all, a school of thought emerged regarding it as 'insignificant' (Lovins, 1988, pp156-157) or 'small' (Schipper & Grubb, 2000, pp367-368, 394-386), meaning that greater efficiency would indeed bring net resource savings. Empirical attempts to measure economy-wide rebound have failed, and theorists have indecisively argued the pros and cons of Jevons's extreme and very important thesis that rebound is not only significant but in truth greater than the savings theoretically possible when equipment becomes more efficient and demand stays constant.

¹ Meadows et al., 1972.

This rebound of more than 100 per cent of theoretical 'engineering savings' is called *backfire* because in this case environmentally motivated efficiency measures are counterproductive. As we will see Jevons's economist predecessors made Khazzoom's point of rebound's necessity in countless passages in their treatises on the principles of political economy. Concerning Jevons's backfire thesis, however, they were largely silent: the question had not yet arisen. Nevertheless, some of their time-tested insights can aid today's search for a definitive answer to how much energy consumption results from greater energy efficiency – an assistance sorely needed in a debate plagued by rudimentary difficulties of definition, taxonomy and methodology (Sorrell and Dimitropoulos, 2006)

Some of the open questions are as follows:

- What is energy efficiency? While energy inputs are perhaps easily defined and measured, with what outputs are they to be compared? Are these in physical, monetary or welfare units?
- What is the strict definition of rebound? Of what, exactly, is it a percentage?
- What would a proof of backfire even look like? What, for that matter, would a proof that greater efficiency begets real savings look like?
- Do we even need the concepts of theoretically possible savings, rebound and backfire, or can we, for example, describe a production function then note that if a factor such as energy becomes relatively more productive, demand for it goes up, perhaps more than it would have otherwise?
- Can one fully trace consumers' reactions to their increased purchasing power (income effect) resulting from lower prices?
- Can we, for instance, measure efficiency elasticities of price and then price elasticities of demand for both the goods and services and the primary energy inputs themselves?
- Many approximations exist for *direct* rebound, in other words the energy-consumption increase entailed by increased consumption of goods and services produced more energy-efficiently. But of what use is this in measuring *indirect* rebound and then the environmentally relevant quantity *total* rebound?
- Is macroeconomic empirical work – regression analysis with energy consumption as the dependent and energy efficiency as an independent variable – even possible? (see Polimeni, this volume)
- At what scale is such work fruitful? Are studies limited to sectors, countries or groups of countries (usually OECD) helpful?

- Can standard models of energy consumption continue treating population size and GDP as wholly exogenous, or are they themselves partly a function of energy efficiency?
- Can we assume that human beings will continue to multiply and consume rather than take 'efficiency dividends' in the form of less reproduction, work and production?
- What is the experience of the last three centuries with increasing *labour-input* efficiency? Have these caused less population and employment, in other words was rebound less than 100 per cent?²

Discouraged by this state of affairs in rebound research, I took inspiration from the title of Jevons's first chapter, 'The opinions of previous writers', and turned to the classical political economists. To be sure, the writers Jevons surveyed by name were not the 'old-timers' of political economy but rather geologists, politicians and mining engineers. Nevertheless, it seems clear that it was the economics texts of the 19th century that gave Jevons much confidence in his thesis and that discouraged challenges by later economists.³ By *The Coal Question's* posthumous third edition of 1906, petroleum had certainly taken the pressure off coal just as coal had taken the pressure off wood (Jevons, pp183-185; Hearn, 1864, pp194-195), but how could succeeding economists resist the chance to wrestle with a paradox unless the consensus saw the question as settled?⁴ For Thorstein Veblen, for instance, it was sure knowledge that latent demand would lap up every efficiency gain (1899, pp32, 110, 241), and Harold Hotelling wrote that the goal of resource conservation, traditionally, was pursued by either proscribing production or prescribing inefficiency (1931, p137).

² In our epigraph Mill is stating that labour-'saving' production processes have led to greater demand for labour: with α as an efficiency coefficient, $\alpha L \uparrow \rightarrow L \uparrow$. With this passage from Mill Karl Marx opened his chapter 'Machinery and Modern Industry' (p323) and Thorstein Veblen broke for the only time his rule of not quoting or citing anybody (1899, ppx, 111). Jevons's claim, taking E for fuel and β as its efficiency coefficient, is that $E = f(\beta E)$, namely $\beta E \uparrow \rightarrow E \uparrow$.

³ The only challenge known to me is that of Mundella (1878).

⁴ After granting the physiocrats a germ of truth concerning the priority of land-product surplus, Smith allows himself a joke at their expense (and perhaps that of the present elucidators of Jevons' paradox): '[A]s men are fond of paradoxes, and of appearing to understand what surpasses the comprehension of ordinary people, the paradox which it maintains, concerning the unproductive nature of manufacturing labour, has not perhaps contributed a little to increase the number of its admirers.' (1776, IV.ix.37-38)

With due respect for the efficiency conundrum – how can per-unit efficiency be outweighed by the the sheer number of consumed units? – but with the reassurance that a paradox is only an *apparent* contradiction, let us examine the main works of William Petty (1675), Richard Cantillon (1755), Adam Smith (1776), Jean-Baptiste Say (1803), Lord Lauderdale (1804), David Ricardo (1817), Jean Simonde de Sismondi (1819), Thomas Robert Malthus (1820), John McCulloch (1825), Richard Jones (1831), Charles Babbage (1832), John Rae (1834), John Stuart Mill (1848), William Hearn (1864) and Karl Marx (1887).⁵ Jevons mentions, and extremely favourably, only Babbage, Mill and Hearn, but all dealt explicitly with efficiency and named it as a cause in their explanations of the increases in population and wealth so palpable in Europe and North America. Efficiencies of varied provenance were increasing: of the individual labourer, of the organization of production, of the institutions of society, and of the technology of using tools, mills, machines, energy and materials, the last constituting Jevons's and our realm of interest. Although for them the increase in demand for labour, land, coal and metals was no less palpable, on our question of whether this increase in wealth entailed an increase in consumption of these *inputs* to wealth, they shed only indirect light. Yet because their and Jevons's analyses contain all the concepts in today's debate, they offer a chance to clear up our thinking. To be sure, today's bone of contention – whether greater consumption of inputs is *due to* (Brookes, 2000, p356; Moezzi, 2000, pp525-526) or *despite* (Howarth, 1997, p3; Schipper & Grubb, 2000, p370) efficiency increases – was not buried for us until Jevons's book of 1865.

Our 'previous writers' did, however, close in on the gist of our subject in their lengthy debate over *labour* as opposed to *energy* efficiency. Alongside energy, space and materials, no production can do without the input of working hours, and it was indeed in terms of labour productivity that 'progress' in the 'arts' of agriculture and manufacture was defined, as when Jevons refers to the labour-

⁵ The named years of publication are those of first editions, cited here except for Say (4th edition 1819), Ricardo (3rd edition 1821), Sismondi (2nd edition 1827), Malthus (2nd edition 1836) and Jevons (3rd edition 1906). *These dates are understood and omitted in all references.* If other writings by these authors are cited, the date is given in the parentheses, for example (Malthus, 1798) or (Say, 1820).

saving invention of gunpowder (p105). Their examples of the making of pins, books, stockings, metal and flour were expressed in terms of output per worker or per man-hour, and analogous to energy inputs one could and did argue that such 'progress' meant unemployment. In his curt rejection of this argument (p140), Jevons was standing on an explicit controversy involving not only Luddites, Owenites and industrialists but also Say against Sismondi and, with more ambiguity, Malthus and McCulloch against Ricardo (and also, later, Marx, Part IV, Ch. XV). Note that in terms of today's debate the position taken by Sismondi that work efficiency causes less total work is analogous to today's position that energy efficiency effects a rebound of less than unity: unemployment, that is, of either labour or fossil fuels. If labour inputs are really saved, *ceteris paribus*, by increasing the efficiency of their use, then any growth in work-hours (including population) must be due to other factors. The contrary position, taken by Say, holds that those immediately and distressingly laid off will find work, albeit usually not in their former occupation. Employment increase can even 'backfire': saving work per unit creates more work overall – our paradox.

This chapter is not organized chronologically but according to concepts and arguments used in today's debate. Statements by the 'old-timers' are enriched with references to similar contemporary ones. The categories are:

- What is output/input efficiency?
- How is the output numerator defined?
- Do efficiency increases cause wealth increases?
- How does efficiency change affect prices and profitability?
- Do efficiency increases amount to a societal free lunch?
- Is rebound proven?
- Do consumers choose further consumption or indolence?
- Is backfire proven?
- How do we deal with population growth?
- Is there technological unemployment?
- What would resource and labour consumption be if technological efficiency had not increased?

Jevons' own conclusions and arguments have been analyzed previously (Alcott, 2005) and are here spread throughout the text.

Please keep these methodological points in mind:

- We are asking whether lower energy or labour inputs per unit of 'product' *cause* lower input consumption economy-wide; our independent variable is thus a ratio. Our dependent variable, on the other hand, is a total or absolute amount, namely of resource depletion or emissions – the values of interest to the environmental problem since, metaphorically speaking, the environment does not 'care about' *ratios* of outputs and inputs or of consumption or pollution per person or per unit of GDP or per rich or poor nation.⁶ The formal problem confronting all rebound measurement is that it is impossible to derive an absolute number from a ratio or change in a ratio; without further factual information, an 'extensive' number cannot be deduced from an 'intensive' one. (Giampietro & Mayumi, 2000, pp183-187, 191, and this volume)
- Must we seek *necessary* connections? In our case this would involve assumptions regarding human nature and the particularities of human societies, mainly whether or not consumers, including marginal ones, are satiated. Absolute saturation regarding all goods and services would mean rebound of zero; the income effect would disappear because people would choose to earn and spend less and theoretical 'engineering' savings would equal real savings. But with any positive price elasticity of demand we have some additional consumption. Thus we must always compute or judge the probability that consumers will keep doing more-or-less like their parents did (Jevons, pp192-196).⁷
- A long-time world-wide regression analysis would have to include data on energy efficiency, energy consumption and energy prices. The latter two can be traced with some certainty,⁸ but, as we shall see, efficiency presents severe data and definitional difficulties. Since products and activities come and go, over time the 'output' part of our ratio is a moving target (Rosenberg, 1982, 1994; Giampietro & Mayumi, this volume) Must we resort to that workhorse GDP, or can we find *physical* output metrics like 'useful work' or 'exergy' or tons or volumes, perhaps unaggregated? We would also have to control for other factors like non-technological

⁶ Most Environmental Kuznets Curve (EKC) studies suffer the fatal flaw of showing ratios on the vertical axis; for critiques see Jänicke et al., 1989; Opschoor, 1995; De Bruyn & Opschoor, 1997; Alcott, 2006, Section 3.5; Luzzati & Orsini, 2007; Giampietro & Mayumi, this volume.

⁷ This belongs to our *ceteris paribus* just as did Malthus' two 'postulata' for his principle of population, namely that we need food and that there is passion between the sexes. (1798, p19) And it was Malthus who insisted that following a labour-efficiency increase we could always choose 'indolence' (p258).

⁸ See for example Jevons, pp85, 91, 256; Schurr & Netschert, 1960; Cleveland et al., 1984; Schurr, 1985; Smil, 2003, pp6-14, 22-34, 82-88.

efficiency increases⁹ and partially-exogenous population and wealth.¹⁰ Nevertheless, few would deny that technological efficiency has increased, and regression analysis offers undisputed insights (Polimeni, this volume).

- *Direct* rebound is a pet subject of study, but in and of itself is not relevant for environmental policy, which needs to know total, or 'economy-wide', rebound adjusted for trade of embodied energy. If nevertheless computed, researchers owe us a demonstration of *how* to use it in calculating *total* rebound. At the minimum, the ambiguity in much literature as to which rebound is being discussed must be eliminated (Greening et al., 2000, pp390-392; Berkout et al., 2000, pp425-431).

Please recall the urgency of this policy question. Depletion and pollution concerns are both inexorable and ethically binding. Among Jevons's many emotional passages are those where he attests the 'religious importance' of the coal question, where he laments living off 'a capital which yields no annual interest' or where he quotes Drayton concerning the fuel voracity of the iron industry: 'These iron times breed none that mind posterity' (pp14, 412, 373, 136). Moreover, Jevons advocated using coal-given prosperity for posterity and for a sort of soft landing at coal's limits (ppxlvi-xlvi, 4, 37, 156, 184, 195, 200, 232, 274-275, 455; Boulding, 1966). Running out of fossil fuels can, however, be spread over a long time horizon or ameliorated by using them as embodied energy in renewable energy installations. But two other sets of concerns stand no postponement: first, and obviously, our present and intensifying planetary greenhouse with its welfare consequences; second, and today often ignored, the side-effects of the machines and infrastructure that enable and embody energy efficiency: noise, accidents, public ugliness, local air pollution, overuse of freshwater, monotonous work, and so on. The community of ecological and environmental economists should waste no more time in delivering a decisive, policy-useful *judgment* on this question: is efficiency part of the solution or part of the problem?

⁹ For example stemming from education, training, increased effort, Taylorite factor-floor organization, free trade, scientific norms, private property and further cutters of transaction costs.

¹⁰ For empirical *sectoral* correlations see Jevons (pp193-194, 232, 275, 154, 387-388); Greenhalgh, 1990; Rudin, 2000; Dahmus & Gutowski, 2005; Pearson & Fouquet, 2005; and Herring, 2006.

What is efficiency?

Like all cost-cutting efficiency increases, energy efficiency until recently exclusively served the goals of higher profits and greater average affluence. Insofar as the costs of the efficiency introduction itself could be amortized, they are the business-as-usual maximization of material well-being. This fact is today often downplayed or ignored when energy efficiency increases are singled out to serve the contrasting *environmental* goal of lowering the yearly rate of energy consumption and/or pollution. In whichever way they are perceived, though, they are the starting point and logical centre of our investigation. As such they warrant careful definition and taxonomy.

Throughout the following examination of our authors' definitions of efficiency it is axiomatic that efficiency denotes a *ratio*. The numerator is output and the denominator is (energy) input. 'Efficacy', 'effectiveness' or more ambiguously 'power' denote in contrast the causation of a given amount of output regardless of cost or input. Ontologically, the thing that is more or less efficient is the input. In classical parlance, *power* resided in the inputs labour and nature, measurable in terms of what a certain amount of these could *produce*; the classical production function was $Q = f(\beta M, M, \alpha L, L)$, where M was material/energy, L was labour and the Greek letters were productivity co-efficients.¹¹ The ubiquitous classical concept of 'productive power' thus implies, like the Latin-based term efficiency, both a 'making' and an 'out of something'. The inverse of efficiency is *intensity* as in the 'material intensity of production' common in today's environmental-efficiency discussion (Schmidt-Bleeck, 1994; Hinterberger et al., 1997; von Weizsäcker et al., 1997). The ratio describes, moreover, the amount of input *per unit* of output. Finally, we are not investigating *consumption* efficiency – for example boiling only the amount of

¹¹ The *causes* of efficiency however lie perhaps ontologically in capital or organization: the piston, the hot blast and the factory system changed, not coal or iron ore or human beings. Yet classically capital was usually reduced to labour and land, as insisted upon also by Schumpeter (1911, pp20-21, 29, 37, 210-219); this historical topic is the subject of work in progress. See for example Smith, II.iii.25ii, 33-34; Say, p293; Rae, pp91, 256, 258; Mill, pp100, 154, 182.

water needed for the cup of coffee or driving in low gears (Hannon, 1975, p96; Etzioni, 1998, p630; Prettenthaler & Steiniger, 1999; Norgard, 2006)¹²

Of a certain area of land William Petty asked, 'How many Men will it feed?', implying an output/input ratio of food over square metres and holding food per Man constant; he offered data on the agricultural productivity of 'improved Acres' (1675, pp286-288). Cantillon likewise employed this agricultural paradigm either as rice/m² or as yield/seed (1755, pp26, 128). Departing from the spatial metric, Petty also attested differences in transport efficiency for 'bulky Commodities' between 'Water Carriage' and 'Land Carriage', a given output of bulk-times-distance achieved by less (water) or more (land) input of time and endo- or exosomatic energy (pp255, 293-294). Using the examples of flour grinding and printing, his 'Arithmetick' showed, for instance, that a mill, after deducting the labour embodied in its construction, 'will do as much Labor, as Four Men for Five Years together' – an efficiency increase of 20 times; with printing a factor of 100 results; the wagon means that 'one Horse can carry upon Wheels, as much as Five upon their backs' (pp249, 256).

Petty's endeavour is to explain why different European nations of similar size and population have different levels of wealth. Like Malthus (1824, p265), Mill (p100) and Solow (1957), his *explicans* turns out to be not such absolute quantities of land or people but their productivity ratios: England was more efficient and therefore richer than France or Holland. Would that we could today use the method of Petty and Solow for our *explicandum* of energy inputs,¹³ a path open to us only if GDP is a good proxy for output; however, both the 'dematerialization' of GDP* and the difficulty of identifying what it is that GDP measures weaken the GDP metric. A godsend would be a time series of two non-trading countries similar in all respects except level of technological efficiency.

¹² *Sufficient* or frugal consumer behaviour, like consumer and production efficiency, also suffers from rebound (Alcott, 2007).

¹³ Saunders in passing quotes Solow that 'it's hard to break the habit,... "factor-augmenting" does *not* mean "factor saving"' (1992, p131).

Presaging today's computations of theoretical 'engineering' savings, Petty even reckons the monetary savings from innovations (pp255-257). If costs of production fall then society, left with at least the same amount of flour, printed matter and transport as before, has purchasing power left over.¹⁴ Petty explicitly attests huge labour savings (pp306-308), but his only remark bearing on labour rebound is that as a result of 'improvement' of 'Art' many millions *could* work, but aren't 'disposed or necessitated to labour' (pp249, 307). This hints at a normative issue that confused the discussion between Say, Sismondi, McCulloch, Mill and Marx: given that work is basically a painful, irksome cost, 'unemployment' would be a good thing, and like today regarding energy inputs, we should hope for low or no rebound.¹⁵ But in the absence of political means to spread work equitably, by bestowing purchasing power work becomes a good thing.

As his title and Introduction reveal, Smith's *explicandum* was wealth or 'produce', usually defined materially (I.v, I.viii.21, IV.ix.38, V.ii.e.10).¹⁶ His favourite explanatory variable was the intensive one of 'productive Powers [of Labour]', itself mainly explained by a number of variables, including division of labour, dexterity, work organization and machines, themselves explained by the 'propensity in human nature... to truck, barter, and exchange one thing for another' (I.i, I.ii.1). The only other factor raising 'produce' is an increase in labour's *quantity* (I.intro.3-4, II.iii.32, IV.ix.34-36). Productive *power* is 'the quantity of work [*produce* such as nails], which... the same number of people are capable of performing' and its increase is 'improvement' (I.i.5, I.i.6). Surrounded by increasing population and production, it is not surprising that Smith does not define efficiency the other way around as a constant output with less input: the fact was that *number of pins* rises (by a factor somewhere between 240, 4800), not that society spends fewer hours making pins (I.i.3). Smith also framed productivity in other terms, attesting, for example, the greater

¹⁴ As shown later, this income effect for consumers, if expressed monetarily, could be balanced by a 'loss effect' for producers.

¹⁵ Say spoke for all economists before and since in attesting the disutility of work: 'labour... implies trouble (*une peine*)' (p85; also Smith, 1776, I.v.4, I vi.2; Mill, p25). Veblen made fun of our seeming love of 'irksome' labour (1899, ppix, 18-19, 110).

¹⁶ Also Say, pp61-62; Rae, pp1, 15, 21.

efficiency of water over land transport, his ratio being that of tons 'carried'/man, and, as with his pins, the waters between London and Leith are plied more often (I.iii.3, I.xi.b.5). Jevons later showed that canals lowered coal prices, a case of greater *transport* efficiency raising *coal* consumption (pp121-122, 166).

Smith's denominator was sometimes space (land, soil), with output as food or wool (I.xi.b.2-6, 15, IV.ix.5-6; see also Say, p295), and sometimes mines (thinkable in m³) of varying 'fertility' (I.v.7, I.xi.c.10-11). The productivity of the soils and mines in turn partially determine the efficiency of labour*. Again, output quantity is a function of both the productivity and quantity of the material and labour inputs, capital being able to increase both productivities. In Say the material factor is the *agens naturels* or *services productifs*, with 'agency' denoting the 'power' and the power's strength determining the agent's 'fertility' or 'fecundity' – here with no reference to labour inputs (pp40, 63-77, 101, 127, 301, 395). Jevons similarly asserted that 'power' was 'in' coal – and that it was power that had through 'increased... efficiency' become *cheap* (pp145-146, 186). In contrast to later neo-classical neglect of material as a productive factor, he held that 'in our successes hitherto it is to nature we owe at least as much as to our own energies' (p318). Similarly, coal and oil, as well as coal mines and oil 'fields', have varying *inherent* fertility in both chemical terms and terms of ease of access. Ricardo confirmed this ambiguity in the concept of material efficiency by noting that 'improvements in agriculture are of two kinds: those which increase the productive powers of the land, and those which enable us, by improving our machinery, to obtain its produce with less labour' (p80; see also Smith, I.xi.d.1; Mill, pp724-725).

As the pin and nail examples show, Smith by no means neglected manufacturing, for example the 'woollen manufacture', where the 'working up' of a 'quantity of materials' was facilitated by 'a variety of new machines' (I.xi.o.12, II.intro.3). His usual denominator was labour input (I.ix.34-35, I.xi.p.4): for land of *given* fertility, then, greater produce results only from the greater 'efficacy of human industry [= *labour*, not manufacture], in increasing the quantity of wool or raw hides' (I.xi.m.14). Note especially that often 'improvement' was expressed

as *less* labour input for 'any particular piece of work' (I.xi.o.1); this formulation holds output constant and is the version of the ratio found in Ricardo, for whom 'economy in the use of labour' or labour's 'abridgement' – by means for instance of engines – meant lower or at least not higher 'charges of production' (pp25, 26, 41, 69, 397). But more often Smith's ratio change held input constant over against a 'great increase of the quantity of work [= *produce*, not labour]' (I.i.5); with good farm capital and the 'best machinery', the same amount and quality of labour made a 'much greater quantity of work' (II.ii.7; I.viii.3, I.xi.o.12).¹⁷ Malthus's rendering of efficiency change likewise described 'a machine in manufactures..., which will produce more finished work with less expenditure than before' (p145).

As with the question of whether a glass is half full or half empty, it matters whether we define efficiency increase as 'less input per unit of output' or 'more output per unit of input'. Although technically equivalent, the former biases our thinking by holding output constant and looking at what could be saved while the latter biases it by highlighting increased output with perhaps no saving. A simple example is replacing an open fireplace with a ceramic stove: one can heat the same amount of space to the same temperature, thus really saving firewood, or use the same amount to heat more rooms warmer.¹⁸ Starting one's chain of thought with the resources still available (lying fallow) for more economic activity after such an efficiency increase is conducive to perceiving large rebound; in Hearn's words, greater efficiency 'sets free a quantity of commodities...or...materials' (p271).

Say's denominators were both labour and materials like land, water, mines, wind and other *agens naturels*. In some cases 'tools and machines... enlarged the limited powers of our hands and fingers'; in China tools for 'drilling, in lieu of the broad-cast, method [of sowing] raises the productivity of land' (pp86, 394). In other cases 'useful machinery' is 'strengthening and aiding the productive

¹⁷ Occasionally Smith explicitly inserted 'capital' as input, thus adding K and γK to the production function, with some given amount yielding 'greater produce' (IV.ix.6; see also Mill, pp100, 154).

¹⁸ This example reveals further outcomes complicating rebound research: 1) the 'saved' firewood can be used for building and is thus not saved; 2) the time 'saved' cutting and stacking wood can be spent for other earning and consumption.

powers of nature', the category within which today's energy efficiency efforts fall (p357). He insisted on the equivalence of ratios with higher numerators (output) and those with lower denominators (input):

Every saving in the cost [*les frais*] of production implies the procurement, either of an equal product by the exertion of a smaller amount of productive agency [$Q_{\text{same}}/\text{expense}_{\text{less}}$], or of a larger product by the exertion of equal agency [$Q_{\text{more}}/\text{agency}_{\text{same}}$], which are both the same thing. (p301; see also pp86, 88, 201, 204, 395)

However, while he sometimes thus underlines the 'saving of productive agency' (p395), Say's excitement is aroused by the opposite case, namely 'to obtain a larger produce from the same quantity of human labour.—And this is the grand object and acme [*le comble*] of industry' (p86).

Note that one of his examples describes an increase of labour efficiency ($\alpha L \uparrow$) whereby one man mills as much as ten men previously when a windmill by means of sails (capital or K) is substituted for a tread-mill (pp74-75)¹⁹ While this is clearly an increase in labour efficiency, a case of 'capital enlarging productiveness' (p77), it is *not* an increase in *wind* efficiency ($\beta M \uparrow$) – unless starting from zero. Similarly, the first internal combustion engine did not increase the economy of fuel but only the economy of transport in terms of time and labour. Therefore, innovation seems not always subsumable under efficiency. Say does hint at a distinction between an invention – effecting the first-time use of a natural resource – and a new 'process' to 'produce... an old [product] with greater economy', for example a new 'method of reducing the friction of bodies' (pp329, 433).²⁰ Another, endearing example was the use of sulphuric acid to destroy the 'mucilaginous articles of vegetable oils', which could then be substituted for expensive fish oil, an efficiency increase, in the broadest sense, that 'placed the use of those lamps... within the reach of almost every class' (p116). Here the production of lumens became more efficient, but not that of vegetable oils in producing lumens, because these were not before used. Brindley, on the other hand, observed that the Newcomen engine wasn't efficient enough for coal to replace 'the power of horses, wind, or air' (Jevons, p143). This seems to be a case of increased efficiency in the use of an

¹⁹ Also Jevons, p177.

²⁰ Also Jevons, pp119, 159, 389.

exosomatic energy source, already stutteringly in use, substituting for others whose efficiency potential had been exhausted.

In discussing rebound we should take this distinction between innovation and technological efficiency seriously: When cutting-tools change from steel to ceramics to carbide (diamonds) these raise cutting efficiency but are not more efficient uses of a given material (Rosenberg, 1982, pp3-4, 65). Malthus's more abstract formulation distinguishes between the invention of machines and the more efficient or 'best' machines' replacing less efficient ones (pp145, 170, 229). With Rae the distinction is straightforward – between 'new arts' and 'improvement in the arts already practiced' (p15; see also pp224, 253). His examples include the plough itself as opposed to better ploughs, macadamized as opposed to stone roads, and better steel tools (pp87, 114, 226-228, 259). He moreover traces the steam engine's invention, improvement and connection with coal mining in terms almost the same as Jevons's (Rae, pp245-248; Jevons, pp142-153.²¹ Hearn wrote that

By [improvement] I mean not the discovery of natural agents previously unknown or unused; but the knowledge of new combinations of agents already known... Those improvements which increase the efficiency of the actual agent [coal] are... distinct from those inventions the utility of which consists in the abridgment of human labour, and the substitutions for it of physical forces. (pp99-100)²²

First, for instance, India rubber was used to do new things, then became more efficient through vulcanization and sulphur treatment; coal likewise was first found and substituted for charcoal, then made more efficient through the hot-blast in smelting (pp100-102).

The point is that greater resource consumption caused in the first place by inventions should not be booked under rebound. That said, Malthus has a point that inventions sometimes 'are the natural *consequence* of improvement and civilization' (p281). In other words, efficiency increase can cause inventions and

²¹ Rae then offers a full-blown analysis in terms of the varying 'capacities' and speed of returns of tools and machines, a function of their cost of production, their durability, and their efficiency (pp87-110), closely resembling that of Malthus (pp71-73). See the analysis of Spengler (1959).

²² Also Jevons, p188; Schumpeter, 1911, pp297-306. Jevons likewise gives many examples of the enlistment of new agents, as opposed to 'subsequent steps in...improvement' (pp119; 113-134, 147-148)

new uses.²³ At any rate, once more, identifying which efficiency changes to measure is vexed both by new products and by better-'quality' products that may even constitute efficiency decreases*. Rae lamented that while of course 'wealth' had vastly increased since Henry VII, there had been 'not only an increase, but a change' (pp18-19; Giampietro & Mayumi, this volume)

For 'efficiency' Malthus uses not only 'productiveness' and 'fertility' but also the 'facility' or 'difficulty' of producing or obtaining output, again almost always in terms of labour input. At times he emphasizes 'saving of labour' or 'relief from labour' in producing 'a given effect' (pp128, 152, 170), at times a greater produce (pp63; 1824, pp281-283), and once simultaneously greater 'finished work' with 'less expenditure' (p145). Referring to Say, who had written that 'a landed estate may be considered as a vast machine for the production of grain, which is refitted and kept in repair by cultivation; or a flock of sheep as a machine for the raising of mutton or wool' (Say, p86 note, p318 note), Malthus writes:

The Earth has been sometimes compared to a vast machine, presented by nature to man for the production of food and raw materials; but, to make the resemblance more just, as far as they admit of comparison, we should consider the soil as a present to man of a great number of machines, all susceptible of continued improvement by the application of capital to them, but yet of very different original qualities and powers. (pp144-145; see also pp66, 111, 115, 168; McCulloch, p278)

Say also repeatedly talked of the 'spontaneous gifts of nature' like air, water, light, fire, gravity, pressure and steel (pp63, 71, 75, 86, 286, 362), all susceptible to improvements through 'industry' which must 'awaken, assist, or complete the operations of nature' (pp63-64; 74, 86; Smith, II.iii.3).

Undoubtedly impressed both by Say and what he observed in rural Canada, Rae likewise repeatedly described the material factors of production and their 'productive powers' (pp10-12); he saw 'fire and water transformed into our obedient drudges' (p14); our 'instruments... draw forth stores' of materials, and 'improvement in their construction... put additional stores within reach of the nation' (pp19, 68); a 'North American Indian' improves a 'wild plumb tree' or

²³ Jevons, pp125-130, 141-144, 152-156, 196-199, 245, 368-378, 405; Sieferle, 2001, pp115-124.

dams 'a very scanty brook' (p83). The doctrine perceives an efficiency ratio in that

the knowledge of the civilized man, compared with that of the savage or barbarian, gives him the power of constructing a much greater number of instruments out of the same materials... (p99)

Just as Petty and Smith had distinguished between the quantity of labour and its productivity,²⁴ Rae's analysis of 'the action of matter upon matter' separated the 'amount of materials' from 'the efficiency of these materials' (pp112-113), but he is additionally discussing the effect of our 'instruments' on matter's efficiency rather than their greater or lesser *inherent* natural power (pp87-110). 'Instruments' roughly mean capital, in other words anything man-made for the purpose of future production, including fields and even food (in classical terms 'circulating capital').²⁵

More than our other authors, Rae thus analyzes material rather than labour inputs (p99). He also conceptualizes the *costs* of efficiency, once even defining efficiency as the total production of an instrument (until its 'exhaustion') divided by the cost of making it measured in units of labour; this is 'the ratio of the capacity... to cost' (pp259, 173, 354-355).²⁶ Smith had already made the pertinent point that the

expence which is properly laid out upon a fixed capital of any kind, is always repaid with great profit, and increases the annual produce by a much greater value than that of the support [depreciation] which such improvements require. (II.ii.7)

With an example of more durable pots and pans taken from Smith, Rae shows that in spite of (because of?) their 'becoming more expensive articles', they 'augment... national capital... with advantage to society' and are 'preferred by good economists' (p21). The relevance of the (energy) costs of energy efficiency to rebound is disputed. One solution is simply to deduct these from the savings theoretically possible during the *operation* of the more efficient

²⁴ 'When we want to double the produce of a field we cannot get it by simply doubling the number of labourers' (Jevons, p195; also Smith, I.intro.1 & 5, I.viii.57, II.intro.4, II.iii.32, IV.ix.34; Say, pp70-71, 303; Mill, pp154, 413-414).

²⁵ Like McCulloch (pp92-95) Rae took this idea to what he admitted to be an extreme, defining his key concept of 'instruments' to include almost everything having social ontology (resulting from man), including not only tools as conventionally understood but also fields, horses and even food as means of maintaining human capital (pp86-88, 115). Although Mill adopted this broad definition for capital he, like Rae, knew it was too broad for 'general acceptance' (Mill, pp153, 10).

²⁶ Petty's comparable example had been that 'a Mill made by one Man in half a Year will do as much Labor, as Four Men for Five Years together' (p256).

instrument – thus lowering the quantity of which rebound is a percentage (Jevons, p446).²⁷

Rae also distinguishes between 'efficiently' and 'effectually' (in the sense of merely getting a job done well), as when the threshing machine not only saves labour but separates grain *better than* the flail method (p20). This again raises the question of the changing quality of the output in our numerator. Otherwise Rae's treatment closely follows Say's, for example in emphasizing the equivalence of ratios with lower inputs and those with higher outputs (pp66, 92, 131, 259). If anything, his bias is toward the latter: adding to manufacturing capital will

effect an increase in the productive powers of the community; that is, they give those powers the capability of producing the same quantity of an article at less expense, which certainly must be allowed to be an increase of them. (p70)

This language comes close to a description of an outward shift of a community's *production possibilities frontier*. This is the key assertion of and proof of rebound, if not backfire: we are *enabled* to produce and consume more without more effort, time or material. Whether backfire obtains depends then on consumer behaviour or, in fancier language, the efficiency elasticity of demand.

Rae and Malthus, whose *Principles'* last edition appeared two years after Rae's treatise, were describing the phenomenon that is the starting-point of our investigation: the human ability to get more out of the same amount of nature. Rae's fellow Scotsman McCulloch had a few years earlier written, in the usual terms, that division of labour 'saves labour', but also that 'the invention and improvement of tools and engines' caused a rise in our variable – 'the quantity of raw materials which the same number of people can work up...' (pp96, 99). His term for output* is here materially expressed, moreover in terms of raw material rather than material objects. McCulloch also introduced the method of assuming an overnight economy-wide increase of efficiency then deriving the consequences (pp166-167; Mill, pp723-725). But whereas today researchers at

²⁷ 'Life cycle' aspects as well as recycling are thus reducible to our output-input efficiency, as demonstrated by Rae in showing that a more expensive but more durable hat saves labour input for the wearer over time (pp200-201). He also gives examples of thick sturdy walls for buildings and good steel for tools, which *both* increase heating or cutting efficiency and last longer (pp109, 114).

Strathclyde, Scotland, similarly assume an 'efficiency shock' of five percent (Allan et al., 2006, pp5, 36), McCulloch's was by a *factor* of ten!²⁸ Say later got rhetorical mileage out of assuming 'that machinery should be brought to supercede human labour altogether' – a labour-efficiency 'shock' of 100 per cent (p88).

Finally, Mill's characterization of efficiency reminds one of *economic* or 'Pareto' efficiency. His causal chain is from an 'extension of the market' (here exogenous) to more 'division of labour' to 'a more effective distribution of the productive forces of society' (pp87-88, 281). In a passage quoted by Hearn (p68) the doctrine presented to Jevons was that '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' (Mill, p106).²⁹ However, greater consumption is merely enabled: equally enabled is a real saving of labour and material inputs. We choose between them.

Mill's numerous descriptions of productiveness epitomize the classical analysis (pp93, 99, 106, 118, 129, 153-154, 710, 724).³⁰ Yet notwithstanding his famous defense of the stationary state (pp752-757), one discerns his preference for the growing economy in his remark that the 'increased effectiveness [efficiency] of labour... always implies a greater produce from the same labour, and not *merely* the same produce from less labour' (p133, emphasis added). He also claimed that 'no one would make or use ploughs for any other reason than... the increased returns, thereby obtained from the ground' (which could pay the plough-maker) (p31). That society as a whole – macroeconomically – could choose the version 'same output less input' is impossible. This reflects the normative position persisting to the present day of the unassailability of

²⁸ Of course while McCulloch was asking after the effects on quantity of output (Q), believing 'the power of production... a thousand or million times increased' (p167), the Strathclyde group was asking after the effects on the quantity of consumed *input* once it is used five percent more efficiently.

²⁹ Also Malthus, 1824, p303; McCulloch, p99; Sanne, 2000, p487.

³⁰ Mill added precision to Ricardo's (p80) two types of agricultural improvements, naming some that 'have not the power of increasing the produce', but only diminishing labour (Mill, p180); these *cannot* raise total output of the farm – here the ratio is output/farm – just as some factory-floor efficiencies might increase not the productivity of the factory unit but only of the labour units.

economic growth, epitomized by Smith's sentiment that Jevons chose for his frontispiece:

The progressive state is in reality the cheerful and the hearty state to all the different orders of society. The stationary is dull; the declining, melancholy. (I.viii.43)

As shown later, Malthus stood alone in objecting that we could indeed choose 'indolence' (pp258, 267-268, 283, 284, 320, 337).

More neutrally, Mill presents his parsimonious theory of production:

We may say, then, without a greater stretch of language than under the necessary explanation is permissible, that the requisites of production are Labour, Capital, and Land. The increase of production, therefore, depends on the properties of these elements. It is a result of the increase either of the elements themselves, or of their productiveness. The law of the increase of production must be a consequence of the laws of these elements... (p154)

These laws enable both extremes: less work and less resource consumption to the full extent of the 'engineering savings' (Alcott, 2005, p10); or an increase of production and consumption so great that in the end even more work and material resources are *put into* the economic process. Other laws, of human nature and of desires, consumption and reproduction rather than production, determine exactly where, between these extremes, we end up (Jevons, pp25, 191-201; Princen, 1999; Sanne, 2002; Alcott, 2004)

What is output?

Energy economics literature offers many terms for our numerator: GDP, units of 'service', goods and services, various physical aggregates, 'product' and, vaguest of all, 'economic activity'. In measuring 'eco-efficiency' Reijnders names five metrics for efficiency: '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, p14). Let us distinguish three broad categories – money (GDP), utility and matter.

- GDP's well-known weaknesses include both ignoring large parts of the economy and valuing some losses as gains (Daly & Cobb, 1989, pp401-455). Specific problems* in energy models are elaborated by Rosenberg (1982, pp23, 55), Jänicke et al. (1989, pp14, 391), Schipper & Meyers (1992, p54), Kaufmann (1992, p54) and Cleveland & Ruth (1998, p35);

Smil 'deconstructs' the concept of energy intensity in monetary terms. (2003, pp66, 71-78, 81).³¹ This contemporary monetary metric of choice was not available to Jevons and his predecessors.

- The utility or services concept dominating the rebound literature posits an 'energy service' such as a 'passenger-kilometre'. However, as soon as two people ride in a car, efficiency would then have doubled with no technological change whatsoever, and when a heavy car replaces a lighter car efficiency would stay the same in spite of a technological change especially relevant to environmental impact. Utility moreover ignores *waste*, an anthropocentric concept referring to tons of gases and materials; at best, integrating them is a complicated exercise in computing and deducting 'externalities'. Should these be excluded from our numerator, or not? For an incisive account of this concept's difficulties see Ayres (1978, pp50-67). Furthermore the common concept of 'energy services' is invalid: since *every* service (and good) involves embodied and/or operational energy input, any distinction over against 'non-energy services' must be arbitrary.³²
- A physical metric (including waste) could be in tons, volume, chemical elements, heat, exergy, work defined in terms of force and direction, or non-aggregated lists of products. Jevons used the metric 'useful work' per pound of coal, expressed in 'foot-pounds', and defines thermodynamic efficiency (pp137-138, 148, 186).³³ A manageable literature has taken up this challenge, usually with the hope of aggregation³⁴ and sometimes attempting to integrate physical and utility/monetary metrics.³⁵ Also, probably all of the technological efficiency changes striven for in efficiency policies are susceptible to physical definition: instead of a 'passenger-kilometre' a ton-kilometre, instead of 'heating comfort' a certain temperature rise in a given volume of space over a given time and instead of a kilowatt hour the amount of primary energy involved. A remaining problem is that, due to the first law of thermodynamics, output always equals input, leaving us without a ratio! Perhaps only a list of consumer and capital goods (and their utilization rates) remains, and an *aggregated* physical metric is impossible.

After ironically speaking of 'the mass of solid goods and useful services', Joan Robinson sought a non-monetary metric for technical progress, choosing the

³¹ Also Robinson, 1954, p18; Radetzki & Tilton, 1990, p21; Manne & Richels, 1992; Saunders, 2000a, p442; Alcott, 2006, Ch6.

³² See Howarth, 1997, p3; Wirl, 1997, p14; Berkout et al., 2000, p427; Saunders, 2000b; Binswanger, 2001, pp120-121; Sorrell & Dimitropoulos, 2006, p3.

³³ Sorrell & Dimitropoulos, 2006, pp3-9.

³⁴ For example Ayres, 1978, pp53-66; Birol & Keppler, 2000, p461; Ayres & van den Bergh, 2005, pp102-103; but see Weisz et al., 2006, p681.

³⁵ For example Cleveland & Ruth, 1998, p35; van den Bergh, 1999, pp551, 559; Dahlström & Ekins, 2006, pp509, 515-518.

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 (1956, pp19, 122, 65). She concluded, however, that 'index-number ambiguities' are insoluble (pp64-65, 115) and that 'economics is the scientific study of wealth, and yet we cannot measure wealth' (p24).³⁶ The classical economists similarly suffered in defining wealth. Its *genus* was material objects or 'produce' for Smith (I.viii.3-9, 21 & 23, IV.ix.38, V.ii.e.10), Malthus (pp20-28, 294) and Mill (pp48-49, 55). Ricardo also regarded 'riches' in terms of the ubiquitous physical concept of 'necessities, conveniences and enjoyments' (sometimes 'luxuries' or 'amusements') which had nothing to do with exchange values in terms either of money or other objects (pp275-276). Rae criticized Smith's various definitions* and tended to treat wealth and capital synonymously and as physical commodities and instruments (pp387-388, 14, 18, 21, 171). But all acknowledged some *differentia* specifying their (use or exchange) *value* to us. In Lauderdale's typical phrase wealth was 'the abundance of the objects of man's desire... [including] lands, houses, shipping, gold and silver coin, wares, merchandise, plate, furniture, etc.' (pp146, 42; see also Malthus, p29; 1824, pp258-259). In avoiding Lauderdale's criticism (p152) of Smith's emphasis on durable objects, Mill chose with questionable ontology 'permanent utilities... embodied in human beings, or in any other animate or inanimate objects' (p48).

If the definition of output* must include some quality or value element, let us ponder Say's reaction to his insight³⁷ that was to become the first law of thermodynamics. He said that we confront a

mass of matter [not]... capable of increase or diminution. All that man can do is, to re-produce existing materials under another form, which may give them a utility they did not before possess, or merely enlarge one they may have before presented. So that, in fact, there is a creation not of matter, but of utility; and this I call *production of wealth*.... [Production is] creation, not of substance, but of utility, so by consumption is meant the destruction of utility, and not of substance, or matter. (pp62, 387)³⁸

Moreover 'creating matter... is more than nature itself can do' (p65). More than the others, Say thus emphasized utility rather than goods themselves and

³⁶ Also Solow, 1957, pp316-317; Rosenberg, 1982, pp23, 55; Victor, 1991, pp204-206.

³⁷ And Cantillon's (p2).

³⁸ Also McCulloch, pp61-63; Rae, pp15, 81-83; Mill, pp25, 27, 46.

posited such a thing as 'immaterial product' (pp62, 119-124). But he also held that 'the ratio of the national revenue, in the aggregate, is determined by the amount of the product, and not by its value' and never denied that some material was necessary for utility to adhere to: the services of musicians and lawyers, for instance, required their food and education as well as wear and tear on their capital (pp295, 122, 124; see also Malthus, 1824, pp258-259; Costanza, 1980).

If we include usefulness in our definition, how do we deal with unwanted objects and waste, both of which affect the environment? While Mill's idea of waste was physical, including 'diving-bells sunk in the sea' and the use of too many horses and men to plough a field (pp8, 51-52), and Hearn gave the example of close parallel mine-shafts (p208), Rae's chapter 'Of Waste' deals with the *economic* inefficiencies of fraud, trade restrictions, transaction costs and so forth – making the point in a very different way that less efficiency means less production and consumption* (pp313-319). Among the classical economists there was moreover some debate as to whether only anthropogenic objects counted as wealth, or also 'air, water, and light' (Say, p63; Mill, pp8, 153), opening up the water/diamonds discussion over use value as opposed to exchange value and scarcity. Jevons, incidentally, counted waste-reduction as an increase of 'economy' (pp30, 271-272).

A large contemporary literature thus discusses various metrics for 'environmental' (or energy) efficiency in terms of *desirable* output.³⁹ The attempt is to abandon purely quantitative measures and introduce the 'quality' of energy, as when 'exergy' is taken to measure input (Ayres & Warr, 2005). Similarly, following a general exposition of energy and its transformations, Jevons offered this definition of efficiency:

Now it will be easily seen that the resources of nature are almost unbounded, but that economy consists in discovering and picking out those almost infinitesimal portions which best serve our purpose. (p163; see also p170)

He elsewhere uses the ratio of 'useful work' to 'power' (pp186-187), thus risking conflation of physical and utility criteria just as Ayres & van den Bergh do when

³⁹ Also Ayres, 1978, pp39-66; van den Bergh, 1999; Birol & Keppler, 2000, p461; Schipper & Grubb, 2000, p369.

insisting on counting high-entropy 'process waste', the difference between 'work done by the economic system [and] the exergy of all inputs'* (2005, p103). For if exergy is already defined anthropocentrically as useful or available energy and can, unlike energy, be destroyed (Ayres, 1978, p52), it itself becomes a (desirable) output. Even taking mass instead of energy in both numerator and denominator, where the output is mass 'embodied in the physical output (finished products)' (Ayres & van den Bergh, 2005, p103) does not escape the fact that to identify 'finished products' we need some anthropocentric criterion.⁴⁰

McCulloch, after acknowledging the law of the conservation of matter, laid down the principle:

And hence we are not to measure consumption by the magnitude, the weight, or the number of the products consumed, but exclusively *by their value*. Large consumption is the destruction of large value, however small the bulk in which that value may happen to be compressed. (p 390; also p61)

But can environmental studies ignore what is produced but has *no value*?⁴¹ All oxidized molecules, unless they are recycled by means of further energy inputs, as with CO₂ sequestration, must count as 'final' output. Space heating can be defined by the time needed for the space to return to (lower) ambient temperature from that desired, but the higher-entropy energy is nevertheless part of output. Lumens rather than 'lighting services' can be measured, but light pollution and heat as a 'by-product' are also output. Steel cannot be made without producing 'scrap'. While a 'first-law' ratio must be one to one, 'efficiency' must be variable, perhaps leaving no way around some concept of utility: We must measure inputs only over against the output we *like*. While GDP thus aggregates unsatisfactorily, physical or combined physical/utility metrics have not yet been found.

⁴⁰ The terms for mass and measure in German are very close (*Masse*, *Mass*); 'pound' in English is both weight and money, as is *peso* in Spanish (Smith, I.iv.10).

⁴¹ Mill distinguishes between the 'absolute waste' of 'unproductive labour' lacking even the utility of 'pleasurable sensation', and the relative waste of 'productive labour' when for instance 'a farmer persists in ploughing with three horses and two men... when two horses and one man are sufficient' (pp50-51; also p28; Say, pp42-43, 121, 404; Alcott, 2004, pp770-776).

Correlation of efficiency and output increase

Whatever 'output' turns out to be, Jevons's immediate predecessor Mill captured the classical conclusion that, formally, productiveness is equivalently lower land/labour inputs and 'increased produce', what everyday observation showed was a 'greater absolute produce' or a 'long succession of contrivances for economizing labour and increasing its produce' (pp180, 189, 706; Smith, I.xi.g.20, II.iii.33).⁴² By 1865 Jevons could write:

When we turn from agriculture to our mechanical and newer arts, the contrast is indeed strong, both as regards the numbers employed and the amounts of their products. But the subject is a trite one; every newspaper, book, and parliamentary return is full of it: factories and works, crowded docks and laden waggons are the material proofs of our progress. (p244; see also pp187-188)

But as Rae lamented, 'all we see is the sum produced by [change], the fact of the increase being more easily ascertained than the manner of it' (p19). Thus, while in dozens of passages all writers previous to Jevons tied increased efficiency to increased product, they seldom formally declared necessary connection. Mill for instance claimed,

It will be seen, that the quantity of capital which will, or even which can, be accumulated in any country, and the amount of gross produce which will, or even which can, be raised, bear a proportion to the state of the arts of production there existing; and that every improvement, even if for the time it diminish the circulating capital and the gross produce, ultimately makes room for a larger amount of both, than could possibly have existed otherwise. (p98)

'Room is made', production *possibilities* increase, but there is no claim of universal causality.

Jevons praised Hearn's *Plutology* as 'both in soundness and originality the most advanced treatise on political economy which has appeared' (p168 note).

Hearn, himself explicitly building on Rae (see, for example, Ray, p260) and Justus von Liebig (1851), described the shift in the production possibilities frontier as follows:

It is self-evident, as Mr. Mill has observed, that the productiveness of the labour of a people is limited by their knowledge of the arts of life; and 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. (p68, emphasis added; see also p184)

⁴² Mill implies a broader array of formal expressions for efficiency when talking of greater produce 'without an equivalent increase of labour' (p180): the term 'equivalent' implies elasticities, in other words efficiency also increases, for example, in the extreme case where both input and output go down, but the former percentage-wise more than the latter.

Jevons then contributed two new thoughts: for 'labour' he substituted 'coal'; and he asked the further question, not of the effects of efficiency on produce, but on input consumption. The doctrine is on the one hand curiously conditional but on the other insistent that growth is impossible without improvement in the 'arts' – a conclusion reached by later growth theorists by statistical means. (see, for example, Solow, 1957 and 1970)

Remember that the classical concept of efficiency included individual, organizational and institutional as well as material or technological types, often attested in one and the same passage.⁴³ Seminal statements of 'economic' efficiency also appear explicitly, wherein what the society does produce is compared to what it could produce given a certain natural fertility and a certain technology (Smith, I.ix.15; Say, pp166, 380; Malthus, pp266, 304). And although not to my knowledge discussed in classical economics, remember that land and labour inputs are mutually dependent; that is, all terms on the right side of $Q = f(\beta M, M, \alpha L, L)$ influence each other, rendering reduced-form expressions inadequate.

Petty already gave a version of classical 'growth theory' in seeing 'greater consumptions' not only of food but of 'Coaches, Equipage, and Household Furniture' due to 'improved Acres' and population density – and even a growth of postage due to transport efficiency (pp287-305; Smith, I.xi.c.7). Cantillon presaged Malthus's principle of population and the concept of carrying capacity using as examples both people and mice: population followed sustenance, itself a function of land and mine fertility as well as the energy and labour of the population (pp43-44, 46, 62, 128). He conceived labour in terms of both its quantity and efficiency r^* , but in any case greater population and greater consumption entailed each other. As shown later, this idea that people are also produced – fully conceptualized by later writers – is crucial for the discussion of the Jevons paradox; models of (energy) consumption or of wealth in general

⁴³ For example Petty, pp256, 261-264, 300; Smith, I.xi.o.1, IV.ix.17 & 34-35; Say, pp127, 286, 432-438; Rae, pp29, 310, 327; Mill, pp87-88, 133-135, 184-189, 706, 723; see also McCulloch, pp73-143.

that treat population entirely exogenously necessarily significantly underestimate rebound.⁴⁴

If wealth was 'necessaries, conveniences, and amusements' or the goods affording these (Smith, I.intro. 1-4, I.v.1 & 9; IV.i.17-18), no writer except Ricardo failed to both attest and laud their *growth*.⁴⁵ Rae for instance made the empirical claim that the wealth of Great Britain was ten times what it was under Henry VIII (pp14, 18). Smith saw the gradual spread of 'universal opulence' (I.i.10) or at least 'almost universal prosperity' (I.xi.g.20) and by mid-century for Mill economic growth was axiomatic:

Production is not a fixed, but an increasing thing. When not kept back by bad institutions, or a low state of the arts of life [technology], the produce of industry [labour] has usually tended to increase; stimulated not only by the desire of the producers to augment their means of consumption, but by the increasing number of consumers [population]. Nothing in political economy can be of more importance than to ascertain the law of this increase of production. (p153)

Jevons reported many statistics on the increase of both per capita wealth and population since the 18th century (ppvi, 196-200, 457). He moreover both extolled and feared for Britain's prosperity and greatness: the 'Age of Coal' enabled

[a] multiplying population, with a constant void for it to fill; a growing revenue, with lessened taxation; accumulating capital, with rising profits and interest. *This is a union of happy conditions which hardly any country before enjoyed, and which no country can long expect to enjoy...* It is the very happiness of civilisation... [Without coal] we must... sink down into poverty [and] *begin a retrograde career*. (see pp2, 11, 231, 201, 454-460; emphasis original)

He quotes Baron Liebig that civilisation 'is *the economy of power*' (p142; see also p156). And since for Jevons the greater economy of coal increased not only affluence but its quicker exhaustion, '*We have to make the momentous choice between brief but true greatness and longer continued mediocrity*' (p460). The discussion today likewise contains the political hope that energy efficiency is the key to both happy prosperity and sparing natural resources. Now, as then, we should not ignore our normative assumptions.

That the correlation between consumption and efficiency reflected causality was, to be sure, denied by no one. Clarity has reigned from Petty onward on the

⁴⁴ See Smith, I.viii.18, 23, 39, IV.ix.12; Malthus, pp61, 130, 180; Mill, p33; Jevons, p213; Giampietro, 1994.

⁴⁵ For example Smith, I.viii.21, IV.ii.9, IV.ix.38; McCulloch, p99; Rae, p7; Mill, p159.

point that *quantities* of land, labour or capital do not suffice to explain the size of the wealth of a nation.⁴⁶ The causal factor for greater wealth, produce, riches, returns and surpluses was higher productive powers of land and labour, often aided by invention and machines.⁴⁷ Mill even asserted that 'improvements,... by the very fact of their deserving that title, produce an increase of return' (p93) and elsewhere *equated* 'the magnitude of the produce' with 'the productive power of labour' (p413). Today also this seems self-evident.

Even for Malthus, despite his observation that we could always choose to really save through indolence or non-consumption, the doctrine was that 'the increased powers of labour would *naturally* produce an increased supply of commodities' (p63, emphasis added). Say said that although lower input and greater output are mathematically 'the same thing' both are 'sure to be followed by an enlargement of the product'; for both producers and consumers 'every thing saved is so much gain' (pp301, 357). It was Rae who, while concurring with the standard causal chain from increased capital through increased division of labour to increased wealth, shifted the emphasis from organizational to technological efficiency: it is 'the intention of the inventive faculty', which creates and improves instruments, to increase 'necessaries, conveniences, or superfluities' and make 'larger returns', 'supplies', 'absolute capital and stock', 'revenue' and 'supply for future wants' (pp67, 258-260; Brewer, 1991). For him the 'effective desire of accumulation' was necessary but not sufficient for the 'increase of stock and capital', which also required 'augmentation', that part of growth occurring 'through the operation of the principle of invention' (pp205-209, 264 and Chs. VI & VII; see also Malthus, p339). And since invention results in higher efficiency a causal arrow goes from efficiency to 'larger provision... made for the future wants of the whole society' (p165). Since instrument formation means cost and 'sacrifice' in the present, without 'some future greater good...

⁴⁶ For example Cantillon, pp19, 62-63; Smith, II.iii.32, IV.ix.34; Malthus, p252; Rae, pp12-13; Marx, p358; Solow, 1957.

⁴⁷ For example Smith, I.viii.3, III.i.1; Ricardo, pp273-274; Say, pp71, 86, 295; Malthus, p296; McCulloch, pp97-102, 166-167, 411; Jones, pp237-250; Rae, pp15, 99, 216, 253; Mill, pp88, 98.

the instrument... will not be formed', yet this results only from greater efficiency*. (pp19, 110-118, 171)⁴⁸

If pressed, no classical economist would have claimed that he was describing mere correlation rather than causality. And since all wealth requires material inputs, in any description of the 19th-century economy rebound is certain and low rebound out of the question. Without efficiency increases and given only certain *quantities* of material resources and labour, not much more in the way of food or any other goods can come into existence; and unless we enjoy these (labour-)efficiency increases wholly and exclusively as the less work and more leisure that they enable, there is *some* consumption that wouldn't be there without the 'improvements'. And this consumption depends on labour and material inputs. Until Jevons, however, the doctrine did not attest backfire. Before surveying classical views on the magnitudes of this new consumption of goods and services, and their inputs, let us relate their descriptions more closely to today's debate by introducing the term *prices* and the *price falls* that result when a good is produced with lower input.

Price falls

In 1815, Ricardo wrote to James Mill, 'I know I shall soon be stopped by the word price, and then I must apply to you for advice and assistance' (Sraffa, 1951, pxiv). And no classical economist failed to warn of conflating money and wealth, with the term 'value' leading an ambiguous life between the two.⁴⁹ But being economists, our previous writers could not avoid monetary terminology altogether. While prices *can* be physically expressed as exchange value in terms of other commodities, the monetary metric is convenient. Thus all of them presaged the point made by Khazzoom in re-opening the debate over the Jevons paradox that efficiency increases have a 'price content' (1980, p22). In Smith's analysis for instance

⁴⁸ Also McCulloch, pp187-188; Mill, pp133-134.

⁴⁹ For example Smith, I.xi.c.7, II.ii.23; Say, pp240-248; Ricardo, pp274-275; Sismondi, vol. 1, pp373-387; Malthus, pp97, 255; Mill, pp71-72, 410; also Robinson, 1956, pp18, 24, 65, 122; Binswanger, 2006.

It is the natural effect of improvement... to diminish gradually the real price⁵⁰ of almost all manufactures... In consequence of better machinery, of greater dexterity, and of a more proper distribution of work... a much smaller quantity of labour becomes requisite for executing any particular piece of work; and though, in consequence of the flourishing circumstances of the society, the real price of labour should rise very considerably, yet the great diminution of the quantity will generally much more than compensate the greatest rise which can happen in the price. (I.xi.o.1; I.viii.57; Jones, p238; Marx, p379)

Although Smith here succumbs to the tendency to exogenize a vague 'flourishing circumstances of the society' (a rise in GDP), the point is well made that because improvement more than compensates rising input prices, output prices fall. He then considers rising and falling prices of 'rude material' and metal inputs together with a comparison of output prices over three centuries (I.xi.o.2-13; see also Barnett & Morse, 1963)

In Malthus's formulation, 'We all allow that when the cost of production diminishes, a fall of price is almost universally the consequence' (p60; see also pp87-88, 145).⁵¹ Favourite empirical examples were cottons in general and stockings in particular.⁵² Printed goods likewise had experienced a palpable, undeniable 'reduction in price' per copy (Say, pp302, 88). Rae liked the example of more efficiently produced, cheaper bread (p259; see also Mill, p181), while Mill liked Say's 'still stronger example' of playing cards (p123). Babbage's example of riveted tanks showed an extreme price fall (p100). Malthus even distinguishes between 'a fall of price necessary... to prevent a constant excess of supply contingent upon a diminution in the costs of production' and one following 'an increased supply of commodities'* , albeit itself due to 'the increased powers of labour' (pp56-57, 63).⁵³

The necessity of this step from efficiency increase to price fall – and then on to consumption increase – lies in producer behaviour. '[C]ompetition of producers brings the price of the product gradually to a level with the charges of

⁵⁰ Roughly, 'real', 'inherent' or 'natural' prices were long-term and determined by costs of production, while 'market' prices were shorter-term results of supply and demand only; 'nominal' prices were in terms of money (gold and silver). See Mill's '*necessary price, or value*' (p471).

⁵¹ Also Jevons, pp120, 140, 154, 156, & ch V.

⁵² For example Say, pp300, 303; Ricardo, pp25, 52; Malthus, pp281-282; McCulloch, pp117, 176, 278.

⁵³ In such passages from Smith, Say, Ricardo and Malthus several questions are often discussed simultaneously: 1) why and how wealth increases, 2) how it is distributed between rent, wages and profits, and 3) how supply, demand and price interact in the short term.

production', wiping out temporarily high profits (Say, pp395, 93). Of course patents must first run out or secrets be divulged, but eventually 'The grinding of corn is probably not more profitable to the miller now than formerly; but it costs infinitely less to the consumer' (Say, p89). For Rae, still in monetary terms, each of

the venders of a commodity wishes to sell as much as possible, and as he can do so most readily by underselling his neighbors, the price gradually falls under a free competition, until the dealers in it receive only the profits that the effective desire of accumulation, and the progress of improvement in the society measures out to them. (p307)⁵⁴

Mill also pointed to producers' 'power of permanently underselling' which can 'only... be derived from an increased effectiveness of labour' (p133; see also p495). Jevons relied on this argument from profitability (pp8, 141, 156) and names the 'series of inventions' by Bessemer, Gilchrist and Thomas as 'modes of economy which, in reducing the cost of a most valuable material, lead to an indefinite demand' (p390).

Rae solves the profits 'paradox' thus: 'Now I apprehend that high profits springing from improvement, can never lessen the sale of goods either at home or abroad, for they do not occasion a rise in their price, but rather a fall in it' (p263). Domar's later version is that 'a rapid growth of [Kendrick's] Index [total factor productivity] in any industry reduces the prices of its output, and thus stimulates sales' (1962, p605).⁵⁵ Malthus once chastises Ricardo for ignoring this point and in effect assuming that profits stayed high – 'at *cent per cent*' (p291). Moreover, whatever the profit-maximizing price policy of a monopolist is, even monopoly profits get spent because, in Say's terms, producers are also consumers (p89; see also Smith, I.xi.o.4; Ricardo, pp386-387, 392-394). This fact casts doubt on today's view that rebound is low in sectors where 'market failures' are high (Grubb, 1990b, pp783-785; 4CMR, 2006, pp5, 14).⁵⁶

⁵⁴ Also Say, p300; Jevons, pp8, 140-142; Schumpeter, 1911, pp297-306.

⁵⁵ Also Mill, pp133-134; Hotelling, 1931, p137.

⁵⁶ Grubb cryptically adds that 'When energy price or availability constrains demand... 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' (1990b, p783). That is, he attests rebound approaching 100 per cent in run-of-the-mill cases.

The classical axiom is that prices of output are the sum of the prices of inputs or charges of production (Ricardo, p397). Say talks of 'a real fall of price, or *in other words*, a reduction in the price paid to productive exertion' (p303, emphasis added).⁵⁷ Output and input prices are exactly proportional. Supply costs fall, prices fall, effective demand rises, number of units sold rises; these are today's 'price and income effects' of efficiency increase.⁵⁸ Rebound is then a function of this new quantity sold (Q) after deducting another quantity no longer sold (Q_s) of units, if any, *for which* the newly more efficiently produced item is substituted.

As for price elasticity of demand, Malthus writes that 'The increase in the whole value of cotton products, since the introduction of the improved machinery, is known to be prodigious', offering the empirical evidence of 'the greatly increased population of Manchester, Glasgow, and the other towns where the cotton manufactures have flourished' (p192; see also pp281-282; Rae, p292). Say observed the same for 'Amiens, Rheims, Beauvais,... Rouen and all Normandy', where there had first been 'loud remonstrances' over the annihilation of local industry, and gives further examples of 'prodigious' price falls (pp147-148, 300-304); he then can't resist imagining prices' falling to zero, which would at once be 'the very *acme* of wealth' and the death of political economy as a science (p304). Finally, Mill makes the empirical macroeconomic claim of falling prices over two centuries, 'accelerated by the mechanical inventions of the last seventy or eighty years' (p182). All these economists were describing, via price falls, a very high 'efficiency elasticity of demand' (Sorrell & Dimitropoulos, 2006, p7). But demand for what? For the newly cheaper good? For everything, as described in the next section? For our topic of interest, material and labour inputs?

⁵⁷ Say indeed calls '*prix*' a measure of '*valeur*' and '*valeur*' a measure of '*utilité*' (p62). But if prices reflect utility and utility is very different from costs of production, then prices confuse environmental analysis. Utility is not an environmentally relevant concept. If Mill is right, however, that prices in their long-run movement to 'natural price' reflect utility to perhaps 1 per cent and efficiency (or difficulty or cost of production) to 99 per cent* (pp462-464), then this objection falls and prices are a satisfactory proxy for environmental impact.

⁵⁸ For example Wackernagel & Rees, 1996, pp127-128; Wirl, 1997, p41; Binswanger, 2001, p120.

But as long as we are thinking in monetary terms, what happens to the *total* amount of money paid for the goods now cheaper *per unit*? This is the new price per unit times the new quantity ($P \times Q$) as opposed to the new quantity physically measured (Q) and was termed by Say '*le montant total*' or sum total (p450). He gives a descriptive example of (direct) backfire in the 'art of printing':

By this expeditious method of multiplying the copies of a literary work, each copy costs but a twentieth part of what was before paid for manuscript; an equal intensity of total demand, would, therefore, take off only twenty times the number of copies; probably it is within the mark to say, that a hundred times as many are now consumed. So that, where there was formerly one copy only of the value of 12 dollars..., there are now a hundred copies, the aggregate value of which is 60 dollars, though that of each single copy be reduced to 1-20 [one twentieth]. (p302; see also Rae, pp216, 249-250)

Taking price and costs as equal and substituting 'labour time' or 'material amount' for 'dollars', we can estimate input consumption. Substituting 12 hours of labour for 12 dollars, if the price elasticity of demand is in a ratio of 20:100, in the end 60 hours of labour are demanded and labour input demanded is higher than it *would have been* without the efficiency increase. Say could analogously describe 'direct backfire' regarding energy efficiency today.

Still referring only to manufactured goods made cheaper, rather than the whole economy, Malthus writes that by means of

the introduction of improved machinery, and a more judicious division of labour in manufactures... not only the quantity of manufactures is very greatly increased, but... the value [price, cost] of the whole mass [$P \times Q$] is augmented, from the great extension of the demand for them both abroad and at home, occasioned by their cheapness... The reader will be fully aware that a great fall in the price of particular commodities... is perfectly compatible with a continued and great increase, not only in the exchangeable value of the whole produce of the country, but even in the exchangeable value of the whole produce of these particular articles themselves. (pp135, 314)⁵⁹

While Khazzoom's demonstration of rebound assumed *any* positive price elasticity of demand (1980, p22), Malthus describes a very high elasticity. The point, in Say's words, is that 'every real reduction of price, instead of reducing the nominal value of produce raised [$P \times Q$], in point of fact augments it' (p303). $P \times Q$ for product or sector X increases following productivity-induced price falls. Following Say that work is done by nature (for example fossil fuels) as well as human beings, in other words it commits 'productive exertion' (pp40, 63, 74-75, 90, 245 note; Rae, pp246, 256-258), we have, for any X, P_{Labour} and P_{Material}

⁵⁹ Also (Malthus), pp190-192, 296, 319-322, 339; Jones, pp237-239; Babbage, pp112, 232-233; Rosenberg, 1982, p106.

both as costs and prices. $Q \times P_{\text{Material}}$ after an efficiency increase is compared with that before, but where Q rises by any amount, direct rebound is proved. The relative degrees of growth of Q and P_{Material} determine the size of this direct rebound.

But what happens in sectors not affected by productivity increases? Or, how can the 'value of the whole mass' (economy-wide) increase unless *money supply* increases? If it doesn't, *less* demand would have to accrue to goods that did not enjoy a productivity increase.⁶⁰ And monetarily, the consumer's gain is perhaps equal to the producer's loss. Monetary analysis also entails identifying cases where substitution of the newly cheaper good for another good occurs then measuring both the price and the substitution elasticities. Should rebound research discard the veil of money and deal only with the ratio of Q to joules, with each unit q measured physically – rather than compare ratios of $P \times Q$ to joules before and after an efficiency shock, as with the concept of energy intensity of a unit of GDP?

Mill's heroic attempt to sort out the concepts of price, use value, exchange value and their application to particular goods as opposed to the whole mass (pp455-459) relegates 'price' to goods' relationship to money and 'exchange value' to an economic discourse dispensing with 'money', namely to 'the command which [a good's] possession gives over purchaseable commodities in general' (p457).⁶¹ He also made the point that 'if inventions and improvements in production were made in all commodities, and all in the same degree, there would be no alteration in [relative exchange] values' (p710). But Say (pp303-305) and Malthus (p135), even when using the term 'exchange value', were talking not sectorally of the 'values' or prices of things relative to each other but of the 'whole mass', conceivably tradable for other things in other countries. Criticizing his predecessors in all but name, Mill concludes that 'All commodities may rise in their money price. But there cannot be a general rise of values' (p459).

⁶⁰ If the whole mass is $X + Y$ where X is the newly more efficiently-produced good and Y is all else, then $\Delta P \times Q_x$ would equal $\Delta P \times Q_y$.

⁶¹ Perhaps Mill's father James led Ricardo to the distinction between the 'net produce' or 'riches' – which always increase with efficiency – and the other 'value of that net produce' ($P \times Q$), which 'may not... increase' (pp391-392, 16), leaving J.S. Mill the work of deciphering.

Mill has a point. If, as Malthus somewhat circularly said, 'exchangeable value is the relation of one object to some other or others in exchange' (p51), then the concept of exchange is of no use in analyzing the *growth* of wealth. And to the extent that prices are an abstract proxy for millions of exchange values, monetary concepts are likewise perhaps inapplicable. In Malthus's words,

When it is said that the exchangeable value of a commodity is determined by its power of purchasing *other goods*, it may most reasonably be asked, *what goods?* It would be absolutely impossible to apply all goods as a measure. (p97 note)

This does not prevent Malthus elsewhere from talking of 'the increase in the exchangeable value of the whole produce estimated in labour' (p192) and even of the value of money expressed in labour (p144 note). And after listing shortcomings of *any* metric of value, which remind one of today's criticisms of GDP, he opines that we can't do without one, if only to compare the total products of different economies (pp247-248, 255-256). Such difficulties in integrating concepts of exchange and price with the 'value of the whole mass' arise in Rae's struggle with the paradox that a limited amount of exchange value in terms of prices coexists with greater wealth [deflation], and he concludes that the relevant magnitude was the *physical* increase in 'absolute capital and stock' (pp259-260).⁶²

Whatever happens economy-wide, price falls and underselling of more energy-efficient goods raises their relative attractiveness. Jevons used the common classical phrase that coal 'commands' iron and steam (p2; see also Martinez-Alier, 1987, p161); whatever is more cheaply or powerfully commanded – products requiring iron and steam – enjoy higher demand. If I can commute to work by bicycle, bus, horse, car or on foot, more efficient motors give the car the edge. This implies high economy-wide or total rebound and even backfire even if economy-wide Q or $P \times Q$ does *not* increase* – a pure 'substitution' effect distinct from income effects and the derived categories of 'direct' and 'indirect' rebound.

⁶² Efficiency and its consequences can be grasped physically. Smith resorts to this method in solving the paradox that 'improvements in... productive powers' are accompanied not only by price falls but 'in appearance' price rises of many things including labour (I.viii.4; also I.i; Malthus, p215).

The purely physical perspective shows us that the actual amount of coal or oil for a steam engine, car or light bulb over its 'lifetime' drops, enabling us to ask after the price or exchange-value effects on the *inputs themselves* rather than the outputs such as a pair of stockings: the initially lower demand at constant output lowers the price of the input, in turn raising demand for it relative to all else. Combining this aspect with the income effects discussed in the next two sections, Burniaux et al., for instance, 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 [autonomous energy efficiency] increase because the energy conservation effect is partly compensated by the relative price and income effects. (1995, p246; Hearn, p99)

The size of this input-price-determined rebound depends also on the price elasticity of supply, for example of petroleum. At any rate, empirical work must analyze energy prices as well as efficiency change and change in the consumption of 'outputs'.⁶³

Societal income effect

Smith's 'invisible hand' is not all that invisible but a name for the mechanism starting with efficiency increase, in other words with dexterity, division of labour, trade and machines 'directing... industry in such a manner as its produce may be of the greatest value' – a 'greatest value' variously called 'wealth', the 'annual revenue of the society', its 'power of purchasing', or 'the exchangeable value of the whole annual produce of its industry'. (IV.ii.4, 9, I.iv.13, I.vi.17, II.ii.21) This revenue or purchasing power – concepts closer to consumption than to production – was divided between labour/wages, capital/profits and land/rents, raising the allocative question which for Ricardo was the defining *explicandum* of political economy (pp 5, 347).⁶⁴ While the others likewise devoted much effort

⁶³ Saunders shows that backfire is consistent with constant prices when the productivity of energy rises in the a production function with capital, labour, energy and material (1992).

⁶⁴ The term 'purchasing power' is explicitly found in, for example, Smith, I.v.3, I.xi.m.19-20, II.ii.21; Malthus, pp42, 49, 53, 80; McCulloch, pp171, 177; Mill, pp67, 458.

to this issue,⁶⁵ their main concern was the question of scale, or the size and growth of production and consumption (Daly, 1992). Malthus even castigates Ricardo by name, writing that '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' (p164). More politely, Say remarks of landowners and capitalists, 'The world at large may be content to comprehend, without taking the trouble of measuring, their respective shares in the production of wealth' (p74 note).

Rae conceptualized this crucial distinction with the terms 'acquisition' and 'augmentation' (sometimes 'accumulation'); the former is a mere shift of wealth from one person, group or nation to another, the latter a rise of the total (or per capita average) amount of produce (pp11-12, 24, 260, 264, 307; Say, p85; Malthus, p35; Mill, p62). Following Say (Say, pp70, 117-118) he names this 'creating wealth', claiming that 'the ends which individuals and nations pursue, are different. The object of the one is to acquire, of the other to create' (Rae, p15). 'As individuals seem generally to grow rich by grasping a larger and larger portion of the wealth already in existence, nations do so by the production of wealth that did not previously exist' (p12). Not Smith's invisible hand, but the state or 'community' must promote and encourage 'progress of art', the 'discovery of new arts' and the 'discovery of improvements in the arts already practised in the country [efficiency]' (pp15, 12).

The clearest description of the augmentation of societal income is Say's:

[T]he aggregate utility will be augmented; the quantum of products procurable for the same [total] price will be enlarged... But whence is derived this accession of enjoyment, 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 has been rendered available for human purposes, that had before been not known, or not directed to any human object;... or one 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. (p299)

He sharpened this concept of greater wealth that nobody pays for by expanding his system boundary to include the whole world, describing sales between nations as mere acquisitions in Rae's sense* and insisting that 'the general

⁶⁵ For example Smith, I.vi.6-18; Say, pp15, 77; Malthus, Book I, Chs. III, IV, & V; Mill, p235.

stock of wealth, existing in the world... can only be enlarged by the production of some *new utility*' (p305, emphasis added; see also p318). Malthus later described this shift of the societal supply curve caused by lower costs of production as a change in the 'conditions of supply... advantageous to the consumer' (1825, p303).⁶⁶ Mill as well identified this rise in 'general purchasing power', caused for instance by 'an invention... made in machinery, by which broadcloth could be woven at half the former cost'; for him, simply, 'all... improvements make the labourers better off with the same money wages...' (pp457-458, 751).

'Wealth, that nobody pays for'? Is there a free lunch after all? (Jones, pp288-289) Evidently yes, once inventors, research-and-development and embodied inputs are deducted as costs. The point is that the source of this lunch is efficiency. This productiveness inheres either in nature, as with increased dexterity or education of humans and the substitution of naturally better materials, or in our ways of organizing themselves and their materials by 'forming' or 'transforming' matter for utility (Cantillon, p2; Say, pp62, 65, 387; McCulloch, p61; Rae, pp81-83).⁶⁷ Virgin land, virgin mines and population growth can bring greater output for constant input per unit, but efficiency brings this result even when the limits of these things are reached, or closely approached.

Once Say had fingered this win-win process he defended it with sarcasm against Galiani and Forbonnais, whose idea that one's gain must be another's loss underpinned the 'systems of all the short-sighted merchants' (pp16, 31 note and 70). More didactically and again reflecting the struggle with the term 'value' he wrote,

If different commodities have fallen in different ratios,... they must have varied in relative value to each other... There is this difference between a real and a relative variation of price [*valeur*]: that the former is a change of value, arising from an alteration of the charges of production; the latter, a change, arising from an

⁶⁶ Also Mill, pp477-487; Khazzoom, 1980, pp22-24.

⁶⁷ Ecological economics parts company with Say when he declares these 'spontaneous gifts of nature...', neither procurable by production, nor destructible by consumption' to lie outside the realm of political economy (pp63, 86). In the frequent classical emphasis on exchange, as in environmental economics' emphasis on allocation, one sees that new biophysical facts, and limits, necessitate a re-definition of political economy (Boulding, 1966; Daly, 1992).

alteration of the ratio of value of one particular commodity to other commodities. Real variations are beneficial to buyers, without injury to sellers; and *vice versa*; but in relative ones, what is gained by the seller is lost by the purchaser, and *vice versa*. (p304; see also Mill, pp457-458)

His summary:

In commercial, as well as manufacturing industry, the discovery of a more economical or more expeditious process, the more skilful employment of natural agents, the substitution, for instance, of a canal in place of a road, or the removal of a difficulty interposed by nature or by human institutions, reduces the cost of production, and procures a gain to the consumer, without any consequent loss to the producer, who can lower his price without prejudice to himself, because his own outlay and advance are likewise reduced. (p101; see also pp89, 301)

He later offers a numerical example expressing purchasing power in terms of 'the quantity of his own particular product' instead of money: once stockings are made cheaper, a sugar tradesman can get the same number of stockings as before for less sugar (p300). He then assumes simultaneous price falls of sugar and stockings, asking whether we are now

authorized to infer, that this fall is a positive fall, and has no reference or relation to the prices of commodities to one another? that commodities in general may fall at one and the same time, some more, some less, and yet that the diminution of price may be no loss to any body? (pp300-301)

McCulloch also argued against the claim that consumers' gains might be balanced by producers' losses, and in his own jibe at Ricardo also saw win-win cases where 'profits... would have risen, without their rise having been occasioned by a fall of wages' (p372). Distribution is here not the issue.* Malthus also empirically attests rising profits and, moreover, lest anyone fear slacking demand, capitalists' rising expenditures 'in objects of luxury, enjoyment, and liberality' (p293). While arguing that labour efficiency causes unemployment, Sismondi had ignored this point that demand for labour originates from profits as well (Sismondi, vol 2, pp335, 322-324). Jevons later added that even when profits through competition fell to their minimum, there is a net gain to society (1871, p254).

This possibility that suppliers' profits as a total amount of purchasing power could fall seemed real. Charles Babbage 'strongly pressed upon the attention' of the manufacturer to very carefully 'ascertain how many additional customers he will acquire by a given reduction in the price of the article he makes' lest profits turn to losses, adding that falling prices would force firms to make further

efficiency gains (pp98-99; see also Say, p87).⁶⁸ Old goods produced more expensively, for instance, must be sold at a loss (albeit a gain for the consumer) (Say, pp305, 390; Ricardo, p274; Malthus, p282).⁶⁹ The profits of the producers of material inputs – for example of energy or mining companies – could also fall since they experience at least initially lower demand and must lower prices; however, the rebound caused by lower input prices in the longer term restores profits.

Smith was describing this economy-wide income effect of newly enabled, costless prosperity by writing for instance that 'all things would have become cheaper in reality'; 'improvements in mechanicks... are always regarded as advantageous to every society'; the surpluses of 'the country', division of labour and trade with 'the town' raise the revenue of *both* (I.viii.4, II.ii.7, III.i, IV.vii.c.88, IV.ix.51; IV.ix; Mill, pp119-122). For Rae 'all instruments at the period of their exhaustion return more than the cost of their formation' (p118) and 'good bread... produced... with half the labor and fuel... would not benefit the bakers exclusively, but would be felt equally over the whole society' (p259). Efficiency is like corn – one seed yields 100 seeds. Jevons likewise later wrote that profits falling to their minimum means that everything is cheaper, and that 'either the labourers themselves, or the public generally as consumers, gather all the *excess of advantage*' (1871, pp254, 257, emphasis added). Finally, Mill quoted Rae's description of the contrasting 'stationary state' society of China (Mill, pp168-169) and referred to the free increase of wealth caused by 'improvement' as an 'increased means of enjoyment' (p724).

If we now make the attempt to approach rebound while ignoring prices, as suggested in the last section, we can for instance assume that before an efficiency increase production is 10X, at 10 joules/X, equaling 100 joules of input. If afterwards there are 12X, at 9 joules/X, this equals 108 joules of input,

⁶⁸ Say also noted that efficiency is the *result* of a profusion of taxes (p473), a point likewise clear in today's debate wherein Pearce, for instance, notes that through efficiency some of the effect of eco-taxes is 'taken back' (1987, p14).

⁶⁹ A friend of mine who wholesaled slide rules once had to throw away several thousand slide rules with the advent of calculators – a process difficult to integrate into this gain/loss calculus and again raising the question of *undesired* output or waste.

in other words backfire. Our writers often claimed that this is the normal case: we can produce not only 10 per cent more X if efficiency increases 10 per cent, but 20 per cent. Is this something coming from nothing? It is easy to accept that 11X are produced, using 99 joules of input, in other words rebound of 100 per cent. But whence the twelfth X? Seen monetarily, the source can only lie with increased purchasing power due to X's price fall, with purchasing power seen as an income effect, or taken away from rival factors of production like labour, or due to a price fall *of the input joules* when the supply function for joules does not shift.

One argument for the possibility of backfire thus does not depend on the concepts of societal income effect or even growth of total output: if a given factor of production becomes more powerful, to use the classical term, demand for that factor will increase relative to rival factors of production whose productiveness remains the same (Marx, p354; Brookes, 1990, 2000; Saunders, 1992, 2000). Brookes writes,

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 implications for demand [for fuel]. (2000, p355)

Jevons similarly concluded his chapter 'Of the Economy of Fuel' by asserting necessary rises in both input and output consumption:

And if economy [efficiency] in the past has been the main source of our progress and growing consumption of coal, the same effect will follow from the same cause in the future. Economy multiplies the value and efficiency of our chief material; it indefinitely increases our wealth and means of subsistence, and leads to an extension of our population, works, and commerce, which is gratifying in the present, but must lead to an earlier end. Economical inventions are what I should look forward to as likely to continue our rate of increasing consumption. (p156)⁷⁰

Again, if we interpret the societal income effect monetarily we encounter the paradox that a consumer with a new park of efficient appliances pays less to the electricity supplier, lowering his income, purchasing power or consumption. Where a high price elasticity of demand is claimed (for example Say, p302, or Malthus, p192), we could encounter a bookkeeping quantity 'that nobody pays for': if before an efficiency event 36 units are sold at £2 each, $P \times Q = £72$, and

⁷⁰ Brookes concurs with Jevons that, *ceteris paribus*, really saving such a material lowers affluence (1990, 2000).

where price elasticity of demand is 1, $7 \times £1$ also = £72. If price elasticity of demand is 2, then 144 units sold yields £144. Whence the additional £72? If withdrawn from sectors previously favoured we must deduct this from rebound. Again, it seems clearer to simply realize that *more output* is here at the same cost in physical inputs. If societal purchasing power is £1,000,000 and newly more efficiently produced things are now £1,000 cheaper, we have a monetary hole that gets filled up with material goods.

High rebound

One conclusion till now is that efficiency-induced consumption of output, entailing as it does *some* input, proves rebound. Before looking more closely at classical descriptions of high rebound, some taxonomy is useful.⁷¹ Increased society-wide purchasing power results from the increased efficiency of producing an average unit of a good of type X, as opposed to Y, representing all other goods. At this moment, as Malthus said, 'there must be a considerable class of persons who have both the will and power to consume more material wealth than they produce...' (p319). This new demand can be

1. for additional X by consumer A, a previous consumer of X;
2. for some Y by consumer A;
3. for additional X by a new 'marginal' consumer B;
4. for some Y by consumer B, who after consuming some X retains some 'consumer surplus'; and
5. for leisure – in the extreme, all consumers choose to lower their purchasing power to the full extent of engineering savings.

Aside from these variations of the income effect, a more efficient production factor is substituted for another one – a 'substitution' effect.

The first and second cases are called 'direct rebound', today's workhorse example being that if my new car uses less petrol per kilometre, my existing purchasing power allows me to drive more kilometres; this is Khazzoom's 'own'

⁷¹ See Sanne, 2000, pp488-489; Binswanger, 2001, p122 note.

price elasticity of demand (1980, p22). The total cost of the car including its use has dropped, freeing income.

The second case is in Malthus's words 'distinct from' the first and pertains when 'the commodity to which machinery is applied is not of such a nature that its consumption can extend with its cheapness' but 'there would be a portion of revenue set free for the purchase of fresh commodities' (pp282-283). Given higher purchasing power, when the price elasticity of demand for the newly cheaper good is low, *indirect rebound* results (even with high efficiency elasticity of price). In unfairly claiming that Malthus missed this point McCulloch offers a clear description of it:

Suppose the price of cottons were reduced in the proportion of ten to one; if the demand for them could not be extended, it is certainly true, that nine-tenths of the capital and labourers engaged in the cotton manufacture would be thrown out of *that* employment: But it is equally certain, that there would be a proportional extension of the demand for the produce of *other* branches of industry. It must be remembered, that the means by which the purchasers of cottons formerly paid for those that were high-priced, could not be diminished by the facility of their production being increased and their price reduced. They would still have the *same capital* to employ, and the *same revenue* to expend. (pp177-178, 188)

The indirect rebound of the second a

nd fourth categories above is likewise in Say's remark that:

A new machine supplants a portion of human labour, but does not diminish the amount of the product; if it did, it would be absurd to adopt it. When water-carriers are relieved in the supply of a city by any kind of hydraulic engine, the inhabitants are equally well supplied with water. The revenue [purchasing power] of the district is at least as great, but it takes a different direction... [I]nferior charges of its production [mean that] the revenue of the consumers is benefited. (pp86-87)

Say's translator Prinsep is explicit: Our revenues are enlarged by lower costs of production of X, and we are free 'to employ them upon some other object [types 2 & 4], or upon an enlarged production of the same object [types 1 & 3]' (p296 note). Ricardo likewise, quoting Smith's attestation of unlimited desires for all but food, brings the example where 'improved machinery, with the employment of the same quantity of labour' quadruples 'the quantity of stockings' [but] the demand for stockings were only doubled', leading to 'the production of some other commodity' (p387). In Malthus's version:

... though the wills and means of the old purchasers might remain undiminished, yet as the commodity could be obtained without the expression of the same intensity of demand as before, this demand would of course not then show itself. (p55)

Based on this consumer surplus, demand could and would show itself elsewhere.

In the classification above good Y could also be a *new good*, i.e. one not existing at the time of the efficiency increase but whose supply and consumption depends on that efficiency increase. Examples are legion – railways following better steam engines and cheaper steel, or emails following the more efficient use of electricity in data transmission. Transportation, milling, printing, and glass-making all count for Rae as consumption areas opened up by efficiency (pp116-117, 245-250, 291-292) while Hearn presaged Jevons' emphasis on new uses and products in observing that:

In many districts the price of coal has been reduced from thirty to forty per cent; and the purposes to which it has been applied have consequently been largely increased. (p274)

Jevons repeated this general point (pp141-142, 197) and named new uses of coal in metallurgy and transportation (see footnote 23). Martinez-Alier points out that instead of substituting for coal, electricity increased demand for it (1987, p88; also Jevons, p181) Sanne draws the exact parallel with new applications of electricity as it becomes cheaper due to increased efficiency of coal-fired plants (2000, p489).

Jevons called this new consumption 'the reaction and mutual dependence of the arts' as when Darby's powerful-blast smelting oven required the substitution of coal for water (pp372, 385). And the fundamental phenomenon of productivity's opening up *new* markets had been sketched early on by Smith (l.xi.c.36) and filled out somewhat by Say (pp89-90) and Rae (pp245, 247, 253). But granted that 'many of the more important substitutions are due to coal' (Jevons, p134), what are the net effects? Coal's efficiency meant that fewer horses and oats were consumed due to railroads, just as today efficiencies of electricity production and use mean perhaps that fewer paper letters are sent due to e-mail. Again, how much of this new consumption should be booked under rebound is hard or impossible to decide, and while today it is implicitly subsumed under 'economy-wide' rather than either direct or indirect rebound it is *ignored* by all rebound studies. Fresh study is warranted of Babbage, von

Liebig (1851), Cipolla (1962), Rosenberg (1982, 1994), Clapp (1994) and Siefert (2001).

As for the direct rebound of the third case, where marginal consumer B purchases X, all writers observed that the efficiency-induced cheapening of X enables marginal consumers to buy it. Say writes,

Suppose that... knit-waistcoats of woollen [cost] 2 dollars each;... those who should have but a dollar and a half left must... go without. If the same article could be produced at one dollar and a half, these latter also might all be provided and become customers; and the consumption would be still further extended, if they should be produced at one dollar only. In this manner, products formerly within the reach of the rich alone have been made accessible to almost every class of society, as in the case of stockings. (p288)

How much of this demand is truly new, in other words not shifted from Y, however, is an open question. Malthus echoes Say, talking of

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 their former value'. (p281; see also p314)

In terms of $I = PAT$ (that is, environmental Impact = Population x Affluence x Technology), $(P \times A)_{\text{after}} > (P \times A)_{\text{before}}$. Sismondi reminded these economists however that since the laid-off workers have no more purchasing power the market extension is inhibited (vol 2, pp316-317, 326-327, 251). We can moreover ask Say and Malthus what the marginal consumer had done with his one dollar and a half before the price of the waistcoat fell from 2 dollars. Whatever would have been consumed without the cheapening of the waistcoat is no longer consumed, constituting to some degree a win-lose situation after all.

Also part of 'indirect' rebound is the fourth category where a marginal consumer's demand for X evidences some consumer surplus, leaving some purchasing power for Y. Taken together the four categories equal total rebound or the societal income effect. Today all rebound researchers acknowledge the difficulty of tracing these effects from direct rebound through indirect rebound to what really matters, namely total or economy-wide rebound. Wirl notes that excluding 'marginal consumers' gets around the 'conservation [or] energy paradox' but yields an underestimation of rebound (1997, pp19-32, 36, 112). Roy believes that there is '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, p433).⁷² What then are we to make of Allan et al.'s assertion that 'rebound is an empirical issue... It is simply not possible to determine the degree of rebound and backfire from theoretical considerations alone...' (2006, pp21-22; see also pp3, 10)?

Malthus already saw this. Assuming, he said, that latent demand in the affected sector was low:

To what extent the spare capital and labour thrown out of employment in one district would have enriched others, it is impossible to say; and on this subject any assertion may be made, as we cannot be set right by an appeal to facts. (p286)⁷³

It is likewise doubtful whether we today have the data necessary for demonstrating that a given increase in one sector constitutes indirect rebound from efficiency in another sector. Direct rebound is apparently more easily estimated. Some sectoral studies calculate high direct or even total rebound (Dahmus & Gutowski, 2005; Allan et al., 2005; Herring, 2006; Fouquet & Pearson, 2006) while some, implicitly or explicitly offering support to the environmental efficiency strategy, show total rebound as low as 26% and thus real energy savings (4CMR, 2006, pp6, 9, 66).⁷⁴ Other studies attest low rebound while however limiting themselves to direct rebound and moreover equivocating between direct and total rebound (Greening et al., 2000; Berkout et al., 2000).

The fifth category, wherein leisure is chosen, is crucial: rebound *can* be zero if price elasticity of demand is vertical. As shown in the next section, only Malthus gave weight to this possible reaction, the others agreeing with Rae that 'improvement [is] absorbed by vanity' (pp289-290) or with Jevons that children will continue doing as their elders did (p199). That is, humankind finds itself in a condition far from satiation. To attest rebound is merely to assert that, short of total consumer satiation, theoretical input savings are never fully realized, whereas backfire depends upon a strong low-satiation premise. The sixth

⁷² Also Khazzoom, 1980, p32; Grubb 1990a, pp235, 195; Rosenberg, 1994, pp165, 166; Schipper & Grubb, 2000, pp368, 383, 387; Sorrell & Dimitropoulos, 2006, p3.

⁷³ Say at times also eschewed empirical study (p102 note), a view shared less categorically by Ricardo (1820-1822, pp362-363).

⁷⁴ Also Howarth, 1997, pp4, 7; Schipper & Grubb, 2000, p384.

category of 'substitution' effects, which includes the effects of a fall in the *input* price relative to other prices, received little explicit attention in Jevons and the classical literature.

The classical input metric was not always of labour, land area and mines, but of materials as well. Mill once observes that 'the tendency of improvements in production is always to economize, never to increase, the expenditure of seed or material for a given produce' (p99). And renewable energy resources concern him in his analysis of the invention of – *nomen est omen* – windmills and watermills (p28). Rae was more explicit:

Every society possesses a certain amount of materials capable of being converted into instruments. The surface of its territory, the various minerals lying below the surface, its natural forests, its waters, [etc.]... are all to be regarded as materials, which, through the agency of the labor of its members, may be converted into instruments. The extent of the power, which the inhabitants of any state may possess, to convert into instruments... is however variable; and increases... as their knowledge of the properties of these materials and of the events [products], which in consequence of them, they are capable of bringing to pass, increases. [K]nowledge... gives... the power of constructing a much greater number of instruments out of the same materials. (p99)

This leads to Rae's long chapter on invention, which always serves efficiency either by changing 'materials' or applying given 'materials' to new arts (pp258-259, 224-229, 242-249). In Smith (l.xi.o.12), Say (pp89-90) and Rae (pp242-244) the insight is that without inventions, water and wind are not used at all, but that once the right equipment is available, the energy is used more and more. The bridge from invention to efficiency is established by Jevons's closely related, ironic observation on the difference between Savery's coal-burning steam engine and those of Newcomen and Watt: Savery's '*consumed no coal, because its rate of consumption was too high*' (p143). Once invention has occurred, the consumption of an input is positively proportional to the efficiency of its use – yielding rebound for sure but not necessarily backfire.

Surplus and indolence

Malthus threw a monkey wrench into the mechanism of output growth described by Smith, Say, Ricardo and himself:

It has been supposed that, if a certain number of farmers and a certain number of manufacturers had been exchanging their surplus food and clothing with each

other, and their powers of production were suddenly so increased that both parties could, with the same labour, produce luxuries in addition to what they had before obtained, there could be no sort of difficulty with regard to demand... But in this intercourse of mutual gratifications, two things are taken for granted, which are the very points in dispute. It is taken for granted that luxuries are always preferred to indolence, and that an adequate proportion of the profits of each party is consumed as revenue. The effect of a preference of indolence to luxuries would evidently be to occasion a want of demand for the returns of the increased powers of production supposed, and to throw labourers out of employment. (p258; see also p9)

Greater consumption following increased efficiency is not necessary but only what 'almost always happens' (p170). What if, he asks, 'after the necessaries of life were obtained, the workman should consider indolence as a greater luxury than those which he was likely to procure by further labour...' (p268)? 'The peasant, who might be induced to labour an additional number of hours for tea or tobacco, might prefer indolence to a new coat' (p283). In richer societies, likewise, it could be that the 'habits and tastes of the society prevent... an... increased consumption' and 'the demand for material luxuries and conveniences would very soon abate' (pp288, 191; see also Mill, p105) – the vision of today's sufficiency strategy (Alcott, 2007).⁷⁵ Even for poorer societies like that of North American Indians, whose 'proverbial indolence' he attests, the rule is that 'to civilize a savage, he must be inspired with new wants and desires' (Malthus, pp103-104).

Malthus's population essay already notes these limits to demand for produced goods (1798, pp95, 120). However, he knows that the 'laws of nature have provided for the leisure or personal services of a certain portion of society', and that the tastes and habits of this leisure class (Veblen, 1899), perhaps due to exposure to items of foreign trade, can sustain a good deal of luxury consumption (pp317, 284). The issue here is not 'Say's Law' – that overproduction is only temporary – but human psychology. Jevons explicitly maintained that we cannot count on consumption or reproduction desires subsiding, and even claims this to be 'the gist of the subject' (p194). He knew that his argument that fuel's very economy was part of the problem needed assumptions about desires, saturation and demand elasticities: the 'natural laws [of growth] which govern... consumption' (pp25, 275) must be firmly assumed in our models of energy use. To be sure, he frames the classical view both of

⁷⁵ His claim is also empirical: 'experience amply shows' this (pp284, 268).

population increase and the desire for greater and greater material wealth in the conditional:

If our parents doubled their income, or doubled the use of iron, or doubled the agricultural produce of the country, then so ought we, unless we are changed either in character or circumstances. (pp193-194; see also pp232, 275)

But nothing else is to be *expected* (p199). Similarly, many later writers have conjectured that *if* consumer saturation were a fact, or *if* we would value the leisure dividend of efficiency increases more, problematic overconsumption and high natural-resource rebound would be mitigated (Schor, 1992, 1999; Grubb, 1990a; Sanne, 2000, pp489-490, 494-495).

Although Say once for some reason writes cautiously that 'the productive agency thus released *may* be directed [*peuvent être employés*] to the increase of production' (p295, emphasis added), aside from Malthus only took this possibility of non-consumption seriously:

If the labourer's command over the necessaries and comforts of life were suddenly raised to ten times its present amount, his consumption as well as his savings would doubtless be very greatly increased; but it is not at all likely that he would continue to exert his full powers. In such a state of society workmen would not be engaged twelve or fourteen hours a day in hard labour, nor would children be immured from their tenderest years in a cotton-mill. The labourer would then be able, without endangering his means of subsistence, to devote a greater portion of his time to amusement, and to the cultivation of his mind. (pp167-168)

Our epigraph shows the mainstream view that indolence is seldom chosen. To be sure, Mill attributes this 'less leisure' only partly to unlimited desires; rising population and diminishing agricultural returns to labour also figure (p12). And indeed if Malthus's own principle of population is taken seriously, and 'multiplication...may be regarded as infinite', demand for more efficiently produced food and clothing is likely to dominate over the 'power to consume... in idleness' what has already been produced (Mill, pp154, 34). Smith's view also ran contrary to Malthus's: while the stomach is limited, our further willingness to purchase is not (I.xi.c.7), and in the end himself seconded this without reservation (pp167-178; see also Petty, p307). The doctrine thus stood that 'the limit of wealth is never a deficiency of consumers, but of producers and productive power' (Mill, p68).

For Rae, likewise, 'All instruments exist solely to supply wants' (p166). As proof he offers a psychological theory *why* indolence loses out to accumulation: 'The

increased facility of production has... in a great measure also been absorbed by vanity' (p289). While he takes leisure and indolence seriously, and regards labour as a cost (pp98, 118, 141, 209), display consumption wins out (p271); indeed his chapter 'Of Luxury' recounts in detail the human tendency towards display, competitive, or prestige consumption (pp265-292), presaging Veblen's famous 'conspicuous consumption' (1899, pp32, 110, 241; Sismondi, vol 2, p318). This relative consumption is by definition limitless (Alcott, 2004, pp776-778).

Unlike Veblen, Rae quotes extensively from other authors like Pliny, Smith, Heinrich Friedrich von Storch and Say's similar but less systematic analysis in his chapter 'Of Individual Consumption – Its Motives and Effects' (Say, pp 401-411). In a nascent appeal for sustainability Rae praises care for 'futurity', 'frugality' and saving in the interests of the 'social affections' (pp60, 265, 275), strongly seconded by Jevons in his worry for posterity over coal's depletion (pp3-6, 373, 412, 454-455). But these succumb in great degree to vanity:

At length, in some quarter or another, an improvement began to be perceived. What do we find to have been the most prominent accompaniment of this change? Is it a diminished expenditure – and increased parsimony – a frugality before unknown? I believe not.' (p23)

Mill even built this power of consumption over investment and indolence into his very definition of political economy, which 'makes an entire abstraction of every other human passion and motive; except those which may be regarded as perpetually antagonizing principles to the desire of wealth, namely, aversion to labour, and desire of the present enjoyment of costly indulgences' (quoted by Bladen in Mill, pxxix). Our fifth (no-)rebound category stands as an extreme: at absolute consumer saturation every efficiency increase would bestow upon us free time and upon posterity relatively more resources.

Backfire

Malthus was the economist most worried about market glut or an insufficient 'extension of the market' (pp285, 288).⁷⁶ But he too in the end attested high rebound and even, with regard to labour inputs, *direct backfire* – for instance in the case of cotton goods where 'notwithstanding the saving of labour, more hands, instead of fewer, are required in the manufacture' (p281). He accordingly defended himself against being 'classed with M. Sismondi as an enemy to machinery' (p282 note). Between the first and posthumous second edition of his *Principles*, 1820 and 1836, many writers had banned thoughts of consumer satiation, if they occurred at all, to the realm of theory. recaps the story thus:

Accumulation [of capital] and division [of labour] act and react on each other. The quantity of raw materials which the same number of people can work up increases in a great proportion, as labour comes to be more and more subdivided; and according as the operations of each workman are reduced to a greater degree of identity and simplicity, he has... a greater chance of discovering machines and processes for facilitating and abridging his labour. The quantity of industry [labour], therefore, not only increases in every country with the increase of the stock or capital which sets it in motion; but, in consequence of this increase, the division of labour becomes extended, new and more powerful implements and machines are invented, and the same quantity of labour is thus made to produce an infinitely greater quantity of commodities. (p96; see also Jones, pp237-244)

Three points of note in this passage are as follows: seems to be considering material rather than labour inputs. Next, circulating as well as fixed 'capital' is endogenized (see also pp94-95 and Mill, p63). Third, if material output ('commodities') really grows as much as he says, then backfire is very likely. Babbage likewise discusses efficiency in material/energy as well as time terms, and regards the growing economy as too obvious to mention (pp100, 112, 222, 273; see also Mill, p106). Rae concurs with McCulloch in almost the same words (pp67-68).

If McCulloch were to visit us today, would he regard his term 'infinite' as an exaggeration? He would in any case see the understatement in his view that the 'admirable machinery invented by Hargreaves, Arkwright, and others [enables] us to spin an hundred or a thousand times as great a quantity of yarn as could be spun by means of a common spindle' (p99). As Rae imagined, were 'some

⁷⁶ Mill also asked who would buy the 48,000 pins now produced every day in Smith's factory, going on to name some conditions for a large market including population and transportation infrastructure (pp129-130).

one of the men of olden time, waked from the slumber of the tomb and raised up to us', to witness even a tenfold yield, 'he might well demand how the power had been acquired that had wrought so great a change' (p14).

Let us take McCulloch literally: Without the efficiency granted us by the machines, we would make *much less* yarn requiring much less cotton. In Jevons's version 'economy renders the employment of coal more profitable, and thus the present demand for coal is increased... [I]t cannot be supposed that we shall do without coal more than a fraction of what we do with it' (pp8, 9, 141, 190). This thought is radical. Today's environmental efficiency strategy claims that an input's more efficient use lowers its rate of consumption. The inverse/corollary of this is that were processes to become *less* efficient, we* would consume the input at a *higher* rate. Or had technological efficiency increase remained unchanged – stopped, say, around 1781 with 'the introduction of Watt's engine, the pit-coal iron furnace, and the cotton factory' (Jevons, p270) – we would according to the strategy's assumptions today consume an hundred or a thousand times as much – or infinitely more – labour or cotton or fuel than we do today after over two centuries of efficiency increase. To maintain that rebound is less than 100 per cent one must defend this conclusion.

Jevons asks, 'Could we desire that Savery, Newcomen,...Darby,... Brindley... and Watt' had not increased our industrial efficiency (p457)? Say envisions the case of frozen technology in imagining that a given road exists still as just a path with much less transport efficiency. He says that we can't measure the 'gain' to consumers of the road because with no road 'the transport would never take place at all' (p443 note). Malthus similarly wrote, 'If the roads and canals of England were suddenly broken up and destroyed... there would be immediately a most alarming diminution both of value and wealth' (p243) – and implicitly of input consumption. As seen above, Jevons's comparable example was that Savery's steam engine '*consumed no coal, because its rate of consumption was too high*'... It was so uneconomical, that, in spite of the cheapness of coals, it could not come into common use' (pp143, 118; Rae, pp247-248). Marx would

later conclude that without machines for example '£2000 capital would in the old state of things, have employed 1200 instead of 400 men' (p393).** More drily, Mill takes division of labour as the proxy for improvement in efficiency and notes, 'Without some separation of employments, very few things would be produced at all' (p118).

Say played further with this mental exercise. In connection with his example of printed pages as a case of direct backfire he writes of efficiency-induced price falls that

sooner or later... cheapness will *run away with* the consumption and demand [and] in all the instances I have been able to meet with, the increase of demand has invariably *outrun* the increasing powers of an improved production (pp87, 302; emphasis added)

That is, imagine the 'relative intensity of supply and demand', which determines price (Say, p290), as showing flat demand curves and steep supply curves.

Now, he said,

suppose... the charges of production are at length reduced to nothing;... Every object of human want would stand in the same predicament as the air or the water, 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. (pp303-304)

Would total, overall, absolute consumption of resources be lower, or higher, in this state of infinite efficiency, where both commodities and their inputs are free and limitless?

Smith casts some doubt on this, writing that if a 'capital... was produced spontaneously, it would be of no value in exchange, and could add nothing to the wealth of society' (II.v.5); but this is only exchange value, and 'wealth' seen monetarily. In contrast Say takes the exercise in the opposite direction:

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. (p302; Smith, I.xi.o.6)

That is, is greater wealth even conceivable under conditions of *decreasing* efficiency? If we take time, material, energy and space inputs and assume all historically known efficiencies away, we most likely arrive at the population and per capita production of hunter-gatherer societies living sustainably.

Sarcasm also distinguished an anonymous 1826 article on the 'machinery question' of technological unemployment:

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, p102; see also Brookes, 2000, p359)⁷⁷

The writer is criticizing Mr. Wakefield and Dr. Chalmers, but also chides Ricardo for his change of heart on this question – of which more in the final section.

Say twice frames his description of consumption growth in terms of inputs.

Demand 'outruns' efficiency in a

production, operating upon the same productive means; so that every enlargement of the power of the productive agency has created a demand *for more of that agency*, in the preparation of the product cheapened by the improvement... When the demand for any product whatever, is very lively, the productive agency, through whose means alone it is obtainable, is likewise in brisk demand, which necessarily raises its ratio of value: this is true generally, of every kind of productive agency. (pp302, 324, emphasis added; see also Brookes, 1990 and 2000, and Saunders, 1992 and 2000)

If the phrase 'ratio of value' refers to amounts of the input before, and after, the improvement, perhaps times their price per unit, Say is presaging Jevons's position exactly. Similarly, depending upon one's interpretation of Smith's term 'fund', he too could be attesting rebound greater than unity when he claims that 'Every saving... must increase the fund which puts industry into motion and consequently the annual produce of land and labour' (II.ii.25).

As shown earlier Rae frequently frames his analysis in terms of materials rather than labour, but he seems usually to denote only the materials *embodied in* tools, machinery, and instruments, as when he speaks of 'the efficiency of... materials when formed into instruments' (p112). However, since fields and foods are also 'instruments' we can infer that efficiency in some cases implies increased inputs of things other than knowledge (pp112-113): 'Every society possesses a certain amount of materials capable of being converted into

⁷⁷ Attributed to William Ellis by Mill (p736).

instruments' (pp99; see also p187). For Rae greater efficiency of an instrument means it yields 'quicken'd' returns (p164) and in general

the effect of improvement, to carry instruments into orders of quicker return..., a greater range of materials is brought within the reach of [the accumulative] principle, and it consequently forms an additional amount of instruments... All [improvements], therefore, place a greater range of materials within compass of the accumulative principle, and occasion the construction of a larger amount of instruments. (pp261, 131, 365)⁷⁸

Furthermore, 'A multiplication of instruments is of no avail, unless something additional be given on which they may operate', and our 'instruments... draw forth stores' of materials; 'improvement in their construction... put additional stores within reach of the nation' (pp29, 19, 68). In addition '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' (p261).

Finally, with a rebound example familiar from today's debate, he notes of the macadamization of roads that 'the facility it gives to transport occasions an increase of transport...' (p114). Hearn similarly writes of invention that it 'enables the labourer to work materials which... were previously beyond his reach' (pp181-183). Taken together these observations are arguably a description of backfire: ultimately, efficiency leads to higher rates of *material-input consumption*. Since each instrument – a field, a steam engine – implies not only embodied but operating materials, we can infer little saving of material inputs from Rae's analysis. He continues by noting that improved instruments increased the amount of land under cultivation and that 'rocks were quarried; forests were thinned; lime was burned; the metal left the mine...' (pp261-262). A rise in Q entails rebound for sure and most likely backfire.

A summary by Mill contains almost all of the concepts introduced till now. Recall that 'circulating capital' covers all the food, fuel and other materials fed into production. Just before considering the 'stationary state' and 'to what goal... economical progress' should be aimed (p752) he writes:

It already appears from these considerations, that the conversion of circulating capital into fixed, whether by railways, or manufactories, or ships, or machinery, or

⁷⁸ Also Mill, pp725-726; Price, 1988; Wirl, 1997, pp51-56, 81-87.

canals, or mines, or works of drainage and irrigation, is not likely, in any rich country, to diminish the gross produce or the amount of employment for labour. How much then is the case strengthened, when we consider that these 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, since they alone enable a country to possess a constantly augmenting capital without reducing profits to the rate which would cause accumulation to stop. There is hardly any increase of fixed capital which does not enable the country to contain eventually a larger circulating capital, than it otherwise could possess and employ within its own limits; for there is hardly any creation of fixed capital which, when it proves successful, does not cheapen the articles on which wages are habitually expended. All capital sunk in the permanent improvement of land, lessens the cost of food and materials; almost all improvements in machinery cheapen the labourer's clothing or lodging, or the tools with which these are made; improvements in locomotion, such as railways, cheapen to the consumer all things which are brought from a distance. (pp750-751; see also p344)

A few pages later our epigraph appears wherein Mill doubts that any labour had been saved by labour-saving devices. This fruit of classical thought fell to Jevons.

The principle of population

Since the classical era population size seems to have declined in importance as a dependent variable; yet the ten-fold increase of population in the last two centuries is surely an *explicandum* of the first order. No classical economist challenged productivity's causal role. Today by contrast this is for instance denied by Schipper & Grubb who, 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, p368). Perhaps the OECD perspective of almost all studies, abetted by shyness in the face of the fact that people do die from lack of sustenance, has prevented the adoption of both agricultural and manufacturing efficiency as an independent variable. Yet if population rise is at least *enabled* by efficiency increase then the wholly exogenous treatment of population in energy-consumption models is wrong (for example Schipper et al., 1996, p174; Howarth, 1997, p4; Lantz & Feng, 2006, p235). It also means underestimation of rebound.

Presaging $I = PAT$, Jevons made the point that the 'quantity of coal consumed is really a quantity of two dimensions, the number of people and the average

quantity consumed by each' (p196). Malthus in both his major works endogenized 'number of people', his metaphorical phrase being that 'the necessaries of life, when properly distributed, [create] their own demand [by] raising up a number of demanders...' (pp113; see also pp114, 130, 181, 223, 251). He then points out that if increased 'powers of production' were not necessary for increased population 'the Earth would probably before this period [mid-19th century] have contained, at the very least, ten times as many inhabitants as are supported on its surface at present' (pp288, 251). In explaining wealth, '[to] suppose a great and continued increase of population is to beg the question. We may as well suppose at once an increase of wealth...' (p252). (Ironically, countless modellers of rebound do exactly this, exogenize GDP, 'economic activity' or total output!⁷⁹) As shown earlier, classical economics almost fully endogenized growth, attributing the size of the annual produce of land and labour partly to 'improvement' – as Mill's statement quoted above shows. Progress raises sustenance (in spite of diminishing returns in agriculture), increasing the extent of the market, which in turn allows more division of labour and larger, more expensive machinery, in turn enabling larger population (Mill, pp33, 129-131, 190, 712-714).

Perhaps building on Petty (p255), Smith states simply, 'The number of workmen increases with the increasing quantity of food, or with the growing improvement and cultivation of the lands...' (Ixi.c.7). Building on Say (pp71, 292-295), McCulloch writes that 'there does not seem to be any good reason why man himself should not... be considered as forming a part of the national capital. Man is as much the produce of labour as any of the machines constructed by his agency...' (p115; see also Mill, pp40-41). Malthus talked of the 'cost of producing a poacher' compared to that of a 'common labourer or... coal-heaver' (p180; see also Jones, p196). Rae abstractly but explicitly named 'invention' as 'the true generator of states and people' (pp31, 323). Sustenance includes not only food but warmth, housing and general health (Say, pp301 note, 373, 378; Mill, pp 154-159). The quantity of labour (and people) is a function of the quantity and quality ('human capital') of labour.

⁷⁹ For example Manne & Richels, 1990, p51; Schipper & Meyers, 1992, pp58-60; Howarth, 1997, p2; Saunders, 2000a, p442; Schipper & Grubb, 2000, pp368, 370.

Starting with Petty's question as to how many Men the Land would feed, all of the old-timers embraced the principle of population, expressed by Malthus in terms of 'tendencies', sustenance, and the effect of prosperity on decisions to marry and have children (1798, pp20-26, 33-34, 41, 52, 70, 74-75).⁸⁰ Jevons of course tied it empirically to coal: '[With] cheap supplies of coal, and our skill in its employment...[w]e are growing rich and numerous' (pp199-200). In terms of the $I = PAT$ production function, we should write $I = f(P,A,T)$, $A = f(T)$ showing our becoming rich and $P = f(T)$ showing our becoming numerous. That population is not *sui generis* is also shown and recognized by recent investigators (for example Giampietro, 1994, pp680-681; Hannon, 1998, p215).⁸¹ Schmookler was one who consciously treated it both exogenously and endogenously (1966, pp104-106; also Rosenberg, 1982, p141). If moreover population and the scale of the economy are partially endogenous, the ubiquitous picture in the literature of a 'race' between a 'growth effect' and efficiency is incorrect (Levett, 2004, p1015).⁸² The question of backfire is begged when growth and efficiency are assumed to be rivals, but the race metaphor again shows the *paradox*: Do efficiency increases compensate for growth or cause it?

Another population-related problem with most rebound analyses is the concept of the energy intensity of a given good, service or expenditure whereby 'energy costs are typically a... component of the total cost of owning and operating energy-using equipment' (Howarth, 1997, p2). '[T]otal energy costs are generally a few percent of GDP' and the size of any rebound or 're-spending effect [where] purchasing power is released for other energy-containing services' is proportional to this percentage (Grubb, 1990b, p784; see also Greening et al., 2000, p391).⁸³ Or, in analyzing indirect rebound one compares

⁸⁰ Also Cantillon, pp43-44; Smith I.viii. 21-39, I.xi.b.1 & c.7, IV.ix.36; Ricardo, p16; Say, pp189, 322, 371-381, 450; McCulloch, p278; Rae, pp28-31, 96, 160, 324; Mill, pp153-159, 187-190; Jevons, pp222-225, 420.

⁸¹ Also Cipolla, 1962, pp49-53, 94-95, 105; Martinez-Alier, 1987, pp99-116; Abernethy, 1993; Pimentel, 1994; Bartlett, 1994; Clapp, 1994; Johnson, 2000; Giampietro & Mayumi, 2000.

⁸² Also Besiot & Noorman, 1999, pp375-377; Binswanger, 2001, p120; SwissEnergy, 2004, pp3, 4.

⁸³ Rebound should however be defined as a percentage of engineering savings, not of GDP.

the energy intensity of the old and the new expenditure to help measure the change in energy consumption. As in Malthus's defence of the concept of natural price, this energy share and the other intensities, for example of labour or capital, add up to 100 per cent. (Malthus, pp66-67).

However, as shown above in discussing Say's 'immaterial objects', buying labour also implies expenditures by the labourers on material and energy, in the older terms of 'reproducing' themselves. Kaufmann's rendering of this 'feedback' effect for capital as well as labour is that when these are substituted for energy, these also have energy costs, which 'offsets some fraction of the direct energy savings and reduces the amount of energy saved by price-induced microeconomic substitution' (1992, p49). Mill's detailed analysis of a loaf of bread for instance names bakers, ploughmen, plough-makers, carpenters, bricklayers, hedgers, ditchers, miners and smelters who share the price (costs) of the loaf (p31). Labour and capital, the more so when seen in the classical sense as previous embodied labour, entail energy consumption and are not energy-neutral (Costanza, 1980). Mill also incidentally rejected the implication of perfect substitutability in these analyses:

When two conditions are equally necessary for producing an effect at all, it is unmeaning to say that so much of it is produced by one and so much by the other; it is like attempting to decide which half of a pair of scissors has most to do in the act of cutting; or which of the factors, five and six, contributes most to the production of thirty. (pp 28-29)

In any event, the notion that 'non-energy' costs have no effect on energy consumption must be rejected: once the creation and support of population is included, attending a concert is not the environmentally friendly act it is alleged to be. The idea of decreasing marginal energy intensity as income rises – also due to the societal income effect – must be doubted.

Global population, along with technologically achieved levels of affluence, entailing as they do human usurpation of the living space of plant and other animal species, engenders interest in possible rebounds in the use of a further productive input, namely space, or land regarded merely as m^2 ($\lambda m^2 \uparrow \rightarrow m^2 \uparrow$ where λ is an efficiency co-efficient). Not only agricultural efficiencies, but also transport and architectural ones, can be expressed in terms of amount of land

use, raising the question of whether for instance more efficient farming reduces the pressure on forests. (Jevons, p200; Pascual, 2002, p497) Whenever classical literature raises this question, the answer is that following agricultural improvement we do *not* take land out of cultivation.⁸⁴

The employment paradox

Because they directly raise population, labour and energy efficiency increases thus indirectly raise the number of work-hours or employment, but given the limited length of the work day is this true when we hold population constant? Labour rebound would be smaller, but as Mill said most likely work-hours don't decrease. Recall that before Jevons economists, except at times Say and Rae, conceptualized all sorts of efficiency changes – not just technological ones – but asked explicitly only after the fate of labour inputs, not of material inputs. Their specific debate concerned whether machines caused long-term unemployment, that is, whether labour-efficiency rebound was less than 100 per cent. Jevons of course saw that with 'every... improvement of the engine... hand labour is further replaced by mechanical labour' and that in *agriculture* 'Labour saved is rendered superfluous' (pp152-153, 243); also institutional efficiency, through free trade, 'raises the economy of labour to its highest pitch' (p413). But he asserted that it was obvious that demand for labour thereby grew:

As a rule, new modes of economy will lead to an increase in consumption according to a principle recognized in many parallel instances. The economy of labour effected by the introduction of new machinery throws labourers out of employment for the moment. But such is the increased demand for the cheapened products, that eventually the sphere of employment is greatly widened. (p140)

He offers empirical proof with the examples of seamstresses, coal miners and iron workers (pp140, 130-131, 153, 213-218, 277-278) as his predecessors had with the examples of flour-milling, printing and cottons. As we shall see this result was not at all obvious for Marx (pp354-392), writing at the same time as Jevons, as it had not been for Ricardo and Sismondi.

⁸⁴ Smith, I.xi.b.2-6, IV.ix.5-6; Say, p295; Malthus, pp139-140; Jones, pp196, 242; Rae, pp116, 259, 261; Mill, pp173-185, 724-729.

The issue is the same as that concerning primary energy: Does an input-saving production system permanently lower, or raise, consumption of that input? We could even call this 'Say's Paradox', for after demonstrating that cheapened products create additional employment he writes:

Paradoxical as it may appear, it is nevertheless true, that the labouring class is of all others the most interested in promoting the economy of human labour; for that is the class which benefits the most by the general cheapness, and suffers most from the general dearness of commodities. (p89 note)

The result that, out of 20 men at a flour mill, the 19 'unfortunate' ones laid off would find other work, was for him admittedly '*survenue*' (1820, p63).⁸⁵ But he claimed that in printing, even if machines had thrown 199 out of 200 copyists out of work, probably 20,000 people were working in the printing trade (p88).

While many energy-efficiency increases cause labour-efficiency increases as a side effect – if only in the mining and distribution of the energy per unit of product – labour-saving changes like new machines, household gadgets or the factory system usually *lower* energy-efficiency per unit of output – say a cup of coffee –, if only due to the substitution effect. Such feedbacks between βM and αL – the efficiencies of use of matter and labour, respectively – have yet to be systematically investigated in complete models of either labour or energy consumption (Rae, p20; Marx, pp386-387; Binswanger, 2001, pp127-128). Again with the example of the ceramic stove's replacing the open hearth: heating requires less time cutting and stacking wood as well as less wood (also Jones, pp249-250; Mill, pp106-107; Martinez-Alier, 1987, p3). Hearn's generalized insight was *both* that 'labour and... time are free to be applied to other industrial purposes' and that 'the introduction... of natural forces in lieu of or in addition to human powers sets free a quantity of commodities' (pp183-185, 271). But the Jevons Paradox concerns only $M = f(\beta M)$, not $M = f(\alpha L)$ as well.

By arguments from price falls, profitability and the income effect, a near-consensus reigned concerning output growth and labour-input growth – epitomized by Mill's quip in our epigraph. Some years before the outbreak of the controversy over machines vs. men Smith claimed that:

⁸⁵ Curiously, this term is left out of Laski's English translation (p63).

the accumulation of stock must... be previous to the division of labour... As the division of labour advances,... in order to give constant employment to an equal number of workmen, an equal stock of provisions, and a greater stock of materials and tools than what would have been necessary in a ruder state of things, must be accumulated beforehand. But the number of workmen in every branch of business generally increases with the division of labour in that branch... The increase in the quantity of useful labour actually employed within any society, must depend altogether upon the increase of the capital which employs it... (II.intro.3, IV.ix.36)

Remembering that 'capital' is both fixed and circulating (in this case wages in the form of food and provisions during the period of production), and that fixed capital always entails heightened efficiency (Jevons, pp150, 155), Smith's view is that technological efficiency ('tools') and organizational efficiency ('division of labour') are the conditions for growth in the number of jobs. There is no hint that machines throw people out of work.

However, the intuition that makes the economy of labour just as paradoxical as the economy of fuel, and the fact that visibly and locally machines *do* replace workers, had by 1820 spawned the theoretical positions of Say, Robert Owen, Ricardo, Sismondi and Malthus. Say first discussed the displacement of workers in his first edition in 1803 (ch IX), making important changes but keeping his conclusions in later editions as well as in the fourth of his *Letters to Malthus* (1820). Lauderdale also explicitly discussed machines that 'supplant labour', first agreeing with Smith that lower labour costs in textile manufacture had lowered prices and that machines generally increase wealth; but he at the same time attests a net loss for the supplanted 'unlettered manufacturers themselves' and sees good reason for the 'riots that have taken place on the introduction of various pieces of machinery' (pp168-171, 184, 189-192, 206).

Reminiscent of much microeconomic work on rebound today, most participants traced the fate of the money amounts of capital or revenue saved by efficiency increase. Employment was gained by making and maintaining the machines, but lost when production processes needed fewer hands; it was gained when employers spent their higher profits on luxuries or servants, but lost if demand for other products failed. The monetary examples are found in Ricardo (pp16, 388-391), Sismondi (vol 2, pp324-326), Say (1820, pp60-61, 65-67), Malthus (pp192-194, 282-283), McCulloch (pp179-182), and Marx (pp392-393). The parameters to observe are: 1) percentage labour-efficiency increase compared

to percentage price fall (usually seen as equal); 2) total fixed capital; 3) total circulating capital shifted between workers in different branches and between workers and capitalists; 4) the income effect of demand for further products; 5) labour demanded for making and tending the machinery; 6) duration of the machine; 7) demand for 'unproductive labour' or 'menial servants' whom these writers do not (usually) count as 'labourers'; 8) foreign demand; and 9) the short-run displacement of labour.

Most of these appear in Ricardo's contradictory discussion. In the third edition of 1821, without explicitly answering Say, he acknowledges a change of mind. Earlier he had believed that an increase of 'net income' (rents and profits) always entailed an increase of 'gross income' (including wages and implicitly jobs), arguing in Parliament against Owen's opposite view (Sraffa, 1951, plviii). But in 1821 in his new chapter 'On Machinery' he is thinks out loud: because the employer has less 'circulating capital*... his means of employing labour, would be reduced' (p389); but with increased profits after the introduction of the machine the 'power of purchasing commodities [of the 'net produce'] may be greatly increased' (pp389-390). In asserting that 'there will necessarily be a diminution in demand for labour [and] population will become redundant', however, his system boundary remains at the single factory or sector, in other words he forgets indirect rebound (p390); yet due to the necessary 'reduction in the price of commodities consequent on the introduction of machinery... there would not necessarily be any redundancy of people' (p390; see also p392).

He then seems to forget price reductions, doubting the demand for instance for a greatly increased supply of cloth (p391). In the simple example of replacing men with horses he sees a case of 'gross revenue' falling while 'net revenue' rises (p394); yet even here, the income of the farm employer could be so great, or 'the produce of the land [so] increased, that all of the unemployed find jobs 'in manufactures, or as a menial servant' (pp394-395). On the one hand he states,

All I wish to prove, is, that the discovery and use of machinery may be attended with a diminution of gross produce... injurious to the labouring class, as some of their number will be thrown out of employment... [A]n increase of the net produce of a country is compatible with a diminution of the gross produce... By investing part of a capital in improved machinery, there will be a diminution in the progressive demand for labour... (pp390, 392, 397)

On the other hand, he believes that 'the employment of machinery should never be safely discouraged in a State [and] that machinery should... be encouraged' – both because its introduction is slow and because otherwise, even jobs in the machinery industry would move overseas (pp396, 395). In the terms of today's debate, Ricardo is arguing that rebound is never greater than 100 per cent and tends to be quite a bit less.

Say directly attacks the issue both in his *Treatise* (pp86-90) and in the fourth of the *Letters to Malthus* (1820). In the latter he explicitly bases his case first on large price falls and high price elasticity of demand (pp56-57), second on latent demand for other commodities that is satisfied by the income effect (which he unjustly accuses Sismondi of neglecting) (pp60-62), third on the fact that the machines can simply *do more work* than men (pp58-59) and fourth on the fact that after all is said and done, the factory produces the same amount of product available for consumption, and the laid-off workers, with this sustenance, will do something else (pp61-63). Mill echoed this last point in making the softer claim that 'if there are human beings capable of work, and food to feed them, they *may* always be employed in producing something' (p66; emphasis added). It seems also to be the case today that as well as labour, also natural resources not used for one purpose get used for another.

Say goes on to convincingly show that Sismondi's monetary example contains some unrealistic assumptions, but himself makes two numerical errors (pp60-61). He then appeals both empirically to the high and increasing employment all around him (p63) and to a historical overview: his 'model' predicts – accurately – that:

if the arts still improve,... they will produce more at less expence [and] fresh millions of men in the course of a few ages will produce objects, which would excite in our minds, could we see them, a surprise equal to that which the great Archimedes and Pliny would experience could they revisit us. (p64)⁸⁶

Two ambiguities mar the comparison of labour and material/energy inputs as well as the classical debate over the former. First, saving material is unmitigatedly good whereas saving labour, because people as opposed to

⁸⁶ He praises the relief from toil offered by machinery (p64).

materials must eat, is not. Holding population constant and raising work efficiency, the same or greater employment than otherwise (rebound 100 per cent or backfire) guarantees livelihoods. Somewhat contrary to the view that labour is painful and irksome, rebound greater than unity is therefore good. On the contrary, while resource consumption is obviously good for affluence, its 'over-consumption' and hence backfire is bad due to scarcity and pollution problems.

Secondly, precisely the bookkeeping offered by the debate's participants shows that the social or livelihood or full-employment problem is soluble: The amount of output does not decrease! Or as Ricardo concedes from the point of view of income rather than production, if employers lay off five of ten men, they nevertheless retain the purchasing power to employ all ten (1820-22, p355). If the fully realized production possibilities of the society supported everybody before, it can therefore support them after all the great and small productivity increases taking place daily. Seeing this, even those who held that efficiency savings were in fact realized – that is, that unemployment resulted – placed blame on the 'factory' or 'capitalist' set of institutions which included neither shorter work hours nor guaranteed employment. Many such as Owen (see Sraffa, 1951, pp1vii-ix; Berg, 1980; Greenberg, 1990, pp710-712) and Sismondi (vol 2, pp312-313, 317) thus mixed ethical or socialist arguments with economic ones. Even Marx maintained that not only in the short run 'in the hands of capital' labour-saving productiveness increase meant 'lengthening the working day', and wrote that:

workpeople [should] distinguish between machinery and its employment by capital, and to direct their attacks, not against the material instruments of production, but against the mode in which they are used. (p351; also 356, 374)

In contradiction to this, though, his final doctrine is that machinery and men are in competition; although new capital can employ many of the newly unemployed and although indeed as much or more 'of the necessaries of life' are still produced, a sufficient rise of demand is uncertain (pp374, 384-386).

The consensus that emerged, though, was that if the remaining work and/or the same or increased output is distributed equally, the problem of computing the

total-employment effects of employment efficiency would lose its social aspect. Again, all agreed with Say's point that even if a wind-driven flour mill does the work of eighteen persons, these 'eighteen extra [redundant] persons are [theoretically] just as well provided with subsistence' (p90; see also Rae, p259). The parallel to energy inputs is that after a machine 'does the work' of one out of two tons of coal, both the coal and the means to employ it remain. And Say, Malthus, McCulloch and Mill, although convinced that even more labour ensued (backfire), recognized that some measures to lessen the hardship of displaced workers are justified. Mill even imagines a 'benevolent government' assuring a just distribution of work, in other words of income (p67). Whatever the final level of employment, one must regard full employment as a social, not an economic, problem, as expounded by Edward Bellamy in his *Looking Backward* (1887).

The result is that if produce stays at least the same, 100 per cent rebound in terms of work-hours – that is, full employment – is likely at no additional cost. As Malthus claimed, the 'net produce' could always employ 'unproductive labourers' such as 'menial servants, soldiers, and sailors' (p191). But the opposite is possible. In a difficult passage which earned him a reputation as an advocate of labour rebound less than unity, he says that even with increasing 'exchangeable value of the whole produce' stable or sinking employment *could* result, namely when the production of 'luxuries and superior conveniences' rose at the expense of necessities; but his more fundamental claim is to deny *any* proportional connection between either fixed and circulating capital, and thus efficiency, and demand for labour: consistent with his *Essay on the Principle of Population*, this depends only on 'the means of commanding the food, clothing, lodging, and firing of the labouring classes of society' (pp190-191).

If production is higher, some combination of raised affluence and raised population results. If, however, we assume that before the efficiency increase every worker was working his maximum number of hours, then without population increase labour *backfire* is logically impossible (Malthus, pp62-63). (Analogous energy-rebound limits perhaps exist due to scarcity or thermodynamic limits.) Malthus in fact concludes that if the 'introduction of fixed

capital' is gradual and 'the funds destined for the maintenance of labour' somehow keep pace, the result is a 'great demand for labour and a great addition to the population [and] there is no occasion therefore to fear that the introduction of fixed capital... will diminish the effective demand for labour' (p193; see also pp281-289). By the early 1830s he accordingly defends himself against being 'classed [by McCulloch] with M. Sismondi as an enemy to machinery' (p282 note), also rejecting the doubts of Ricardo and the opinions of 'M. Sismondi and Mr Owen' that labour-saving machines are 'a great misfortune' (p295 note).

McCulloch was indeed just as convinced as Say that the 'extension and improvement of machinery is always advantageous to the labourer' (p165), but not only because more work hours result. His first original point is that if machinery would lower demand for labour by raising labour's productivity, then so would any 'improvement of the science, dexterity, skill, and industry of the labourer'; therefore 'M. Sismondi could not... hesitate about condemning such an improvement as a very great evil' (pp165-166). As seen above McCulloch's macroeconomic assumption of a tenfold efficiency increase would also allow more leisure (pp166-168; Mill, pp105-106). His result entails considerable rebound in material/energy consumption; there is no backfire in labour consumption but rather a real savings of labour inputs; and the imagined cornucopia would enable society to politically assure full employment.⁸⁷ But he assumes no population growth. If population and/or work-hours increase, L-backfire could ensue.

Microeconomically McCulloch argues explicitly with the standard price falls, large price elasticities of demand and indirect rebound (pp176-180). In apparent contradiction to his vision of shorter working hours for all he then relies on both theory and observation to show that the machines of 'Hargreaves, Arkwright, and Watt' created employment for 'thousands and thousands of workmen' (p117). This raises our paradox again: According to Dolores Greenberg, Owenite John Brooks in 1836 calculated that machines in Great Britain and

⁸⁷ See Bellamy, 1887.

Ireland were doing the work of no less than 600,000,000 people (1990, p711; Jevons, p411). Can we infer from this that therefore 600,000,000 people were out of work – perhaps even in the sense that they had starved or not been born? If the machines were doing the work of only 300,000,000 people, would employment be twice as high?

Some of Jevons' statistics on population and substitution hint at these questions.

In round numbers, the population has about quadrupled since the beginning of the 19th century, but the consumption of coal has increased sixteenfold, and more. The consumption per head of the population has therefore increased fourfold. (p196)

Pertinent to today's 'renewables' discussion he computes, for instance, that since an 'ordinary windmill has the power of about thirty-four men, or at most, seven horses... the great Dowlais Ironworks... would require no less than 1,000 large windmills!' (pp164-165; 203-205) And when he writes that 'it cannot be supposed that we shall do without coal more than a fraction of what we do with it', we may ask both how many are in this 'we' (p9) and how well-off we would be, since 'with coal almost any feat is possible or easy; without it we are thrown back into the laborious poverty of early times' (p2).⁸⁸

Say, Malthus and McCulloch do not show labour backfire with *certainty*. They show us not that more work hours must result, but that less work hours must not result. Even Sismondi saw cases when for instance workers were not 'rendered superfluous' due to the stocking-machine – but only because of the three exogenous factors 1) changes of taste, 2) increased population and 3) increased wealth (vol 2, pp316-317, 330-331).⁸⁹ But in the normal case and contrary to Say's claims in ridiculing him (1820, pp 61-62) Sismondi does say that the stockings are cheaper and that demand can therefore rise due to the income effect in sectors having nothing to do with the one affected by the efficiency increase (here, stockings); but he treats the total purchasing power as no greater than that spent on the more expensive spats previously or even as

⁸⁸ That agricultural productivity increases raise population is clear; manufacturing and fuel-using efficiency increases do this less obviously through better housing and clothes, better medicine, better availability through transportation, etc. (Jevons, pp200, 205, 233, 243-245, 369).

⁸⁹ Just like the very similar independent variables of Schipper & Meyers (1992) and Schipper et al. (1996), Sismondi thus begs several questions.

less: 'new demand will never have the same proportion as that thereby lost by the laid-off workers' (vol 2, pp317, 323-324, 322; see also McCulloch, pp186-187) A further lack of certainty marks Say's empirical claims: perhaps backfire in cottons and printing is proven, given a demand function, but these are mere sectoral studies with no necessary economy-wide implications (p57).

One of Sismondi's arguments for low labour rebound is that while a machine may lower *labour* costs by 99 per cent, since the price of stockings consists of more than just labour costs, the price cannot fall in the ratio of the laid-off workers (vol 2, pp323-324). Similarly, many argue today that since energy costs are only a fraction of GDP the efficiency elasticity of price is low (Howarth, 1997, pp2, 3; Allan et al., 2006, pp18-19). Although this argument loses force if rebound is measured as a percentage not of total economic activity but only of potential engineering savings, its plausibility is a reason why Jevons' paradox is a paradox. If prices fall 50 per cent there is nevertheless more real purchasing power in the economy, whether the efficiency of a given input rises 51 per cent or 99 per cent; perhaps the concept of the efficiency elasticity of price, compares apples and pears.*

Mill, finally, confronts the problem we named earlier that the purchasing power drawn to the cheaper, more efficiently-produced goods is lacking for the older, previously purchased goods, thus lowering employment in those sectors. On the one hand he attests that:

Every addition to capital gives to labour either additional employment or additional remuneration... If it finds additional hands to set to work, it increases aggregate produce: if only the same hands, it gives them a larger share of it; and perhaps even in this case, by stimulating them to greater exertion, augments the produce itself. (p68; also p87)

But he adds that the standard argument – greater employment through cheaper goods through more efficient production through applying fixed and circulating capital to this sector –

does not... have the weight commonly ascribed to it... [I]f this capital was drawn from other employments; if the funds which took the place of the capital sunk in costly machinery, were supplied not by any additional saving consequent on the improvements, but by drafts on the general capital of the community; what better were the labouring classes for the mere transfer? In what manner was the loss they sustained by the conversion of circulating capital into fixed capital made up to

them by a mere shifting of part of the remainder of the circulating capital from its old employments to a new one? (p96)

Mill seems here to envision a zero-sum process, which indeed the economy is if measured monetarily with constant money supply. Perhaps his premise is wrong that the capital must be drawn from other, previous employments rather than from the real increased produce or 'returns' per unit of input. This is the answer Say would have given and that Rae gave (p118). Although Mill's subsequent attempt to counter his own argument is unsuccessful he then concludes with Say that employment is not threatened after all but in the end increased (pp133-134, 749-751, 119-120).

Today no one either hopes or fears that labour efficiency increases do not backfire. It is accepted that for over two centuries such 'improvements' have been accompanied by rising employment and population. A causal connection is even often explicit: More efficiency of all sorts, such as free trade, lower transactions costs, restructuring for synergies in industry as well as everyday streamlining of work processes, is known to further the economic growth upon which an expanding job market depends. But material/energy inputs are perceived differently, with different goals and hopes. Just as the older debate was fraught with the ambiguity of 'labour' seen negatively as a cost and 'labour' seen positively as a proxy for 'income', today's debate contradictorily lauds efficiency of any sort as a tool for lower environmental impact as well as for growth and affluence. If however energy rebound is close to or greater than unity, environmental ends are better served by direct means such as taxation or rationing (Hannon, 1975; Brookes, 2000, pp363-364; Sanne, 2000, pp488, 491-492; Fawcett, 2004; Simms, 2005).⁹⁰

⁹⁰ Jevons however repeatedly notes that such solutions to the coal question are limited by Britain's 'system of free industry' (pp5, xlix, 13, 136, 442-447).

Conclusions

Jevons opened his seminal chapter on fuel 'economy' (his term for the efficiency ratio) by quoting Justus von Liebig, who wrote:

Cultivation is the economy of force. Science teaches us the simplest means of obtaining the greatest effect [output] with the smallest expenditure of power [input], and with a given means to produce a maximum of force. The unprofitable exertion of power, the waste of force in agriculture, in other branches of industry, in science, or in social economy, is characteristic of the savage state, or of the want of true civilization. (1851, p462)⁹¹

Then, as now, force and therefore affluence and civilization lie in fossil fuel. But pollution and pending scarcity reveal the dark side of the prosperity that we so welcome. Roughly in the order of the sections presented above some conclusions can be drawn on whether more efficiency, *ceteris paribus*, achieves not only affluence and greater population but environmental relief.

Efficiency is an attribute of humans and other natural agents as well as capital and organization, but is always an output/input ratio. Seeing efficiency increase as larger output, as the classical economists usually did, biases us to find high rebound plausible; seeing it as smaller input biases us toward low rebound and real savings. The term 'rebound' itself is a metaphor describing a bouncing ball, but a bounce all the way into the backfire zone unfairly implies *perpetuum mobile* or more. Furthermore, an analysis of energy consumption is possible without computation of engineering savings derived when one holds consumption constant, and thus without the concepts of rebound and backfire.

In regression analysis, to explain increasing (rates of) energy consumption an independent variable 'technological efficiency' could be taken. But how is this measured for all sectors, all economies, over time and integrating new products? An adequate aggregate metric, whether in monetary, utility or physical terms, is hard to come by, but its absence makes empirical research difficult. The environmentally most relevant path of measuring output physically must seek a metric free of the anthropocentricity implied in terms such as

⁹¹ Jevons here misquotes von Liebig as 'Civilisation is the economy of power' (pp142, 163). Jevons had just finished his chapter attributing Great Britain's greatness to coal and technology, whereas von Liebig was in the middle of an essay on agricultural productivity.

waste, usefulness, quality, service and value, for these conflate environmental with affluence criteria.⁹² Rather unscientifically, though, we all assume that technological efficiency continually increases. The classical economists also attested this and correlated it not only with growing production of wealth but sometimes with growing labour and material input quantities. Jevons for instance offers the empirical evidence for backfire that alongside great rises in coal consumption, population and affluence there were increases in the economy of fuel, for example in pig iron production by a factor of about seven in 35 years (pp387-388, 145, 196, 261-271; see also Martinez-Alier, 1987, pp86).

Fruitful empirical research must be at a scale large enough to capture not only indirect rebound in all sectors but also an economy's consumption of imported embodied energy (Jevons, p317). This need to ultimately cover all sectors and economies has been acknowledged.⁹³ As McCulloch said we must investigate efficiency effects 'in a country surrounded by Bishop Berkeley's wall of brass' (p185), a good description of the whole globe. The more so since environmental problems are global, our studies should be both global and measure total rather than only direct rebound.

But in the absence of hard empirical results we must resort to theory, and indeed both sides in today's debate over the environmental effects of efficiency claim 'counterfactually' what energy consumption *would have been otherwise*, in other words without efficiency increases (Khazzoom, 1980, pp22, 31; Howarth, 1997, p3; Brookes, 2000, p356; Moezzi, 2000, pp525-526; Schipper & Grubb, 2000, p370). Which model, then, better predicts this correlation? That of Jevons can perhaps be quantified as containing a technological rebound factor of slightly over 100 per cent, or an efficiency coefficient in a model of energy consumption of, say, 1.01. Holding all other variables constant, this model predicts the increase in energy consumption better than models assuming rebound less than unity which yield a large gap between predicted and real

⁹² A given CO₂ molecule, for instance, has no marker on it indicating its human value.

⁹³ For example Saint-Paul, 1995; Cleveland & Ruth, 1998, pp44-45; Giampietro & Mayumi, 2000, pp182, 185-186 & this volume; Weisz et al., 2006, p694; 4CMR, 2006, pp24, 52-53; Rhee & Chung, 2006; Polimeni, this volume.

consumption, a gap usually filled by exogenous GDP. Such models must moreover show what the causes of increased consumption then in fact are, if not efficiency increases.⁹⁴ And these causes must be strong enough to *overcome* the alleged consumption-reducing effect of greater efficiency.⁹⁵

Efficiencies of all provenances have continually expanded the world economy's *production possibilities frontier* and thereby its consumption frontier. Grasping this physically – including the physical inputs into this consumption – can avoid some of the difficulties arising in microeconomic monetary analysis in terms of income effects and societal purchasing power. Yet while this immediately renders large rebound plausible, to directly infer backfire would beg our entire question; the Jevons *Paradox* must be taken seriously. In any case no answer can do without assumptions or empirical evidence concerning the (non-)satiation of material desires and greater production's affect on population size.

The policy situation is remarkable. The likelihood that theoretical and real input savings are identical is zero; some rebound is uncontested, and the lowest macroeconomic total-rebound estimates lie in the range of 25-40 per cent. It is therefore truly astonishing that with a handful of exceptions,⁹⁶ government agencies and policy assessment companies do *not* correct for it,⁹⁷ but rather, using a purely 'engineering' approach, set real savings equal to technologically possible savings. However, a rebound coefficient of 0.5, which is at the present state of knowledge justifiable, would significantly alter estimates both of efficiency's effectiveness and its cost-effectiveness.

Remarkably, Smith's 'human stomach' passage – written about 230 years ago – contains practically all the concepts needed to approach our question:

But when by the improvement and cultivation of land the labour of one family can provide food for two, the labour of half the society becomes sufficient to provide food for the whole. The other half, therefore, or at least the greater part of them, can be employed in providing other things, or in satisfying the other wants and

⁹⁴ See Saunders, 2005.

⁹⁵ See Howarth, 1997, pp2-4, 7; Schipper & Grubb, 2000, p384; Solow, 1970, pp33-35, 38.

⁹⁶ Rebound coefficients crop up in Defra, 2002, p4; NRC, 2002, sections 4.1, 5.24-25; 4CMR, 2006, pp5, 12, 21, 35, 72-75.

⁹⁷ EEB, 2000, p32; INFRAS, 2002; CEPE, 2003, pp6, 32, 35, 44, 55; DTI 2006, pp36-60, 149; EnergieSchweiz, 2007.

fancies of mankind. Cloathing and lodging, houshold furniture, and what is called Equipage, are the principal objects of the greater part of those wants and fancies. The rich man consumes no more food than his poor neighbour. In quality it may be very different, and to select and prepare it may require more labour and art; but in quantity it is very nearly the same. But compare the spacious palace and great wardrobe of the one, with the hovel and the few rags of the other, and you will be sensible that the difference between their cloathing, lodging and houshold furniture, is almost as great in quantity as it is in quality. The desire for food is limited in every man by the narrow capacity of the human stomach; but the desire for the conveniences and ornaments of building, dress, equipage, and houshold furniture, seems to have no limit of certain boundary. Those, therefore, who have the command of more food than they themselves can consume, are always willing to exchange the surplus, or, what is the same thing, the price of it, for gratifications of this other kind. What is over and above satisfying the limited desire, is given for the amusement of those desires which cannot be satisfied, but seem to be altogether endless. The poor, in order to obtain food, exert themselves to gratify those fancies of the rich, and to obtain it more certainly, they vie with one another in the cheapness and perfection of their work. The number of workmen increases with the increasing quantity of food, or with the growing improvement and cultivation of the lands: and as the nature of their business admits of the utmost subdivisions of labour, the quantity of materials which they can work up, increases in a much greater proportion than their numbers. Hence arises a demand for every sort of material which human invention can employ, either usefully or ornamentally, in building, dress, equipage, or houshold furniture; for the fossils and minerals contained in the bowels of the earth; the precious metals, and the precious stones. (I.xi.c.7)⁹⁸

Here we find efficiency as 'improvement' and 'division of labour', greater output and an expanded production frontier as food surplus, greater population seen endogenously, the irrelevance of the energy proportion of a service, the reduction of quality to quantity, the limitlessness of latent demand, marginal consumers, the empirical fact of consumption's going hand in hand with efficiency and the derived large demand for material inputs including fossil fuel.

Greater technological efficiency enables us to squeeze more useful material out of a given amount of input, or more non-work time out of the 24 daily hours (Sanne, 2000, pp487, 494). This is Jevons' state of 'happy prosperity' (p276). But if it simultaneously increases demand for natural resource inputs, we face a trade-off between affluence and sustainability. With the evidence at hand today, and given a certain urgency in finding an answer, good judgement is called for. If asked by policy-makers today whether we can count on greater energy efficiency to lower energy consumption, how many economists can answer with a whole-hearted 'Yes'?

⁹⁸ Also Ricardo, p293; see Say on cheaper corn and 'dress and household furniture' (p301).

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This work on the history of ideas relevant to the rebound question certainly helped clarify and flesh out some of the concepts. It also brought into focus the following chain of reasoning in estimating high rebound:

1. technological efficiency increase itself, taken exogenously but including our reasons for doing it, entailing as it does certain costs;
2. the effect of technological efficiency increase on economic growth, i.e. growth in the amount of goods and services;
3. that this increase in society's production possibilities frontier was in some sense for free;
4. the effect on a natural resource's price when it is used more efficiently;
5. the result that such efficiency increase enabled population increase;
6. the central question of how efficiency in using resource X, through the medium of economic growth, affects the amounts of resource X consumed;
7. analogously, that labour inputs had been determined not to go 'unemployed' when used more efficiently;
8. and, mysteriously, that efficiency increases led to new products and thus perhaps to even more consumption of the input than before the efficiency increase.

Of course this study was no more conclusive than any of the dozens of attempts to measure direct rebound; but several sceptics found it convincing, perhaps due to the hoary reputations of the studied 'previous writers'.