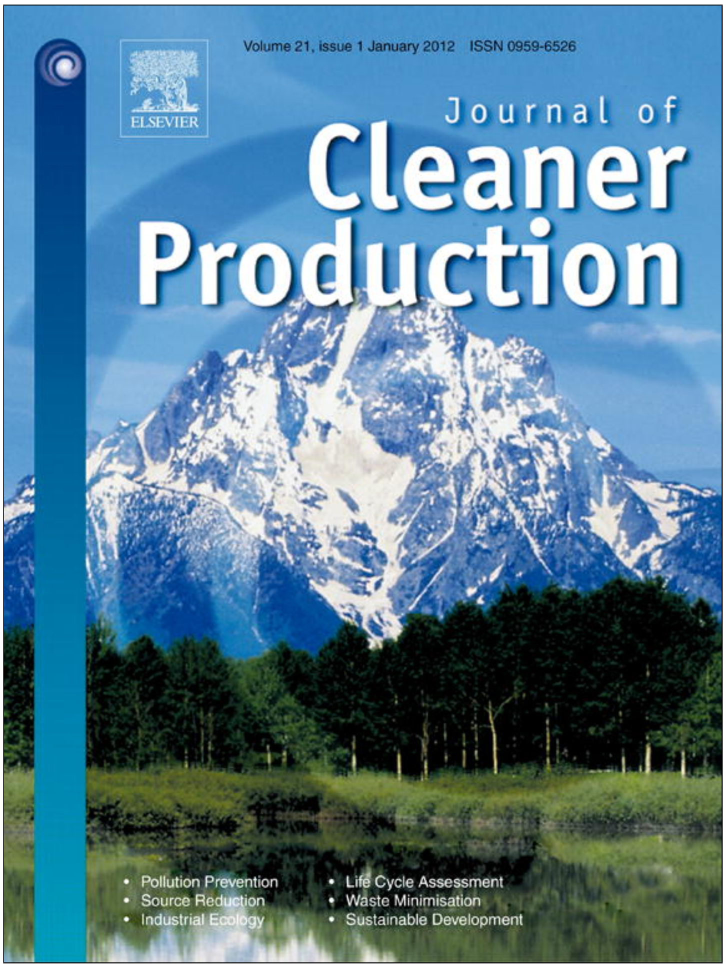
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Mill's scissors: structural change and the natural-resource inputs to labour

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A B S T R A C T

The environmental structural change strategy claims that by shifting our expenditures to economic sectors with lower environmental intensity, absolute resource consumption and environmental impact can be lowered. Environmental Input–Output methodologies for computing these intensities attribute no resource consumption to labour or households because these are not classified as sectors. The suggestion that service sectors entail less environmental impact, however, loses force if a unit of labour contains embodied energy, and attributing these inputs to labour drastically reduces intensity variation between sectors. Relative growth of service sectors has furthermore not been accompanied by decreased resource consumption; thus models whose intensity computations cover not only inter-firm payments but also labour earnings and household expenditures may have superior predictive power. If moreover natural-resource and labour inputs to product are incommensurable, intensity ratios themselves have perhaps only monetary, rather than real, significance.

Epigraph

> Some writers have raised the question, whether nature gives more assistance to labour in one kind of industry or in another; and have said that in some occupations labour does most, in others nature most. In this, however, there seems much confusion of ideas. The part which nature has in any work of man, is *indefinite* and *incommensurable*. It is impossible to decide that in any one thing nature does more than in any other. When two conditions are equally necessary for producing the 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. (John Stuart Mill, 1848, 28–29)

1. Introduction

The *environmental structural change strategy* holds that when keeping expenditures at a constant level but shifting them to economic sectors deemed to have relatively low environmental intensity, depletion and pollution can fall (Costanza, 1980, 1222). There is however no empirical evidence that structural change towards services or tertiary sectors has been accompanied by lower environmental impact if imports, air travel and shipping are rigorously measured (Brookes, 1972; Rothman, 1998; Jackson and Marks, 1999; Vringer and Blok, 2000; Torras, 2003; Helm et al., 2007; Peters, 2008; Ausubel and Waggoner, 2008; Miller and Blair, 2009, 421–423; Holm and Englund, 2009). The strategy thus relies on theory, in particular on methodologies for attributing resource consumption to certain sectors of the economy that omit labour from the analysis. Yet since shifting from resource-intensive sectors means shifting *to* labour-intensive 'service' ones, depletion and pollution can fall only if labour-hours themselves require low or no environmental inputs. This paper re-opens a debate that was truncated around 25 years ago over the environmental consequences of buying a unit of labour.

The search for explanations of levels of pollution and natural-resource consumption has yielded mature methods for counting the material and energy embodied in physical products such as cars, plastics or bottles, but no clarity on the same things embodied in the labour that is bought with every expenditure: Does an hour's work have zero environmental impact, or must we count the worker's metabolic and muscular needs, plus perhaps the energy costs of his or her physical workplace, clothes and commuting, or even all of the energy, either directly utilised or embodied in goods and services, that the worker's hourly wage purchases?

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The paper combines literature review and conceptual analysis to argue for attributing natural-resouce consumption not only to goods, processes and firms, but to individuals as labourers and final consumers. In light of strong evidence that *if* this is done the environmental intensity of expenditures is virtually constant among sectors (Costanza, 1980), the methodological decision of where to draw system boundaries is of central importance for structural-change hopes within sustainable consumption.

Concerning terminology, please accept four simplifications:

1. When characterising inputs and intensities 'environmental', 'natural-resource' and 'energy' are used synonymously; the more specific 'energy' is often used, but the analysis pertains to any natural-resource input into production.
2. For brevity, and since many co-efficients exist for converting amounts of resource consumption into emissions, the paper speaks of natural-resource depletion rather than pollution, species loss, climate change, etc.
3. The term 'labour' as both a physical and an income category subsumes not only wages but categories such as capital and entrepreneurial services, profits, and rent. For any given expenditure it is contrasted with payments for goods and services or raw materials delivered by firms as taxonomised in National Accounts.
4. The paper uses 'EIO' or 'EIO(-LCA)' (Environmental Input-Output(-Life-Cycle Assessment)) for any environmental accounting using National Accounts sectors, input–output co-efficients and cradle-to-grave summation.

Section 2 describes the environmental structural change strategy. Section 3 describes the *direct* and *indirect* natural resource inputs or 'costs' entailed by any expenditure, loosely within the framework of Life Cycle Assessment. Section 4 presents arguments for including the natural-resource costs of labour in environmental accounting. Section 5 presents two objections to including these costs. Section 6 points to several open questions and lists the far-reaching repercussions of drawing wider boundaries.

2. The environmental structural change strategy

Holding expenditure level constant, a given consumer or an entire economy can alter its "spending patterns" so that a greater percentage of expenditures goes to sectors or economic activities deemed to be less environmentally harmful (Vringer and Blok, 1995, 901). The analysis upon which the strategy rests "only explores the effects of changes in *patterns* of consumption without any change in the *level* of consumption" (Alfredsson, 2004, 517). This 'dematerialisation' is by the same token however a 'labourisation': holding total outlays constant, the less spent on physical goods, materials and energy the more spent on labour. The strategy is one of several indirect environmental strategies including population reduction, lower affluence, and greater technological and consumer efficiency.

The call is for shifting expenditures

> Obviously, different consumption activities differ very much with regard to their environmental impact, and in principle it is easy to imagine a continuous growth in economically defined consumption without a corresponding growth in the consumption of resources… if the population used income increases to buy labour-intensive goods and services: theatre and music performances, courses in new skills, lectures on interesting topics, art objects, high quality clothes and houses made as handicrafts, child care, and massage treatments. (Røpke, 1999, 401).

This paper analyses such an "art object", a new *painting*, to show that buying such a "labour-intensive" product causes significantly lower environmental impact only if the resource consumption of the painter is ignored.

In terms of Material Input Per unit of Service (MIPS), if we buy from sectors with smaller "ecological rucksacks", input could fall while units of service rise; the two ratios MIPS + LIPS (labour input per unit of service) add up to unity; since we spend the same amount we must not "do without" (Schmidt-Bleek, 1994, 21–24, 115–119, 184–185).[1] In EIO terms the "value-added" portion of an expenditure can rise, "diluting" its greenhouse-gas intensity and recommending itself to environmentally responsible consumers (Suh, 2006, 6559).

"Structural economics" describes the strategy in terms of "change in the lifestyles of households" (Duchin, 1998, 2, 20, 51). Using the methodology of counting energy inputs from all sectors into any sector we can thus identify "more sustainable consumption patterns" by households (Kerkhof et al., 2009, 1160–1161) and reduce expenditures in those "consumption clusters activating the most resource flows throughout the product life-cycle" (Spangenberg and Lorek, 2002, 134). We can compute emissions intensities for say 27 consumption sectors, yielding a sector ranking (Common and Stagl, 2005, 132–133). In Brazil for example the "food" sector is computed to use 10.1 MJ per $, "recreation" 8.7, "clothing" 6.4, and "communications" 3.6 (Cohen et al., 2005, 557). "Ecological structural change" is when "material-intensive sectors shrink, others grow" (Hinterberger et al., 1996, 101). LCA's role is in society's "dematerialisation and substitution" (Robèrt et al., 2002).

Let us define the strategy as follows:

1. The economy's structure is the portions of monetary exchanges (GDP) spent in economic sectors numbering from three highly-aggregated ones (agriculture, manufacturing and services) to around 1000.
2. The environmental inputs into each expenditure, sector, or GDP are the natural resources (N) in input–output processes measured in either monetary or physical units; as in all economy-wide EIO monetary units are unavoidable, and using natural-resource prices one can derive physical quantities.
3. The environmental intensity ratio is the amount of input in physical or monetary units per unit of output (Q) in monetary units.
4. All other inputs into Q purchased by the expenditure are subsumed under the generic term 'labour' (L) – paid work time; for a $1000 expenditure, $-value of N/$1000 plus $-value of L/$1000 = unity.
5. If sectors have different intensities, shifting a given level of expenditures to less N-intensive ones would reduce N-consumption.
6. To enable commensurability between expenditures the strategy makes no assumptions about the relationship between expenditures and psychological satisfaction or utility (Ròbert et al., 2002, 200–206).

4) and 5) together mean that after shifting, the consumer is purchasing *more* units of labour than before. The strategy is distinct from that recommending purchases within a sector of goods with less natural-resource input but the same utility – e.g. a wooden

[1] *Also* Kaufmann, 1992, 38–39; Hinterberger et al., 1996, 84–97; Ritthoff et al., 2002, 9.

instead of a metal table (Hannon, 1982, 271). Not only would the wooden table be cheaper, but product comparisons do not yield intensities since the denominator is simply 'a product'. Like the strategy, and unlike process analysis, this paper compares expenditures, not products.

3. Indirect energy inputs into an artist's work

The inconclusiveness of empirical work and the fact that many variables determine resource-consumption levels renders it necessary to turn to theory. As a start suppose that we abide by the structural-change strategy and use our earnings for a new $1000 painting instead of a $1000 plane trip. The artist we buy the painting from, however, could use the proceeds for a plane journey, and oil is consumed merely by a different person (Lloyd, 2007, 5815–5816).[2] While we don't know that the artist would board the plane in our stead, the assumption is legitimate that the environmental intensity of his or her expenditure is society's average.

Again, if a given expenditure is responsible for less natural-resource consumption than another of the same size, it is responsible for *more* labour consumption, and the amount of the theoretical decrease in *N*-inputs due to the shift thus depends on whether the purchase of these additional labour units entails zero, or some, embodied natural resources – and if not zero, how much. Conventional EIO ignores labour, entering the environmental intensity of a pure service, e.g. Herendeen's sectors "domestic service" and "auto registration and fees", as zero (1998, 173; *also* Wright, 1974, 309; Spreng, 1988, 138–140; Graedel, 1997). This holds equally for physical input–output analysis (PIOT) if it traces only inter-industry transactions, without final demand (Miller and Blair, 2009, 399). An early diagram showed the inputs and outputs of an oil refinery: extraction energy, energy costs of tankers, materials, plant, and fuels used for organic chemicals, but nowhere a human being able and willing to work (Chapman, 1974, 100). Even if the output-denominator metric is physical, the issues are whether labour is a sector at all and whether inputs to labour include household consumption (Spreng, 1988, 7, 136).

This section describes the contrasting method of accounting total household consumption, leaving for Section 4 some arguments for it. Middle positions are also tenable whereby the energy cost of labour-hours "offsets some fraction of the direct energy savings" – reducing, but not eliminating, variation in sector intensity (Kaufmann, 1992, 49–54). One could count only energy use over and above what an unemployed person would consume (Hall et al., 1986, 106–108). Appendix I shows a spectrum of consumption enabling the production of labour, some or all of which could be counted.

It is universally accepted that in energy accounting energy inputs for metabolism and muscular movement differ in no way from the energy needed to run a car factory. Since EIO counts the energy embodied in steel reaching the factory, consistency would mean counting the parallel category of that embodied in workers – yet even basic metabolism cannot be counted if labour is not a category in input–output tables. From the beginnings of energy accounting it was seen that there is "some arbitrariness" in what to count:

> [I]s it the physical energy contributed by the labourer to the production process, or the energy content of the food he eats, or the primary energy needed to produce all the goods and services he enjoys?... Excluding [labour] is appropriate to [regarding] people enjoying consumption for its own sake rather than to facilitate their contribution to the production process. (Wright, 1974, 309–310; *also* Chapman, 1974, 93; Gilliland, 1975, 1052)

The course was set for recognising that labour is produced, yet ignoring it.

Supporting the arbitrariness of choosing system boundaries, Smil asks:

> Once the decision is made to account for the energy cost of labor, which approach is more rational: the minimalist choice of counting just the thermodynamic equivalent of the invested muscular exertion or the maximalist option of finding the total existential energy requirements?... These challenges have no satisfactory solutions. (2008, 273–274)

This paper nevertheless argues that the 'maximalist' solution is, for the purposes of environmental policy, satisfactory. If our research question covers the entire energy system, why draw boundaries at all?

To be clear what is meant by the *indirect* natural-resource costs of or inputs into labour, Table 1 analyses a hypothetical purchase of a $1000 painting requiring 30 h of labour.

Following conventional EIO, this product from a purportedly low-impact sector entails environmental inputs beyond the paint, frame, canvas and gallery wall (Cell 1); the expenditure entails further the 'ecological rucksack' or natural resources embodied in or required for the production and delivery of the paint, frame, canvas, etc., plus the atelier's amortisation (Cell 2).[3] The painter's *time* requirements are similarly divided into the hours we are billed for (Cell 3) and those previous to these without which the artist would be *incapable* of painting (Cell 4). Returning to the environmentally relevant natural-resource inputs, there is the metabolism of the painter while actually painting plus less obvious inputs like protective clothing and coffee breaks (Cell 5). Finally we have our bone of contention, the inputs into the daily life of the artist that are necessary because, were the wages part of our expenditure not large enough to buy them, the artist would not work (Cell 6). Cells 4 and 5 thus supply the time and energy for the capacity (ability) to work while Cell 6 constitutes the consumption necessary for the *willingness* to work.[4] Cells 2, 4 and 6 might also include the physical and institutional support labour receives from the community, similar perhaps to a study suggesting the inclusion of government because its resource use is "an upstream part of household consumption" (Spangenberg and Lorek, 2002, 135).

A rough quantification of the amounts of energy included in Cells 5 and 6 shows that choosing system boundaries makes a large difference. Basic metabolic consumption is about 0.5 MJ h^{-1} (Fluck and Baird, 1980, 101–105; Odum, 1995, 265; Smil, 2008, 124–131) and approximately ten times this amount is embodied in the food enabling this metabolism (Hall et al., 1986, 107). Taking total primary energy consumption of 160GJ/European/year (Smil, 2008, 258) and assuming 2000 working hours per year, roughly 80 MJ is attributable to an hour's work. Cells 5 and 6 are a percentage of lifetime energy consumption proportional to the percentage of the 30 h in this example to total labour-hours.[5]

Some research does address the hidden energy requirements of labour beyond basic metabolism (moving from Cell 5 to Cell 6) using the example of the service *"a day in a hospital"*: To computations for the hospital's buildings, machines and transport, and the

[2] The alternatives "holidays abroad" and "works of art" (Druckman and Jackson, 2009, 2067) are common in the literature.

[3] Ratios between Cells 1 and 2 could be in tonnes/tonne (Robèrt et al., 2002).

[4] Hall et al. reject maximalist accounting because they emphasise ability, rather than willingness, to work (1986, 40, 107–108).

[5] Assuming 45 working-years, or 90,000 h, also yields 80 MJ h^{-1}.

Table 1
Six categories of inputs into a painting. The direct and indirect labour-time and natural-resource *preconditions for* the production of a painting.

OUTPUT (*Q*)a painting	Natural-resource INPUT (*N*)	Labour INPUT (*L*)	*N*-INPUTS *into L*
direct inputs	Cell 1 weighable canvas, paint, frame; utilisation energy *during painting* for light & heat etc.	Cell 3 time (hours) actually painting the painting	Cell 5 (direct) artist's food, water, etc. *during painting*; required for metabolism, comfort & muscular exertion
indirect inputs	Cell 2 natural resources 'cradle-to-grave'; *N* embodied in atelier; 'ecological rucksack'; transport; waste	Cell 4 time spent for *ability* to paint: health, education, inspiration, rest; commuting	Cell 6 (indirect) *N*-inputs for Cell 4 and during commuting; lifestyle, affluence, entertainment; *willingness* to paint

utilisation matter-energy in heating, electricity, laundry, etc., the analysis breaks convention by adding "the education, further training and maintenance of the hospital employees" (Schmidt-Bleek, 1994, 185–187). Although "maintenance" could be interpreted in a minimalist or maximalist way, it is here at least 'on the map' and raises this paper's question, as did another conventional study identifying "energy used in acquiring and maintaining knowledge" and arguing that "ignoring… the energy cost of labor is a deficiency" (Stern, 1999, 388–393).

Maximalist analysis is distinct from the result, using conventional EIO-LCA, that so-called service sectors, "whose own product is actually immaterial, e.g. banking, consulting, trade and transport, [are] responsible for about one-fourth of all material movements" (Hinterberger et al., 1996, 96). The insight is rather that these service sectors are *defined by* the (large) percentage of expenditures in them going to employee compensation or entrepreneurial income and that this part, whatever its size, is left out of embodied natural-resource calculations.

One rare study of the environmental intensity of service sectors, for example, notes that although wages make up 45–80% of costs, they "were assumed not to cause any material or energy flows", leaving the entire environmental burden on office premises, business travel, office equipment, etc.; although personnel income has environmental impact through private consumption, wages are given zero intensity in spite of the fact that even "expanding the system boundary" to include commuting would result in the 'wages' sector having the second highest impacts of all measured sectors (Junnila, 2009, 424, 428, 431).

Table 2 monetarily compares a new painting with a plane trip, the metal sculpture illustrating that products in any sector lie on a spectrum of conventionally-tallied intensity. At one extreme in an 'art objects' sector would be an Andy Goldsworthy work consisting of only natural objects, labour receiving perhaps $990 with $10 going for photographs of the work. Carl Andre's *144 Magnesium Square*, consisting of metal floor plates, would be even less labour-intensive than Table 2's sculpture. Note that there are approximately 2,000,000 artists in the US (florists, news announcers, singers, dancers, writers and architects) each earning yearly on average $34,800 (Tages-Anzeiger, 2008). Is the environmental impact of these professional groups, whose livelihood is supported by purchases in these sectors, zero?

The maximalist method can be cast not only in terms of the 'downstream' expenditures of wage recipients but also the 'upstream' acquisition of a consumer's purchasing power in the first place. In terms of time the artist's flight looks forward, while the analytical boundary can be expanded backwards to the precondition of the purchases made by the addressee of the structural change strategy: productive activity entailing natural-resource consumption. Consistent with the normative tenet of consumer responsibility, the observation is that the consumer chose to work and earn, and it seems justifiable to assume that the material-energy implications of the economic activity are the average of the economy. Conventional analysis, however, considers the past history of labourers/consumers to be "outside the domain of the analyst" (Ayres, 2004, 431). EIO excludes as a matter of principle "investments made in the past", even in "capital goods" (Tillman et al., 1994, 22).

4. Including indirect resource costs of labour

Two arguments have thus emerged for including the entire natural-resource consumption of the labourer:

1. The logic is no different from that behind LCA's widest possible computation of 'ecological rucksacks': "Just as a machine tool must be manufactured and have an end of life, a worker must have a childhood and an end of life" (Zhang and Dornfeld, 2006, 190). The natural-resource costs of labour input should include non-working hours.
2. Our painter must be willing to work. The condition for non-slaves is a wage proportional to their lifetime consumption of energy, etc., for hygiene, housing, cooking, clothes, transport, entertainment, further education, hobbies and holidays – consumption induced by his or her wages.

This section also examines the arguments that labour is in reality produced, and that the incommensurability of labour and natural resources prevents the computation of real intensities in the first place.

4.1. A double standard?

Counting only metabolism is analogous to counting the utilisation but not the embodied energy of a car – a battle won long ago by conventional energy analysis. Buying a car is buying also the steel entering the car factory, the energy embodied in the steel, and so on, and just as metal, glass and rubber cross the boundary into an automobile factory, so do the workers. It must be tractable to measure the energy embodied in a hour of their work – if we cease focussing only on physical objects and materials – since well-developed analytical tools can be used for any factor of production. However, even writers who in principle accept the energy cost of labour as a category of indirect inputs often in the end ignore all but metabolism: For Spreng, for instance, "proper accounting" excludes energy input into labour unless "a special camp has to be built to house workers… or where travel to work is exceptionally long…" (1988, 138–140, 260–261).

Researchers of social metabolism, as well, have attested the soundness, in principle, of explicitly counting the the wages sector:

> Typically, only the technical infrastructure… is considered as material stocks [and thus within the accounting system] and not

Table 2
Three consumer choices. A breakdown – fictitious but consistent with real intensity estimates[a] – into the part of the $1000 going in the first analysis of natural resources and labour.

Inputs ↓ Q →	Painting	Sculpture	Flight
hours worked á $30/hour (Table 1, Cells 3 & 4)	30, = $900 artist	20, = $600 sculptor	13.3, = $400 pilot, ground crew, attendants, CEO
natural resources (Table 1, Cells 1 & 2)	$100 wood, canvas, paint, atelier, transport	$400 metal, torch, polishing, atelier	$600 kerosene, aeroplane,airport, meal
Total price	$1000	$1000	$1000

[a] Wright, 1974; Costanza, 1980; Hannon, 1982; Spreng, 1988; Druckman and Jackson, 2009.

> the… human and livestock populations. From a strict input–output perspective, this results in inconsistencies, and theoretically this shows an 'industrial' bias that is hard to justify. (Fischer-Kowalski and Hüttler, 1998, 116)

One must apparently not infer, though, that counting them renders sector intensities more or less equal (Giampietro, 2006, 179).

Only one recent study, however, makes a full attempt to attribute part of society's primary energy supply to labour, counting moreover much more than work-hour metabolism:

> We argue that the energy associated with human labor must include the energy of infrastructure in addition to that of food, where infrastructure includes housing, transportation, health care, etc. If defined in this way, the energy use of labour can be a significant contributor to manufacturing energy use. (Zhang and Dornfeld, 2006, 189–190)

Even after subtracting specifically *industrial* energy supply, the authors must adjust the energy intensities of labour-intensive processes upward: standard "process-based LCA would in fact grossly underreport the environmental costs of a service or an entirely handmade product" and exaggerate sector variance (192). Only by applying a double standard can one count the utilisation and embodied energy of the machine tool with which a machinist works but not the (larger) amount of the machinist (189–190).

Before moving to further arguments for the maximalist position please note that we must not re-invent the wheel. Classical economics was well aware of hidden material inputs into services, deconstructing the notion of 'immaterial products': doctors, teachers, musicians or prostitutes require not only tools or places of work but also material investments in themselves for upbringing, education, housing, and entertainment.[6] Furthermore, just as EIO-LCA shows how services presuppose physical inputs, Mill listed the labour inputs into a physical loaf of bread: bakers, millers, sowers, reapers, carpenters, bricklayers, hedgers, ditchers, miners, smelters, and transporters "so back to the origin of things" (1848, 31–32; *also* Chapman, 1974, 92). The inverse question arises: Were we computing the indirect *labour* inputs into goods, would we ignore the labour put into the transformation of raw materials and the fashioning of a final consmer object? Surely not, since transformation through labour is a condition of a good's or service's price. Just as goods are not purely material, neither are services pure labour.

We can also refer back to Leontief, in whose input–output matrices labour was endogenous (in monetary units as "wages and salaries"/"capital and entrepreneurial services") – an industry like any other because the economy of households is like "the production of an enterprise" (1936, 106–107; Table 5; 1951, 41–42). Only the 1970s and 1980s departed from this practice, influenced perhaps by the search for engineering responses to oil-supply shocks, and the norm today is the full exogenisation of labour and households as value added and final demand (Wright, 1974; Bullard and Herendeen, 1975; Hannon, 1982; Miller and Blair, 2009). To be sure, two workshops of the International Federation of Institutes for Advanced Study in 1974 and 1975 debated exactly which natural-resource costs of labour might be counted, but without resolution (Spreng, 1988, 126). The default position became to ignore them.

4.2. Hiring labour induces energy consumption

One early study retaining Leontief's personal-consumption column and employee-compensation row argued that individual expenditures as well as inter-business ones "induce" energy effects (Penn et al., 1976, 664–665). This is of course the most basic argument for doing any embodied energy analysis at all, as expressed clearly by Spreng who, after comparing energy accounting in the 1970s to a game without any rules, formulated an abstract rule that "all the energy requirements necessary for the operation of [an economic] activity" be counted, i.e., if the "economic activity otherwise would not be done" (1988, 125–126, 137, 155). Since labour, and the activities of households/consumers, are undeniably 'economic', and since full wages are a necessary condition for labour's being done, it should follow that we count total rather than only intermediate expenditures. We should furthermore *attribute* these energy requirements to labour. Again in terms of willingness to work, would the labour be brought to market had the labourer not commuted, had a good night's rest, pursued hobbies and looked forward to a holiday?

Another early study (Fluck and Baird, 1980, 100–105) was maximalist in counting lifetime "lifestyle support energy…, that energy sequestered in the goods and services purchased by the wages earned by working." In contradiction to Wright (1974, 309–310) but in line with Cell 6, Table 1, the authors believe we work for family members and leisure, not merely for muscular energy, and counting only the exosomatically-powered machines used by the worker is also not enough. For them the strengths of this position outwiegh the danger of possible double-counting. Røpke recently sympathised, suggesting that "the consumption of food, shelter, education etc. could just as well be seen as intermediate products, and then the concept of final consumption disappears" (1999, 400). Consistent application of LCA logic would seem to entail treating the consumer/earner as part of the analysed system (Boustead, 1996, 150; *see* Appendix I).

In more economic terms the claim is that the energy used up when a worker is hired to do X hours of labour is a proportion of his or her lifetime energy consumption equal to the proportion of these X hours to the worker's total lifetime working hours. A plausible proof of this is that if these costs were omitted, output would be significantly cheaper than it is. Using Puntí's example, counting metabolic energy per working hour but not even the energy costs of producing food for this metabolism masks large differences between, say, Andalusian manual/animal agriculture of the 1940s and U.S. mechanised/fertilised agriculture of the 1970s (1988, 80–83). Energy analysis of service sectors is in principle difficult with conventional EIO, and "if wages earned in the service sector are the same or higher, then there is no reason to expect a decrease in energy consumption" (82). Socio-economic context matters.

Finally, it is an unrealistic result of EIO's exclusion of induced energy costs of labour that there is little or no environmental

[6] Say, 1803, 119–127, 301–319, 373; Mill, 1848, 154–159.

difference in buying, at going wages, a painting from a Ghanan artist and a U.S. artist; process analysis and to a lesser extent EIO would yield similar material intensities. What's more, the curious policy implication is that for environmental reasons we should shift our expenditures from, say, Ghana to the US, since richer countries have lower MJ/$ ratios.[7]

4.3. Labour is produced

Herendeen succinctly sums up the two arguments above: just as in the energy analysis of a car, "the energy consequences of the labor force's spending of its wages is as important as the energy needed to make the steel" (1981, 616). The next concept deserving separate attention is labour as a *product*: following Leontief, each household is a factory producing (among other things) labour. This requires, however, a consistently ecological approach to the human economy – inclusion of humans in the environment rather than the separation associated with neo-classical economics.

Recalling the double standard discussed above, Ayres similarly argued that if we regard "human labor as an independent primary input – not an intermediate input", an inconsistency arises:

> if a handloom is replaced by a power-loom (capital), the energy required to operate (and also to make, or replace) the power-loom… is taken into account explicitly [but] economic theory does not count the food, clothing, housing, and other consumption by workers – nor their education and training – as part of the cost of production. (2004, 431)

An EIO matrix including labour as an industry, and not separating final and intermediate demand, might well resolve this inconsistency.

Assuming we do choose, supported by the above three arguments, an expanded system, what then are the consequences of shifting outlays to categories otherwise deemed to be more environmentally friendly? In reality, since expenditure size is held constant, the shift means buying more labour (or capital), and Costanza's (1980) empirical exercise confirmed that therefore energy consumption remains much higher than predicted by the narrower matrix. Adding government and labour/household sectors to the 90 intermediate supply-and-demand sectors of the 1967 US economy and correspondingly re-attributing energy inputs vastly reduced intensity variation between sectors. Taking sector energy input as the independent and sector dollar output as the dependent variable, the measure of correlation R^2 rose from about 0.55 to about 0.99.

4.4. Mill's scissors – monetary vs. physical economics

Let us identify at least briefly some apparent anomalies in the use of monetary metrics in analysing physical impacts of production and consumption. To draw environmental consequences from structural economics by comparing sector intensities, one must measure the relative sizes of L and N, requiring aggregate metrics for them as numerators – a task known as Petty's Problem.[8] Yet common physical units for labour and natural resources (as well as for 'goods and services' in the output denominator) are impossible. Forming and comparing intensities must therefore rely on prices – monetary metrics – enabling quantification of labour-hours/GDP and natural-resources/GDP. Moreover, joules per dollar, or labour-hours per dollar, cannot be added to input-dollars per output dollar (Gilliland, 1975, 1051; Miller and Blair, 2009, 406). For this reason Mill (Epigraph) denied that Petty's Problem, in real terms, makes sense.

Wright (1975, 34–35) noted the further problem for energy accounting that although labour and profits are not included in counting energy inputs, because they are excluded from the total requirements matrix, they are part of commodities' prices. Another anomaly arises concerning a $1000 gift. Similar to our earlier questions concerning a Goldsworthy artwork involving only the rearrangement of natural objects, it would be counted in the GDP income accounts but would not fall into any industrial sector – no product or material is bought from the recipient. Environmental impact is implied, however, in the fact that the $1000 was earned by productive activity. In both these examples, in any case, it should be clearer what is exogenous and what endogenous. It is even ironic that the structural change strategy begins with consumer responsibility for household expenditures, a category outside the intermediate matrix.

Further analytical difficulties arise concerning the primary energy sectors. When tracing environmental flows through monetary proxies the energy intensities of primary energy sectors themselves are so high they must be treated, unsatisfactorily, as outliers (Costanza, 1980; Spreng, 1988, 146). What's more, payments for primary energy at the wellhead, say, actually consist fully of payments to people as wages, profits and rents. These of course eventually appear exogenously as household income or value added, but natural resources themselves have no bank account and literally receive nothing, entering the physical transaction matrix with positive values but the monetary matrix for free (Gilliland, 1975, 1053). Purchases from these sectors would thus logically belong to value added and fall outside the boundaries of the conventional EIO matrix.

For illustration let us pursue Suh's observation that while services are allegedly material-free, each dollar spent in the U.S. in service sectors includes about twenty-five cents for purchases from the non-service sectors manufacturing, utilities, transport (2006, 6560). These $0.25 expenditures in the manufacturing sectors would in turn contain a percentage going to labour, and so on until we see that an expenditure is entirely attributable to personal income. But if all are ultimately wages, profits and rents, and natural resources and labour-hours are physically incommensurable, how can one establish that a given good-or-service costing $1000 is caused to certain percentages by labour or nature? All is nature, all is labour or: with his scissors analogy Mill was suggesting that we cannot compare labour and natural-resource intensities at all.

5. Arguments against including labour

Why, then, should the consumer be responsible only for the environmental consequences of the non-labour, inter-industry parts of an expenditure? Two reasons have emerged in the literature: reluctance to regard labour, and thus people, as produced; and the intricacies of double-counting.

5.1. People are produced

It seems at least internally consistent to regard output bought by households as input into the members of the households, and thus into their hours of labour. To accept this analytical framework, however, one must be willing to regard people themselves as sustained and even produced by economic processes, presuming

[7] In $ of purchasing power parity (PPP), a Bolivian (8.8 MJ/$) should spend in Argentina (5.0 MJ/$), a Chinese (8.4/$) in Germany (5.9/$), a Togoan (12.6/$) in Switzerland (4.2/$), a Bulgarian (10.9/$) in the U.K. (4.6/$) and a Jamaican (15.5/$) in the U.S. (8.0/$) (IEA, 2010; EIA, 2010; CAIT, 2010).

[8] Classical economics' standard example was a watch spring, the price of which was perhaps 90% labour, 10% metal. Finding an aggregate physical unit for all natural resources is a separate problem.

a normative or cultural judgement on the "propriety of removing humans from their 'controlling' position outside the economy and making them endogenous…" (Costanza and Herendeen, 1984, 157). When treating households exactly as any other industry, Leontief had similarly urged us to discard our "psychological resistance to this type of approach – due to memories of ill-conceived subsistence cost theories of wages…" (1951, 41).

As Puntí observes, this is Marx's uncontested concept of the reproduction of the labourer, who had to be produced, physiologically maintained and, for example, trained – entailing natural-resource costs (1988, 81–82; *also* Hall et al., 1986, 107). Labour does not fall exogenously from heaven but is a function of previous labour and natural resources. The classical concept was the 'natural price of labour' in terms of real physical inputs.[9]

While this perspective is out of fashion in economics, it is not fully unknown within environmental accounting, e.g. in Kaufmann's concept of energy "used to produce and support factors of production (e.g., labor and capital)" (1992, 53–54). The basic principle has also re-emerged more recently in the concept of the environmental consequences of having a child (Hall et al., 1994; Shi, 2003). Murtaugh and Schlax (2009) even performed an environmental impact analysis for the act of reproduction, estimating natural-resource consumption induced throughout several generations. Another recent study used the Japanese EIO category of a "labor coefficient vector [representing] the number of workers needed for a unit of total output" – analogous to a vector showing per sector amounts of MJs (Nansai et al., 2007, 882). In the study treating labour thus as produced led to the unique finding that shifting to low-environmental-impact commodities would reduce employment, in contradiction to the usual view that shifts in spending to low-impact sectors help combat unemployment. (883–884) In sum, endogenising households/labour requires a normative break with current philosophy.

5.2. Double-counting

Agreement reigns on how much energy a nation consumes, measured either physically or by its price; it is only accounting systems that are in dispute. Therefore Costanza (1982) answered Huettner's (1982) objection that including labour must double-count energy by noting that the additional labour and government sectors required merely a bookkeeping redistribution of energy – in the case of labour proportional to the proportion of employee compensation to total financial outlays. The number of industries or sectors varies anyway among national accounts systems, requiring redistribution done successfully without double-counting. Similar criticism by Herendeen (1981) led to a joint paper by Costanza and Herendeen (1984) showing that the two new endogenous rows (sectors) received joules no longer attributed to the conventional sectors; the system, not the amount of energy, had been expanded.[10]

While not as sanguine about double-counting as Leontief (1936, 111) or Ayres, for whom it is "a no no" only occurring in the first place only because economics regards labour only as an input but not an output (2004, 431–432), this paper can only hint at formal solutions. Within EIO, one could partition each conventional inter-industry cell into 1) wages and salaries and 2) all eslse paid on to other firms. This parallels the treatment of "secondary production" where each cell contains information on two "products" (Miller and Blair, 2009,140–143; Wright, 1974, 309; Bailey et al., 2004). In his endogenous labour services row Leontief analogously debited each industry with wages and salaries (1936, 112, 126). Alternatively, Zhang & Dornfeld merely deduct already-counted *industrial* primary energy supply from total consumed joules, implying perhaps that conventional EIO must under-count (2006, 189–190).

Other possible templates include the "by-product correction method" (Strømman et al., 2009) and "disaggregating industry sectors" by subtracting energy values in the non-labour part to avoid double-counting (Suh and Huppes, 2005, 691–692) – the opposite of Leontief's "consolidation of accounts" (1936, 108). For example $30 for a meal in a restaurant buys not only physical food prepared in a physical kitchen and served at a table on plates, but also the services of the cook, dishwasher and waiter. "When more than one product is produced, the environmental loadings are distributed among the product studied and its by-products or other secondary functions, according to certain rules of allocation" (Tillman et al., 1994, 23). We must only be willing to perceive working hours as *produced*. Appendix II shows rudimentary construction of such tables.

6. Discussion

Evidence referenced in the Introduction points to a shift in many economies to more labour-intensive service sectors; since 1992 for example the primary, secondary and tertiary sectors have on average grown respectively 1.0, 2.6 and 3.0% per year (OECD, 2008; *also* Hannon, 1982, 276). However, several studies taking this change in consumption patterns as the independent variable, while holding expenditure level constant, have found no correlated reduction in resource depletion or pollution (Wright, 1974, 314; Vringer and Blok, 2000; Alfredsson, 2004). Brookes (1972) even showed cross-country correlation between high services proportions of GDP and high energy/GDP ratios; energy/GDP ratios were moreover higher than energy/industrial-output ones. Holm & Englund similarly found for up to 139 nations a positive correlation between "per capita energy use and the proportion of GDP that can be attributed to the service sector…" (2009, 884; *also* York et al., 2005, 150). General time trends show moreover no dematerialisation, neither absolutely, nor per unit of GDP, nor per capita under roughly $26,000 (Luzzati and Orsini, 2009; *also* Smil, 2008, 243, 338; DOE, 2009). Since these correlations are necessarily inconclusive, all that can be said is that the theory that natural-resource consumption is a function of the size of expenditures, not their type, better explains the data. At least it seems incumbent upon EIO-based theory to name the factors that *do* drive resource consumption, counter-acting the claimed conservation effect of structural change.

Perhaps the language of EIO-LCA should be revisited, employing as it does a discourse largely in physical terms: material inputs, products and processes, goods, commodities, equipment, tons of steel or chemicals. While this is appropriate for product or process analysis, it seems lacking for comparison of *expenditures* of constant size and analysis of whole socio-economic systems (*see* Tillman et al., 1994, 21, 28). Even if the vocabulary of structural change shows a bias towards treating services as somehow immaterial it is to be welcomed that energy accounting is "changing focus from commodity to services" (Robèrt et al., 2002, 200) – services defined in the first place by their high percentage of labour costs.

Finally, if including labour is realistic and if, correspondingly, environmental intensities of sectors or expenditures do not significantly vary, there are far-reaching consequences in research areas depending on environmental-intensity concepts as

[9] Ricardo, 1817, 93–94; Malthus, 1820, 130, 113–114, 177–182, 250–252; McCulloch, 1825, 115; Mill, 1848, 33–35, 245.

[10] Herendeen later puzzlingly decided that "Labor and government services are assumed to have zero energy intensity relative to the consumer", the justification being "to avoid double-counting" (1998, 172). The issue haunts the debate.

conventionally computed. In addition to the structural change strategy these include:

1. specifically targeting consumption 'clusters' in the field of sustainable consumption (Spangenberg and Lorek, 2002; Druckman and Jackson, 2009);
2. shifting taxes revenue-neutrally onto natural resources from labour (Common and Stagl, 2005, 419, 434);
3. computing, on the basis of an income effect, relatively low energy-efficiency rebound because marginal expenditures will likely be less energy intensive (Binswanger, 2001, 126);
4. bookkeeping for UNFCCC country inventories that takes the energy intensities of exports and imports into account (Helm et al., 2007, 20–21; Peters, 2008);
5. the European Communities' Integrated Product Policy (Kerkhof et al., 2009, 1167).

In light of these implications it is hoped this paper will draw critical examination.

7. Conclusions

We are led by conventional methods of quantifying implied natural-resource consumption per expenditure of a given size to believe that $1000 spent on a concert or painting impacts the environment less than $1000 spent on a flight or a set of cast-iron garden furniture. This paper's analysis of the alternative method of regarding labour as a product requiring natural-resource inputs casts doubt on this. Perhaps no such expenditure is less environmentally intensive than another. Keeping in mind Environmental Input–Output (EIO) analysis's goal of reducing natural-resource depletion, the paper argues for adding labour as an input–output category and holding consumers responsible for the natural-resource consumption entailed by labour's total wages.

For environmental strategy it matters greatly whether the input–output bookkeeping system attributes no natural-resource consumption to a work-hour, as in conventional EIO, or pro-rates one's total lifetime consumption to that hour, as here suggested. Since shifting expenditures to sectors computed to have higher labour intensity entails correspondingly greater *indirect* resource use – for households to produce labour-hours – the case is strengthened for consuming and producing *less*, rather than merely *differently*. While it is widely accepted that at least metabolism, working-clothes, commuting and energy embodied in the workplace could be atttributed to labour as such, this cannot be done if the EIO system used to rank economic sectors according to their environmental intensity lacks a labour sector in the first place. An alternative matrix, with a labour sector receiving its share of resource consumption, reveals that the economic sectors of national accounts differ practically not at all in energy intensity (Costanza, 1980). Indeed, since labour and resource inputs are commensurable only if monetary metrics are adopted, Mill was moreover probably correct in saying that labour or resource intensities cannot, in real terms, be compared at all.

While much empirical evidence shows strong correlation between GDP and resource use/pollution, there seems to be none between observed structural change to environmentally 'less intense' sectors and lower resource use/pollution – results better explained by a model wherein hiring labour at the rate necessary for the labourer to be willing to work entails consumption at the average level of the society. The paper has therefore pursued a debate truncated in the 1980s over exactly which indirect resource inputs into production should be included to best guide conservation strategy and concludes that we must choose between the painless strategy of shifting expenditures and the tougher one of less absolute resource consumption, achieved either voluntarily or by caps or taxes.

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Appendix I. Countable inputs to labour

If we accept labour (row) and households (column) as additional sectors or industries in an inter-industry matrix, what embodied natural-resource inputs could we count? Imagine a pure 'service' (labour) sector of receptionists or masseurs. Most items are taken from the literature, and the list moves from the minimal to the maximal ends of a spectrum.

1. Basic metabolism (desk job)
2. Physical exertion (carpenter, athlete)
3. Workplace: building, heating, lighting, water
4. Commuting
5. Special (e.g. protective) clothing
6. Education and training
7. Sleep in a house
8. Bodily repair and care (teethbrushing, haircut, medical care, holiday)
9. Fun, psychological repair and care (games, books, art, religion)
10. Furniture, cutlery, briefcase
11. Beauty (clothes, body, landscape, flowerbeds)
12. Tools (hammer, laptop)
13. Offspring
14. Institutions (physical infrastructure, laws, government, charity)

Part of any payment recorded in EIO goes directly for wages and salaries; for the same reason that steel entering a factory is 'accountable for' its embodied energy, paying a wage entails a worker's total embodied energy. How many of the listed items should be counted? A reasonable rule is that if what a wage purchases is a *necessary condition* for an hour's work to be done, it should be counted and moreover attributed to the wages part of the expenditure.

Appendix II. Incorporating a labour sector into input–output tables

Tables 3–5 show radically simplified transactions matrices with inputs and outputs in energy units. Table 3 is a conventional table with only 2 sectors. Table 4 divides each cell (arbitrarily) in half, the lower figure attributed to labour and the upper to all other deliveries to or inputs into the sector and measuring embodied energy conventionally. Parallel to standard treatment of joint products, this treats joint *inputs* and applies Herendeen's insight that "every economic sector pays wages… and these expenditures are a large fraction… of the total". (1981, 617). Table 5 alternatively attributes these quantities to the new row and new column entitled 'labour' whose cells can be seen as quantities previously exogenous – the 'employee compensation' part of value added and the 'household consumption' part of final demand. Energy outputs equal energy inputs; they are re-distributed rather than counted again. If the treatment of primary energy sectors can be resolved, future work should update Costanza's (1980) similarly expanded matrix – where net output is not GDP but capital formation – using real, international data.

Table 3
Transactions table in energy units.

	Sector 1	Sector 2
Sector 1	10	25
Sector 2	20	10

Table 4
Transactions table with energy disaggregated into energy related to labour and that from other 'inter-industry' sources.

	Sector 1	Sector 2
Sector 1	5 / 5	12.5 / 12.5
Sector 2	10 / 10	5 / 5

Table 5
Expanded transactions matrix with a labour sector.

	Sector 1	Sector 2	Labour	Total energy output
Sector 1	5	12.5	17.5	35
Sector 2	10	5	15	30
Labour	15	17.5	0	32.5
Total energy input	30	35	32.5	

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