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A simple extension of dematerialization theory: Incorporation of technical progress and the rebound effect

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ABSTRACT

Dematerialization is the reduction in the quantity of materials needed to produce something useful over time. Dematerialization fundamentally derives from ongoing increases in technical performance but it can be counteracted by demand rebound -increases in usage because of increased value (or decreased cost) that also results from increasing technical performance. A major question then is to what extent technological performance improvement can offset and is offsetting continuously increasing economic consumption. This paper contributes to answering this question by offering some simple quantitative extensions to the theory of dematerialization. The paper then empirically examines the materials consumption trends as well as cost trends for a large set of materials and a few modern artifacts over the past decades. In each of 57 cases examined, the particular combinations of demand elasticity and technical performance rate improvement are not consistent with dematerialization. Overall, the theory extension and empirical examination indicate that there is no dematerialization occurring even for cases of information technology with rapid technical progress. Thus, a fully passive policy stance that relies on unfettered technological change is not supported by our results.

1. Introduction

Attempting to answer the basic underlying question and concern of sustainability –whether humans are taking more from the earth than the earth can safely yield- is the main objective underlying the concept of *dematerialization*. Malenbaum (1978) was one of the first researchers in this area and his key results are still among the most important. He utilized the concept of intensity of use defined as the ratio of the amount of materials (or energy) measured in bulk mass divided by GDP. When plotting intensity of use over time, he found "inverted U curves" peaking at different times in different countries (and for different materials) but at roughly a given GDP per capita for given materials. Also importantly, the peak intensity for a given material reached by subsequently developing countries decreases over time (relative to earlier developing countries). These two regularities are the essence of the conceptual basis for the "theory of dematerialization" according to Bernardini and Galli (1993). These authors speculate that the decreasing maximum intensity over time with usage of materials/energy per GDP might be a positive signal of a real dematerializing trend, but they eventually conclude that the empirical information at that time (1993) were insufficient to draw such a conclusion and suggest further examination of data.

Given the potential importance of the overall sustainability question, it is not surprising that there has been significant valuable work from the dematerialization perspective (see the next paragraph) and other perspectives, as for instance those claiming the urgent necessity of abating economic growth [the so-called 'degrowth' strategy, among whom are differing perspectives such as Knight et al. (2013), Turner (2008), Davidson et al. (2014), and Lamb and Rao (2015)].

From the dematerialization perspective, there has been significant work since Malenbaum. Dematerialization, is often defined as the reduction of the quantity of stuff and or energy needed to produce something useful and is then often assessed by a measure of intensity of use or throughput (consumption/production of energy and/or goods per GDP). Some of this research, Ausubel and Sladovich (1990) and Ausubel and Waggoner (2008), is encouraging emphasizing continuing decreases in consumption as a fraction of GDP. However, other researchers [Ayres (1995), Schaffartzik et al. (2014), Senbel et al. (2003), Schandl and West (2010), are not as encouraging about continuation of economic growth with global dematerialization. Among discouraging papers, Allwood et al. (2011) and especially Gutowski et al. (2013) call for much more attention to reducing the amount of material needed to fulfill a given function (referred to as "materials efficiency") and point out that decreasing usage of materials as a fraction of GDP is not sustainable unless absolute decreases in materials use occurs. The very recent and extensive work of Pulselli et al. (2015), presents a very interesting 3-dimensional analysis (resources, organization, and

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products/services) with which the authors scrutinize 99 national economies and conclude that no country is evidencing a dematerialization of economic activity, pointing out also that non-sustainable economic activity can take place over a wide range of income distributions.

There has also been extensive research on a closely related issue- usually called the Environmental Kuznets Curve (EKC). The EKC states that *emission of pollutants* follow a inverted U curve as affluence increases.[1] Despite this being a relative and not absolute comparison, the concept was very positively viewed by some starting in the early 1990s [Grossman and Krueger (1991, 1994), IBRD (1992)] as offering the strong possibility that emissions and pollution would not choke off economic growth but that economic growth might instead help eliminate pollution. However, the generality of the EKC has been seriously challenged on empirical, methodological and theoretical grounds [Stern et al. (1996), Stern (2004), Kander (2005)].

Although the two issues, dematerialization and EKC analysis, differ in what is being considered, many fundamental issues are similar if not equivalent. Both discuss inverted U curves (in the first case of materials usage per capita, and in the latter of emissions) as affluence (GDP per capita) increases. Indeed, the term EKC has been also applied to dematerialization research (Canas et al., 2003) and a fundamental linkage was discussed by Kander (2005):

> "However, it is in principle true that economic growth may be reconciled with environmental concerns if dematerialization takes place."

Kander also establishes a strong base for skepticism concerning a suggested cause of such inverted U curves. She shows that the transition to a service economy does not necessarily lead to less industrial production, and supports her argument theoretically (using Baumol's insight about service growth as a portion of the economy being due to smaller productivity gains than industrial production) and empirically using data from 1800 to 1980 for Sweden. Kander also suggests that the analysis of EKC by Stern (2004) can be applied to the dematerialization issue. Performing such an analysis, she concludes that changes in output mix are minimal (and in the wrong direction) and that the progress made in Sweden is at least partially due to politically determined changes in fuel mix.

The analysis in the present paper focuses on technological change (which Kander indicates may have also contributed to the Swedish EKC.). A key goal of the simple theoretical extension presented here is to allow a broad set of cases to be examined concerning the absolute level of dematerialization achieved. The analysis and cases will deal with global consumption and not national consumption that would involve consideration of trade. The theory of dematerialization is extended by explicit consideration of the ongoing technical progress on dematerialization. We do not treat substitution among technologies in this simple extension, nor do we treat structural change in the economy and we do not directly treat recycling. Instead, we focus on the direct effect of technological change over long periods of time. However to do this requires that we also consider a highly researched issue- rebound, more widely known as the Jevons' paradox.

The paradox was first studied by Jevons (1865) and asserts that *energy* use is increased rather than decreased when more efficient energy technologies are introduced. This "paradox" is also known as the Khazzoom-Brooks postulate [Khazzoom (1980), Brookes (1984, 2000)], is also sometimes called backfire, and sometimes take back as well as rebound. The terminology is complex partly since an important issue is how much of the energy efficiency is essentially overwhelmed by increased energy consumption (backfire is the term used when improved energy efficiency results in increased (rather than decreased) energy consumption. Jevons as well as Khazzoom, Brooks and others argue that this strong effect is inevitable. In this paper, we are essentially adding some new approaches to examining whether technological progress relative to material usage does or does not lead to backfire for materialization- that is whether improvement in technical performance over time increases rather than decreases material consumption on an absolute global basis. Davidson et al. (2014) identify this issue in their analysis of the increasing impact of resource use over time (which they refer to as the 'effort factor'). Although there have been and continue to be authors who deny the rebound effect (especially the strongest or backfire result), there has been extensive theoretical work showing that the effect (Khazzoom-Brookes or Jevons) is at least a reasonable hypothesis (Saunders, 2000, 2005, 2008) and various systemic studies [Alcott (2005), Sorrel (2009), Schaffartzik et al. (2014)], have tended to support the reality of such effects.

However, Section 4 in Sorrel (2009) opens with the following statement:

> "Time-series data such as that presented in Table 1[2] are difficult to obtain, which partly explains why relatively little research has investigated the causal links."

In addition to the theoretical contribution of the paper in quantitatively treating the effects of technological change and rebound to our best knowledge for the first time, this paper also significantly expands the number of empirical cases (time series data) that have been analyzed for technical change and dematerialization. Although the additional cases involve materials and technologies, they have wider interest concerning the interplay of technological progress and rebound. Since energy is arguably more important to the economy than specific diverse materials (Sorrel, 2009), dematerialization in specific materials should be possible even if backfire occurs generally for energy technology. On the other hand, if rebound overcomes technological progress in numerous specific dematerialization cases, Jevons' paradox and authors who have supported it receive important additional supporting evidence.

2. Dematerialization theory extension

As stated before, in this work we extend the theory of dematerialization by explicit consideration of two important factors that can enhance and/or mitigate the dematerialization process: i – the ongoing improvement in technical performance; ii – the rebound effect. We only consider cases of specific materials (or physical devices) and whether technological progress leads to an actual decrease over time in utilization of the materials.

In order to analyze dematerialization quantitatively the following measures will be considered:

1- the rate of change of per capita materials consumption – dm_c/dt or dm_{ci}/dt for a specific material, where c denotes the per capita measure and i some specific material/technology.
2- the rate of population growth – dp/dt
3- the rate of growth of GDP per capita – dG_c/dt
4- the yearly *relative* increase of technological performance, defined as k and as k_i for a specific technology, i.
5- the demand income elasticity ε_{di} for goods and services, defined as relative increase in consumption of i divided by the relative increase in national income
6- the demand price elasticity, ε_{dpi} is the relative increase in consumption of i divided by the relative decrease in price of the good or service
7- the rate of change of cost of a good or service with time, dc_i/dt, the rate of change of the performance of the good or service with time, dq_i/dt and the rate of change of demand for a good or service with time, dD_i/dt.

[1] Although Kuznets did not discuss pollution or emission effects, his name is used since he postulated a similar inverted U shape for income-inequality as a function of affluence-GDP per capita.

[2] referring to lighting data from the UK given by Fouquet and Pearson (2006)