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Extrapolation or saturation – Revisiting growth patterns, development stages and decoupling

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ABSTRACT

The contemporary debate considering the use of natural resources in economic growth centres around the concept of 'decoupling' driven through improvements in resource efficiency. Many studies extrapolate future demand from a short time series of previous years. However, we believe there should be greater attention on the underlying demand assumptions and the possibility of long-term changes. Accordingly, this paper is concerned with a potential saturation in material use as a result of countries moving through stages of development over decades from early industrialisation, over mass production and into a mature stage. An observation of such saturation is relevant for global environmental change as future demand for resources could be lower than currently expected, leading to less associated environmental pressures. In particular, emerging economies are undergoing changing growth patterns, and their future resource use may be significantly lower than contemporary analysis suggests.

This paper combines the analytical strands of resource economics and material flow analysis. It investigates both material-specific demand and stock build-up trends over an extended time horizon of a century. Four materials (steel, cement, aluminium and copper) are analysed applying an indicator called 'Apparent Domestic Consumption' (ADC) and using international trade data for four industrialised countries (Germany, Japan, UK, USA) together with China as the most preeminent emerging economy.

Our results confirm the occurrence of a saturation effect for most materials considered. While the evidence is strong for the per capita apparent consumption of steel, copper and cement in the four industrialised countries, it is somewhat weaker for aluminium. Also, such saturation in material use can start at different income levels, with the saturation beginning to occur relatively early for steel and cement ($12,000 GDP/capita) and later for copper ($20,000 GDP/capita). The results suggest a time gap of around thirty + years from the take-off of large-scale adoption of one type of material and any saturation occurring. We also shed light on the build-up of stocks in the economy, where our findings suggest there is a delayed saturation of at least twenty years compared to apparent consumption depending on the lifetimes of capital goods.

With regard to China, a demand saturation for steel and copper has already started to occur, and our analysis suggests such saturation will soon take place for cement. These findings provide a more moderate outlook on China's future material demand compared to an extrapolation of recent dynamics.

Our new insights on the nexus between economic growth, development stages and the use of natural resources have implications for the decoupling debate and for investments into commodities. From a wider environmental policy perspective, one may expect China and other emerging economies to achieve a saturation effect soon and therefore also peak their industrial emissions of greenhouse gases, supporting the nationally determined contribution (NDC) to the Paris Agreement on Climate Change.

1. Introduction

The turmoil encountered in Chinese stock markets during 2015–2016 can be viewed as part of a broader picture about fundamental uncertainties related with growth expectations for emerging economies and the world economy as a whole. Although changes in growth rates are due to a number of factors, one important driver relates to commodities and the consumption of natural resources. There

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is an interest in understanding how different future socio-economic pathways may accelerate the use of resources as well as how resource prices may feedback on to growth rates. Recent studies suggest the world economy could double the amount of global extraction by 2050 compared to 2015 (UNEP, 2016: 10;Schandl et al., 2016), or a tripling compared to 2010 (UNEP, 2011: 28f), although with a great level of uncertainty.

One fundamental issue is whether the Chinese economy will shift toward a more service- and consumption-based economy. If so, Chinese production may well increase its resource use at a slower rate compared to previous increases, or perhaps even experience an absolute reduction at a certain stage. There appears to be a clear acknowledgement that, in policy terms, the implications of development stages for resource futures require further attention. It is therefore pertinent to ascertain what the impacts of changes in growth and materials use and stocks will be on the overall demand for natural resources and the wider economy?

This transition in a country's structure is often referred to as decoupling the use of resources from GDP. The International Resource Panel calls it the "imperative of modern environmental policy" (UNEP, 2017: 14). With a view to emerging economies such as China, however, it appears that the contemporary debate has to reconnect with nuanced analysis on a saturation effect, i.e. a deeper understanding of development stages and the intensity of material use over time as put forward by Malenbaum (1978) and summarised by Cleveland and Ruth (1998). Insights into a saturation effect are relevant for global environmental change as the future demand for resources may be considerably lower than expected, leading to less associated environmental pressures. In particular, emerging economies are changing their growth patterns, and their future resource use may be significantly different from what the contemporary analysis suggests.

A key issue is to adopt a long-term view. Any analysis which is looking ahead to 2030 – when the SDGs ought to be delivered – or 2050 and beyond requires analysis of previous decades to understand how countries have already developed. Such analysis should include the period after WWII when growth rates in most industrialised countries were remarkably high and, if possible, the entire last century to account for the build-up of infrastructures. Research should not adopt a year such as 1990 as a starting point for decoupling analysis or for extrapolations (which is the base year of the UNFCCC and some databases e.g. Wiedmann et al., 2015) as limitations for analysing structural changes and foresight are obvious.

Under such a circumstance, this study aims to identify the levels in economic development after which the use of key materials saturates or even declines. Our article analyses the use of four refined materials (steel, cement, aluminium and copper) in four industrialised countries (USA, UK, Germany, and Japan) and China over the 1900–2013 timeframe. In order to include the embodied imports in semi-finished and finished goods, we move away from a focus on production towards one on 'Apparent Domestic Consumption' (ADC) by including the material intensities of key product groups and internationally traded commodities. Adopting a conventional production view on those materials would imply that countries which rely on net physical imports to cater for their domestic demand appeared to perform well in terms of decoupling, while in reality they are simply shifting elements of their production base abroad. Our indicator 'Apparent Domestic Consumption' (ADC) is able to give a more nuanced view where such bias is minimised. We also use this method to estimate the build-up of stocks. The underlying questions are:

- Is there a trend in those developed countries toward a saturation of demand for materials and can a value for such saturation levels be estimated? What are the trends for China? What are the development patterns of the build-up stocks in industrialised countries and is there evidence of a material-specific stock saturation?
- How can the projections of material consumption in emerging economies be informed by a potential stock saturation in developed economies? What evidence can be given for a time gap of material consumption between developed and emerging countries given their heterogeneous development stages?

In order to answer such questions, an integrated approach that combines the strengths of different methods should be adopted. We follow an international life-cycle perspective of using materials that is specific to Material Flow Analysis (MFA) and industrial ecology. However, considering our focus on refined materials and not on raw materials (e.g. iron ore, bauxite), we adopt the 'Apparent Domestic Consumption' (ADC) indicator employed in other cross-country steel use studies (Wårell, 2014; Pauliuk et al., 2013) and apply it to four materials in five countries. Terms and methodological differences are explained below. We also consider income per capita over time measured in real terms as we intend to gain insights for future research on modelling socio-economic pathways. The authors acknowledge some inherent limitations, as possible substitutions are likely to be overlooked (e.g. increased applications of plastics), and analysing resource productivity in general requires the inclusion of feedback effects using more comprehensive data and relevant issues such as the rebound effect. Future research will be able to use our approach and fill those gaps. The wider picture of shedding light on future demand of emerging economies for macro-economic modelling purposes, and the delivery of the SDGs (in particular SDG 12 on sustainable resource management) encourages such a study.

The structure of the paper is as follows. After this introduction section, Section 2 briefly reviews the debates on intensity-of-use, decoupling, and metabolism in the broader context of growth and resources. Section 3 describes our research methodology. Section 4 presents our research results and Section 5 discusses these findings. Finally, Section 6 draws research conclusions and provides policy implications for future infrastructure investments in emerging economies. Additional information on the material intensity data and a sensitivity analysis is given in the Supplementary information files.

2. A short review on growth and resources

A number of growth theories emerged from the 1950s. Among them Rostow (1960) developed a growth theory covering different development stages which posits that all economies experienced various transformations from early take-off to industrialisation and then move towards mature economies where services and consumption are the dominant patterns. Although this proposition was contested by other development and growth theories, it reappeared in the 1970s, with a focus on 'limits to growth' (Meadows et al., 1972) along with the unprecedented price peaks for energy and other commodities. Rostow also argued against any evidences of scarcity for raw materials and pointed at innovation as well as at the decline of the rate of raw materials use in relation to increases in real income in the more advanced industrialised nations (Rostow, 1978: 616).

An 'intensity use' hypothesis was developed by Malenbaum (1978), and further elaborated by Tilton (1985) and Auty (1985), adding empirical evidences for a number of materials across different countries and time periods. However, the overall findings on whether materials intensity per GDP declines with economic maturity remained ambiguous at that time. The basic concept was seen as vaguely defined because the data and measurement efforts had several limitations which did not yield unequivocal results, and the underlying drivers were still unclear. Later, with emerging input-output data, it was concluded that future research should be based on better and more comprehensive data (Auty, 1985). Cleveland and Ruth (1998) conducted a further survey on the state of this debate. However, research progress has been limited, with few contemporary publications explicitly referring to a saturation level. Although Tilton and Guzmán (2016) published a textbook on mineral economics and policy, they did not conduct any analysis on such issues. Wårell (2014) investigated the intensity-of-use hypothesis

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