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ORIGINAL PAPER

Intensity of use reexamined

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Abstract The intensity of use hypothesis is widely used both as an explanation of trends in materials consumption over time and as a predictive tool. The paper examines significant weaknesses in the data normally used to test the hypothesis. An examination of long-term trends in the intensity of apparent first use of aluminium, copper and steel in eight countries shows a tendency for usage per unit of GDP to follow an inverted *U* shape as per capita GDP increases. Cross country comparisons for individual years do not demonstrate such a relationship. Apparent first uses are not always good guides to actual consumption, and the weaknesses in the data are discussed. Per capita GDP is only one influence on materials usage, and the paper looks at other factors, and most notably at the structure of both output and expenditure. China's intensity of use appears anomalous, raising questions about future trends in its materials usage. Avenues for future research are outlined.

Keywords Intensity · Hypothesis · Consumption

Foreword
This paper is respectfully and affectionately dedicated to Marian Radetzki as he approaches his 81st year. Age cannot wither, nor custom stale, his infinite variety of interests in the energy and mineral industries (with apologies to William Shakespeare).

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Introduction

The intensity of use hypothesis[1] states that there is an inverted U-shaped relationship between the amount of a material used per unit of output, or its intensity of use, and the level of economic development, as reflected in gross domestic product (GDP) per capita. The existence of such a relationship was first suggested by Wilfred Malenbaum in the context of steel demand.[2] "At the early stages of economic growth when per capita income levels are low, material requirements are also low, for such economies are based largely on unmechanized agriculture. As industrialization occurs, manufacturing, construction, and other material-intensive activities expand. As development continues, however, the need for houses, factories, roads, automobiles, and machinery gradually is satisfied, and consumer demand increasingly shifts toward services. The service sector, it is argued, is less material-intensive than the manufacturing and construction sectors, so this shift in consumer demand leads first to a slowing and eventually to a reversal in the upward rise in intensity of metal use as per capita income advances."[3]

The hypothesis is widely used both as an explanation of trends in materials consumption over time and as a predictive tool. It has been tested on a range of metals over different time periods with a variety of statistical techniques. Nearly all these published studies look at trends in the intensity of first use of

[1] Also known as the material Kuznets Curve.
[2] International Iron and Steel Institute (1972), Projection 85: World Steel Demand, Brussels, 1972.
Malenbaum (1978). World Demand for Raw Materials in 1985 and 2000, McGraw-Hill, New York.
[3] Radetzki and Tilton (1990), in World Metal Demand: Trends and Prospects, Resources for the Future, Washington.

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individual metals in a variety of developed countries from the 1970s onwards.[4] It would be invidious to single out any one study, but this paper argues that the underlying foundations of data on which most are based are inherently weak. This paper is not concerned with elaborating the underlying theory, nor in developing appropriate statistical tests. No matter how statistically significant relationships may appear, their economic significance may be poor. They cover too short a time span, ignore important structural changes in trading relationships of recent decades and first use may be a poor guide to true usage within an economy for a variety of reasons.

The paper starts off by setting the scene in showing long-term trends in the intensity of first use of aluminium, copper and crude steel for selected countries over a much longer time period than other studies have used. It then makes cross-sectional comparisons across countries for finished steel and cement before going on to examine the various weaknesses in the generally used data for metals usage, with reference to aluminium, copper and steel. It then looks at some of the factors that may complicate any simple relationship between usage of materials per unit of GDP and per capita incomes, as reflected in GDP per head. The broad conclusion is that, with the present limitations of data, the explanatory power of the intensity of use hypothesis is limited and that it cannot be a reliable tool for forecasting. The paper concludes with some suggestions for further research to improve the basic data and to elaborate the simple hypothesis.

Longer-term trends in aluminium, copper and steel

In examining the longer-term trends, it is tempting to concentrate on developed economies for which the published data are generally more comprehensive than for other nations. Many of the cited studies do concentrate on such countries. Unfortunately, the progressive economic integration of European economies since the signature of the Treaty of Rome in 1958 means that their usage of primary materials, the starting point for analysis, has become increasingly divorced in some instances from their final consumption of those materials. The UK's negligible usage of 23,000 tonnes[5] of refined copper in 2015, for example, does not accurately measure the amount of copper actually used in the country. Analyses for individual European countries will all have been distorted in varying degrees by their progressive integration, and this distortion is generally not picked up by any of the published studies. The same difficulties do not apply to Japan or the USA to anything like the same extent.

Another concern is the time span of many studies, most of which go back only to 1970, or the late 1960s. The per capita incomes of most developed economies and, indeed, of many emerging or developing countries, and their usage of materials per unit of output were then already well advanced. Subsequent trends seldom capture the full progression of materials usage relative to per capita incomes and longer time series are needed not only for developed economies but also for other nations.

Figures 1, 2, and 3 show the relationship between per capita GDP in constant prices and the usage of primary aluminium (Fig. 1), crude steel (Fig. 2) and refined copper metal (Fig. 3) per unit of GDP for eight countries. These are the USA, Japan, Korea, Taiwan, China, Malaysia, Brazil and Mexico. The sources and methodology are described in Appendix A.

The data for primary aluminium go back to 1900 for the USA, 1960 for Korea and Malaysia, and 1950 for the remaining countries. Those for refined copper also go back to 1900 for the USA and 1950 for Japan, Brazil, Mexico and China. They go from 1951 for Korea and Taiwan and 1980 for Malaysia. The figures for crude steel extend back to 1875 for the USA, 1924 for Japan and Mexico, 1930 for Brazil, 1950 for China, 1951 for Taiwan, 1955 for Korea and 1967 for Malaysia. The series for each country is based on figures for GDP and GDP per capita in national currencies at constant 2010 prices. For comparative purposes, these are converted into US dollars at 2010's official exchange rates.

The patterns of usage vary considerably both between the metals and between countries. The tendency for usage per unit of GDP to follow an inverted U shape is, however, apparent for the three metals and most of the countries. Both the USA and Japan display similar trends in usage per unit of output for the three metals, although Japan's steel usage per unit of output did not reach the same heights as in the USA. The peaks in both countries' usage of primary aluminium came at much higher levels of per capita income than their peaks in copper and steel. The performance of the remaining four Asian economies has differed markedly from that of the two Latin American nations. Malaysia appears to have experienced a much steeper rise in usage per unit of output than Brazil or Mexico, and a more precipitate decline. In Taiwan and Korea, peak usage of copper and steel came at higher per capita incomes than in the USA. Chinese and Taiwanese usage of all three metals per unit of output has greatly exceeded that of the other countries at similar levels of per capita GDP. China also appears to be at a relatively early stage of the transition, especially for aluminium.

Gross domestic product per capita

Over the long periods covered the composition of per capita GDP has changed radically. The goods and services produced

[4] Inter alia Roberts (1996); Canas et al. (2003); Guzmán et al. (2005); Focacci (2005, 2007) Wårell and Olsson (2009); Jaunky (2012); Wårell (2014).

[5] World Metal Statistics Yearbook 2016, World Bureau of Metal Statistics, Ware, Hertfordshire, United Kingdom.

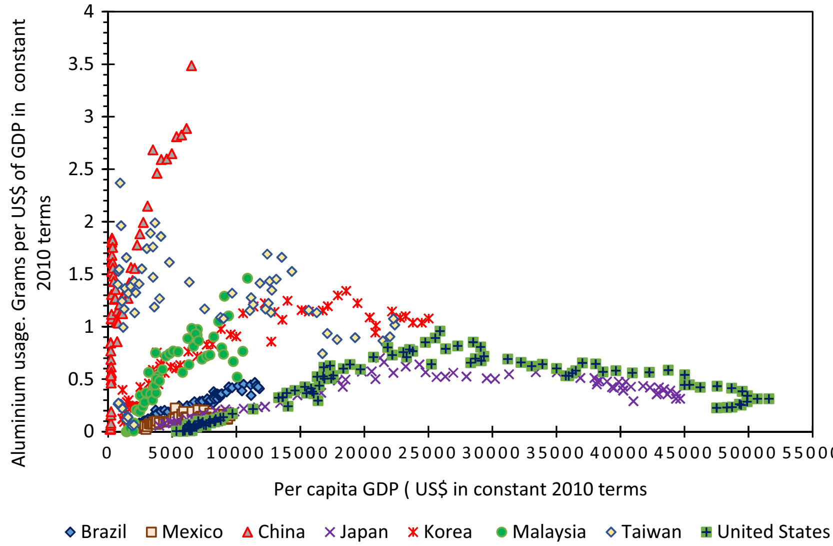


Fig. 1 Primary aluminium usage/GDP and GDP/head in 2010 terms

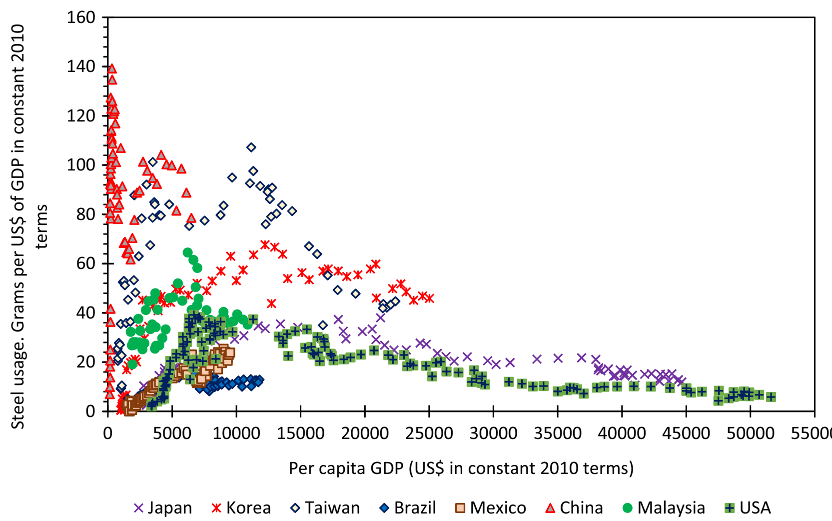


Fig. 2 Crude steel usage/GDP and GDP/head in 2010 terms

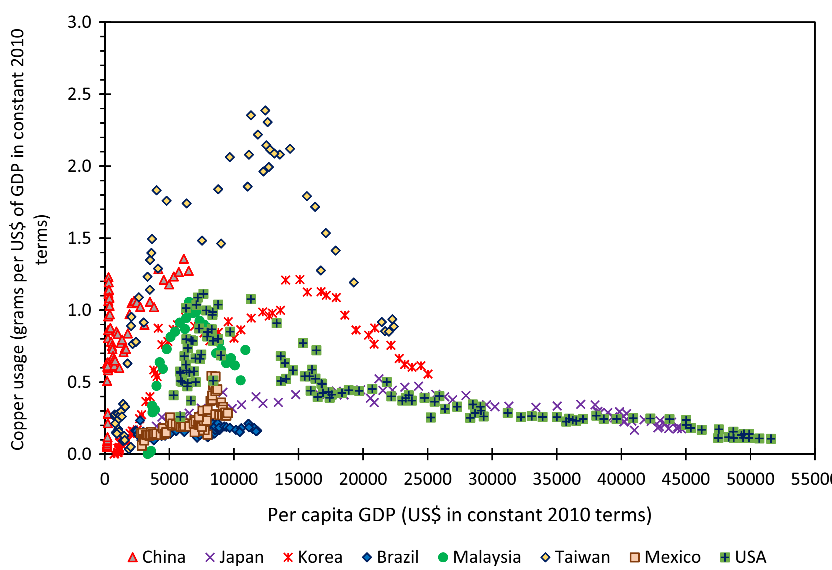


Fig. 3 Refined copper usage/GDP and GDP/head in 2010 terms

and consumed 50 years ago were markedly different in all cases from the present baskets. We shall explore some of the implications later.

Figures 1, 2 and 3 use official exchange rates to convert trends in national currencies to US dollars. These do not always adequately reflect differences in local purchasing power. In general, price levels are much lower in most countries and a dollar buys a bigger basket of goods than in the USA. Purchasing power parity (ppp) exchange rates, by contrast, aim to adjust for differences in price levels that are not reflected in the official rates and provide more realistic comparisons of GDP across countries. As Table 1 shows, usage per unit of GDP is lower and per capita incomes are higher in ppp dollar rates than at official rates. The table gives index numbers based on the US level as 100 in each column. Thus China's GDP per head was only 14.3% of the US level at official exchange rates in 2015, but 25.2% at ppp rates.

Using ppp exchange rates will not affect individual countries' trends in intensity over time, but it does narrow some of the gaps between them.

Intercountry comparisons

One corollary of the tendency for intensity of use to vary with the state of economic development is that a similar inverted U-shaped curve should be apparent from cross-sectional comparisons between countries. Figures 4 and 5, which plot the comparative intensity of finished steel usage and cement production against per capita GDP for a wide range of countries, using ppp exchange rates, show that there is a wide scatter, with no obvious tendency to cluster around an inverted U-shaped curve for either material. Again the sources and methodology are discussed in Appendix A. Production is a reasonable approximation for cement usage because of limited international trade.

Table 1 Comparative GDP/head and steel usage per unit of GDP in 2015 at official and ppp dollar exchange rates, based on the US levels as 100

	GDP/head $		Steel/GDP (grams per $)	
	Official	PPP	Official	PPP
Japan	58.9	68.0	298.7	258.5
Korea	48.5	65.3	778.8	579.0
Taiwan	39.7	83.5	743.3	353.4
Brazil	15.2	27.4	246.3	136.5
Mexico	16.1	31.3	465.7	238.8
China	14.3	25.2	1175.0	666.7
Malaysia	17.4	48.0	725.4	262.7

Source: see Appendix A

The patterns are very different for the two products, demonstrating that each product needs separate analysis and that there is no standard model to describe all materials. The wide scatter not only reflects differences in the natural resource usage of individual countries but it also highlights some of the weaknesses both of international comparisons and of the intensity of use hypothesis. It is these to which we now turn.

Deficiencies in the data

Most analyses of intensity of use are based on first uses of primary metal such as crude steel or refined copper rather than on the amounts of a material actually used in final products within a country. There are several complications. First, the contribution of most secondary materials to usage is not taken into account. Whereas most steel scrap is reprocessed into crude metal that is not the case with many other metals. Certainly, some copper scrap is used in secondary refineries, but by no means all, and primary aluminium is different from secondary aluminium. The shares of unrefined secondary materials in total usage vary widely, both over time and between different countries. In the global copper industry, for example, such directly melted scrap accounted for 24% of total copper usage in 2007 and 18% in 2013.[6] The contribution of scrap tends to be much higher in mature than in developing economies which lack such large inventories of material in use. Unfortunately, the available data are insufficient to show long-run trends in total usage for each country.

Estimates of apparent usage of metals take no account of changes in raw material inventories throughout the production chain. Over the longer-term swings in such inventories are likely to balance out. From one year to another, however, changes in apparent usage are likely to differ from shifts in genuine usage because of such inventory movements. Moreover, as apparent usage is normally taken as production plus net trade no adjustment is made for the build-up of any unrecorded stocks. This means that annual usage may be consistently over-estimated, particularly in China, but also possibly in Korea and Malaysia which host London Metal Exchange warehouse companies that may also store off-warrant metal which is generally not recorded.

The first users of primary metals may not only use directly melted scrap but also they create scrap in their production processes. This may be reused within the same manufacturing plants or sent for reprocessing. Consumption of primary metal in finished products will thus differ from the usage of the primary metals. In this context, finished products mean the semi-fabricated products such as castings, bars, ingots, sheet, rod, wire and other shapes that are used in manufacturing

[6] Source: The World Copper Factbook 2015, International Copper Study Group, Lisbon.

Fig. 4 Cement intensity in 2013

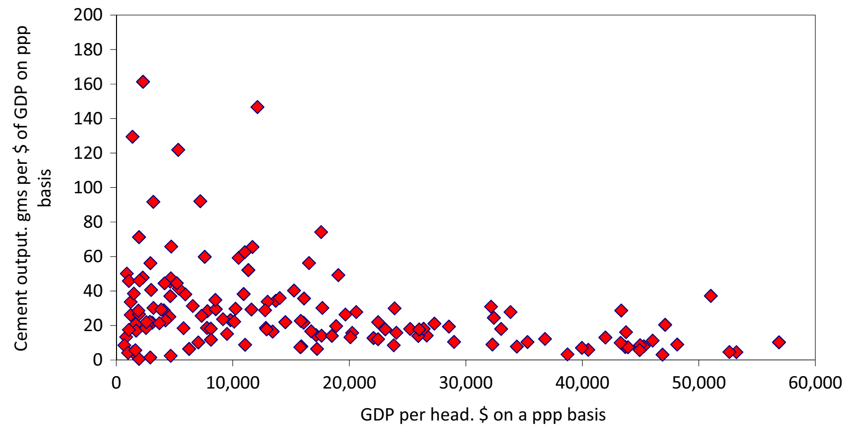
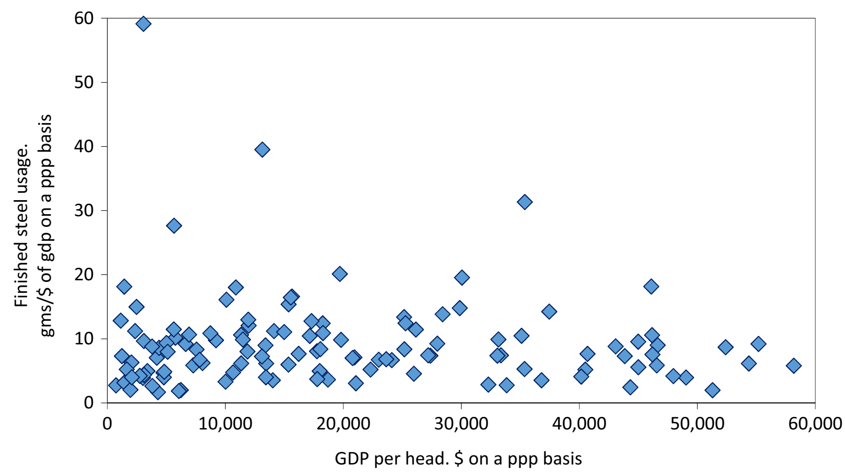


Fig. 5 Steel intensity in 2014



rather than the metal contained in final uses. Changes in fabricating techniques will alter the relationship between the usage of crude metal and finished metal products. For example, the introduction of continuous casting reduced the amount of crude metals required to produce bars and rods. Furthermore, there is considerable trade in semi-finished metals which should be taken into account when looking at the genuine usage of metal within a country. The World Steel Association's estimates of the apparent usage of finished steel take such trade into account.

Table 2 shows how the apparent usage of finished steel has moved as a percentage of crude steel usage in Japan, Korea and China since 1974. In general, the apparent consumption of crude steel, the basis of Fig. 1, has risen less than apparent finished usage, the basis of Fig. 5.

Table 2 Apparent finished steel usage as a percentage of crude steel usage, 1974–2014

	Japan	Korea	China
1974	88.8	61.2	76.9
1984	92.9	84.2	77.9
1994	81.8	94.8	86.5
2004	95.4	96.2	93.0
2014	92.8	96.0	96.0

Sources: Steel Statistical Yearbooks, World Steel Association, Brussels

Similar data are not available for earlier years or for other metals. The statistics of trade in semi-manufactures of both aluminium and copper include not just pure metal but also alloys containing varying proportions of the primary metal. Nonetheless, Tables 3 and 4 show the approximate importance of trade in semi-manufactures of both metals in 2001 and 2015 for the countries coverd by Figs. 1,2 and 3.

The net trade in aluminium semis includes aluminium alloy semis, regardless of aluminium content. In the case of copper, it is arbitrarily assumed that copper alloy semis contain 80% copper. Trade in copper wire rod is included.

Brazil, Japan, Korea and Taiwan have been net exporters of both aluminium and copper semi-manufactures, whereas Mexico is a sizeable net importer. China has swung from being a net importer to an exporter of aluminium semis, and its net imports of copper semis have contracted. Conversely, the USA has moved from being a net exporter to a net importer of aluminium semis and its net exports of copper semis have shrunk. For all countries the intensity of use, adjusted for trade in semis, has shown

Table 3 Aluminium: primary use, net trade in semis and domestic use, '000 tonnes

	2001				2015			
	Primary use	Net trade in semis	Domestic use	Ratio of domestic to primary	Primary use	Net trade in semis	Domestic use	Ratio of domestic to primary
Brazil	552.8	−116.6	436.3	0.79	801.2	−97.6	703.6	0.88
Mexico	113.1	323.2	436.3	3.86	183.9	604.2	788.1	4.29
China	3492.2	247.1	3739.4	1.07	31,068.1	−3796.6	27,271.5	0.88
Japan	2014.0	−212.7	1801.2	0.89	1778.7	−199.7	1579.0	0.89
Korea	849.6	−110.4	739.2	0.87	1365.8	−240.7	1125.1	0.82
Malaysia	152.5		152.5		482.3		482.3	
Taiwan	321.3	−1.9	319.4	0.99	540.5	−15.1	525.4	0.97
USA	5720.0	32.1	5752.1	1.01	5220.0	−263.1	4956.9	0.95

Source: World Bureau of Metal Statistics and US Geological Survey

Table 4 Copper: refined use, net trade in semis and domestic use, '000 tonnes

	2001				2015			
	Refined use	Net trade in semis	Domestic use	Ratio of domestic to refined	Refined use	Net trade in semis	Domestic use	Ratio of domestic to refined
Brazil	336.1	−27.4	308.7	0.92	433.8	−4.6	429.2	0.99
Mexico	421.0	61.5	482.5	1.15	345.0	261.3	606.3	1.76
China	2357.1	720.0	3077.1	1.31	11,353.1	280.9	11,634.0	1.02
Japan	1146.3	−231.3	915.0	0.80	997.5	−156.8	840.7	0.84
Korea	836.0	−431.7	404.3	0.48	704.9	−254.7	450.2	0.64
Malaysia	160.2	41.0	201.2	1.26	239.0	−63.7	175.3	0.73
Taiwan	540.0	−209.2	330.8	0.61	470.9	−227.3	243.6	0.52
USA	2620.0	466.5	3086.5	1.18	1789.0	17.5	1806.5	1.01

Source: World Bureau of Metal Statistics and US Geological Survey

different trends from the unadjusted totals used in Figs. 1, 2 and 3.

Even making allowance for trade in semi-manufactures does not fully adjust the data to reflect purely domestic usage as some metal will be incorporated into exports of manufactures. The World Steel Association does estimate true steel usage, after adjusting for steel incorporated in exports of manufactured goods. Accordingly, Table 5 compares true and apparent usage of finished steel in 2002 and 2014 for our selected countries. Earlier data are not available.

Such indirect exports might possibly be regarded as domestic usage as they reflect each country's economic structure and level of economic development. Yet they do not satisfy domestic needs so that there is no reason why they should rise with per capita incomes. The economies of Korea, Japan and Taiwan are based on exports of manufactures and they will consequently have different patterns of consumption from a country like Brazil. Even ignoring indirect exports, however, the previous comments show that the measures of usage or consumption used in most studies of the intensity of use of metals do not properly reflect the true trends in domestic offtake of materials. The various deficiencies highlighted in

Table 5 True usage as a percentage of apparent usage of finished steel

	2002	2014
Brazil	95.4	109.1
Mexico	105.1	86.1
China	94.6	92.2
Japan	75.4	77.0
Korea	75.1	70.8
Malaysia	105.1	86.1
Taiwan	86.9	85.2
USA	104.8	101.8

Sources: Steel Statistical Yearbooks, World Steel Association, Brussels the data are probably more important than the methods used to calculate what may appear to be statistically significant relationships between per capita GDP and intensity of use.

The nature of the relationship between materials usage and per capita incomes

There is an implicit assumption in the simple model that the relationship between intensity of use and per capita GDP is stable. Relative factor endowments, changes in the pattern of demand, substitution between materials, and above all changing technology will, however, influence the intensity of use. The consequence of the many influences on demand is that intensity of use is liable to shift over time relative to the simple theoretical model. There will be a family of intensity of use curves for each material rather than just one; each based on a given state of technology. The observed data, whether from individual countries over time, or from cross-sectional analyses, will come from different curves.[7]

Substitution and the application of new technology can swamp the impact on intensity of use of the long-term structural changes in the nature of economic activity that underpin the intensity of use hypothesis. Shifts between different curves can be at least as important as movements along the curve as per capita incomes increase. As newer technologies tend to be less materials-intensive than those they replace, the general tendency might be for the observed relationship to shift downwards over time. Technological change and substitution do not proceed steadily in step with changes in per capita income, but in fits and jerks. Moreover, not all innovations lead to falling usage of materials, but they can boost the specific consumption of apparently mature materials. This means that some developments will raise observed intensity of use. The specific usage of copper in automobiles, for example, which was trending downwards in the 1970s and 1980s, has been boosted by the electrification of previously manual operations and by the development of electric vehicles.

Countries at different stages of development will not follow an identical economic path, but will naturally adopt the latest available and lowest-cost technology, regardless of the paths followed by other countries. As Figs. 1, 2 and 3 clearly show, intensities of use have followed radically different paths in different countries, with no tendency for later developers to show the same levels of intensity as more mature economies like the USA and Japan. This runs contrary to the previous paragraphs which imply that their usage per unit of GDP should be lower rather than higher at given levels of per capita GDP.

[0] See Radetzki and Tilton (1990) in World Metal Demand: Trends and Prospects, edited by J Tilton. Resources for the Future, Washington.

We have already noted, in the context of Table 5, that the nature of their productive activities and the structure of their economies will affect each country's intensity of use of particular materials. The economies of Korea and Taiwan, following the earlier example of Japan, have been biased towards the export of metal-based manufactures. Malaysia followed a similar route in the 1990s. China has also rapidly developed its manufacturing sector. Table 6 shows the shares of manufacturing in GDP and in exports for the selected countries in 2000 and 2015.

Those countries with the highest shares of manufacturing in GDP will tend to use more metals per unit of GDP than countries, like Brazil, with much lower shares.

Concentration on the relationship between per capita incomes and intensity of use tends to overlook the importance of a country's geographical area and population in driving its patterns of demand. Proportionally, more infrastructures of all types will probably be required in larger than in smaller countries to service a given level of per capita income, regardless of their levels of development. Table 7 accordingly compares land areas and populations for our sample of countries.

Obviously land area alone is a very coarse measure of a country's size, as the proportion of usable land varies widely. Much of Brazil, for example, is still tropical forest. Moreover, size is not everything, as witnessed by Korea and Taiwan. It should not, however, be completely overlooked when examining materials usage. China's large size and population may well partially explain why its intensity of use appears very high at low levels of per capita income in Figs. 1, 2 and 3.

Another very important factor is the way in which GDP is allocated between different types of expenditure. Spending on construction and infrastructure is more materials-intensive than other categories of expenditure apart from military hardware and consumer durables. Accordingly, the intensity of use of metals, and especially of the three covered in this paper, will be strongly influenced by levels of investment, by the share of gross fixed capital formation in GDP. This is shown for 2000 and 2015 in Table 8 for our sample.

In all countries save China, the shares were lower in 2015 than in 2000. The two extremes are the relatively low share of investment in Brazil and the very high share in China. The tendency of developing economies to devote a high share of income to investment in the early stages of economic growth and then switch more to consumption underpins the intensity of use hypothesis. China has not yet made that transition and its heavy bias towards capital expenditure helps explain trends in its intensity of use of materials.

Figure 6 relates the usage of crude steel not to GDP but to gross fixed capital formation (GFCF). It compares total usage of crude steel per unit of GFCF with GFCF per capita from 1960 onwards for all the sample countries except the USA. Taiwan's pattern differs from most others for much of the period, probably in reflection of its dependence on the export of manufactures.

Table 6 Percentage shares of manufacturing in GDP and exports, 2000 and 2015

	Share of manufacturing in GDP		Share of manufacturing in exports	
Brazil	15	11	58	38
Mexico	20	18	83	83
China	32	30	88	94
Japan	20	18	94	88
Korea	29	29	91	90
Malaysia	31	23	80	67
Taiwan	26	30	n.a.	n.a.
USA	16	12	83	64

Sources: World Development Indicators, World Bank, and National Statistics, Republic of China (Taiwan)

n.a. not available

On this admittedly arbitrary basis, China's experience above very low levels of GFCF per capita has been much more in line with other countries' experience. The importance of capital spending to China's steel usage is highlighted by Fig. 7 which gives index numbers, based on 1990 as 100, of the development of usage per unit of GDP and of GFCF annually since 1960. Both series show cyclical fluctuations, but the latter has trended downwards from the late 1960s, whereas usage per unit of GDP has followed a different path.

Concluding comments

The paper has solely examined historical data and has not strayed into prediction. It does, however, implicitly raise questions about future trends in materials usage, particularly in China. One important message is that projections based on simple relationships between usage and per capita GDP, although often used, are likely to prove misleading.

More immediately, the paper's main thrust has been to draw attention to the many deficiencies in the basic data that are normally employed to illustrate and confirm the intensity of use hypothesis, no matter how sophisticated the statistical techniques used. It has also pointed out that the progression of per capita income is only one influence on the development of materials usage. Many of the other influences may not be directly, if at all, correlated with per capita GDP. If the intensity of use hypothesis is to become anything more than an expositional device there is a need to broaden analysis to include more variables than per capita incomes. This paper has highlighted several possibilities that might offer avenues for detailed research.

Research is also needed to determine the full impact of European integration on materials usage in the European Union's individual member countries. This would not pose such a problem if the basis of analysis could be widened from first use to account for the various complications discussed in the paper. Although trawling through statistical archives is often boring and time-consuming that is essential in order to provide a sounder basis for analysis than reliance on the first use of metals over the past 30 or 40 years. Certainly, as shown in Figs. 1, 2 and 3, it is possible to take the data back much further than is usually done by examining historical trade and production statistics for individual countries. Some of the other weaknesses identified can also be remedied, at least partially, by detailed research into the available data. That this is not always readily accessible, and is rarely digitalised, is a challenge rather than an insuperable barrier.

Table 7 Land area and population in 2015

	Land area ('000 sq. km.)	Population (millions)
Brazil	8512	208
Mexico	1973	127
China	9561	1371
Japan	378	127
Korea	99	51
Malaysia	333	30
Taiwan	36	23
USA	9373	322

Sources: Pocket World in Figures, 2010 Edition, The Economist (2010), London, and World Economic Outlook Database October 2015, International Monetary Fund, Washington

Table 8 Percentage shares of gross fixed capital formation in GDP, 2000 and 2015

	2000	2015
Brazil	19	18
Mexico	23	23
China	34	46
Japan	27	24
Korea	33	28
Malaysia	27	25
Taiwan	26	21
USA	24	20

Sources: World Development Indicators, World Bank, and National Statistics, Republic of China (Taiwan)

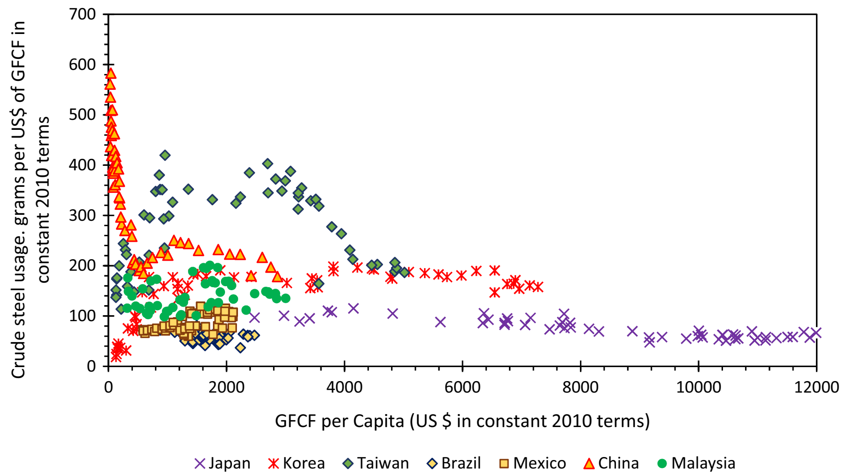


Fig. 6 Crude steel usage/GFCF and GFCF/Head in 2010 terms. Source: See Appendix A

Appendix A

Sources and Methods

The paper has drawn on a wide range of sources for the data underlying the figures.

Figures 1, 2, and 3: US *metals usage* from the US Geological Survey's Historical Statistics for Mineral and Material Commodities in the USA, data series 140. https://minerals.usgs.gov/minerals/pubs/ds05-140/. *GDP and* per capita *GDP* from the Bureau of Economic Analysis's (2017) National Income and Product(NIPA) tables and from Historical Statistics of the United States, and *population* from the Bureau of the Census.

Other countries' *apparent usage of crude steel*, *finished steel and true usage* from successive Steel Statistical Yearbooks of the World Steel Association (n.d.). The data only go back to 1969. For earlier years' estimates of apparent crude steel usage are made from the statistics on production, imports and exports contained in successive issues of the Statistical Summary of the Mineral Industry, World Production, Exports and Imports, and its predecessors published by the Institute of Geological Sciences (IGS) [now British Geological Survey BGS)], London.

http://www.bgs.ac.uk/mineralsuk/statistics/worldArchive.html.

Usage of refined copper from 1950 from Metallstatistik (n.d.), successive issues, Metallgesellschaft AG, Frankfurt, and International Copper Study Group (n.d., 2016), Lisbon. Earlier years estimated from production and net trade from IGS/BGS, as for steel.

Usage of primary aluminium from World Metal Statistics Yearbooks, successive issues, World Bureau of Metal Statistics, Ware, England, and from Metallstatistik (n.d.), successive issues, Metallgesellschaft AG, Frankfurt., with earlier years from IGS/BGS.

Population back to 1960 from World Development Indicators, World Bank, Washington (www.worldbank.org), and World Economic Outlook Database, successive issues, International

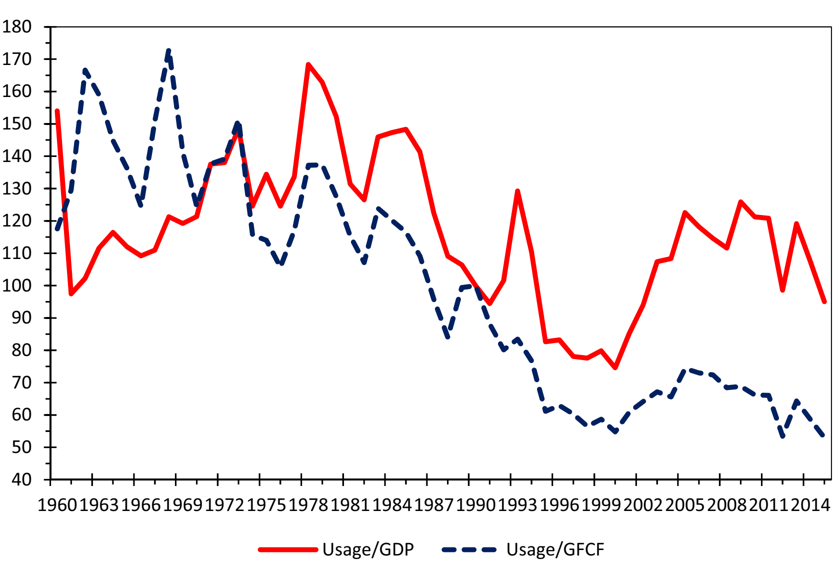


Fig. 7 Index numbers of China's usage of crude steel per unit of GDP and of GFCF, 1960 to 2015, (1990 = 100). Sources: See Appendix A

Monetary Fund. Washington (www.imf.org). Data for earlier years come from www.Worldometer.info/world-population/.

Gross Domestic Product (GDP) and *GDP* per capita back to 1960 from World Development Indicators, World Bank, Washington, (consulted on March 1st 2017) for all countries except Taiwan. Data in constant local currency units are converted to US dollars at 2010 exchange rates to give figures in constant 2010 US dollar terms. Earlier data are taken from data from the Groningen Growth and Development Centre's Historical National Accounts (www.ggdc.net/ and www.ggdc.net/databases/hna.htm) which update data originally produced by Angus Maddison. Taiwanese data are from World Economic Outlook Databases for April and October 2016, International Monetary Fund, Washington supplemented from Taiwanese sources (National Statistics Republic of China, www.eng.stat.gov.tw).

Figure 4 Apparent use per capita of finished steel products from Steel Statistical Yearbook, 2016, World Steel Association (n.d.), Brussels. Per capita GDP in US Dollars at purchasing power parity exchange rates taken from World Economic Outlook Database, October 2016, International Monetary Fund, Washington. Usage per unit of GDP obtained by dividing per capita usage by per capita GDP

Figure 5 *Cement* production from Minerals Yearbook 2014 (https://minerals.usgs.gov/minerals/pubs/commodity/cement/). Population and per capita GDP in US purchasing power dollars from World Economic Outlook Database, October 2016,International Monetary Fund, Washington.

Figures 6 and 7 The shares of *Gross Fixed Capital Formation* (*GFCF*) in GDP at current prices back to 1960 come from World Development Indicators, World Bank for all countries save Taiwan, whose figures come from the Taiwanese National Accounts (www.eng.stat.gov.tw). These shares are applied to GDP per capita, from the sources for Figs. 1, 2 and 3 to give GFCF per capita. This is divided into per capita usage of crude steel to give crude steel usage per unit of GFCF. One weakness is that the price deflators for GDP and GFCF may follow rather different trajectories, and it would be more appropriate to use the shares of GFCF at constant prices. As the figures are only included for illustrative purposes, any errors are unlikely materially to affect any conclusions.

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