Factors of Material Consumption

by

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Submitted to the
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ABSTRACT

Historic consumption trends for materials have been studied by many researchers, and, in order to identify the main drivers of consumption, special attention has been given to material intensity, which is the consumption of materials (in mass quantities) per GDP per capita. For our analysis, a new factor, material price, has been taken into account when analyzing the consumption of materials. Rather than focusing only in material intensity, material consumption has been studied in comparison to GDP per capita divided by price, which denotes purchasing capability. Furthermore, material consumption is decomposed into different factors and their contribution is determined for five different materials (aluminum, steel, copper, zinc and cement), for the USA, India, China and at the global level, beginning from 1900 until 2005.

For the United States it can be seen that while the consumption per capita vs. purchasing capability shows an initially linearly increasing trend, a drastic slope change occurs posthumously. Similarly, on the global scale, a positive linear trend is observed initially, but is followed by a leveling of the consumption per capita, demonstrating saturation with respect to purchasing capability. On the other hand, the graphs for China and India show an increasing trend throughout the full studied period. Additionally, it has been found that on the second half of the 20th century, the US industry share of the GDP has decreased, as well as the material use within industry, balancing out the increase in population and GDP per capita. China and India on the other hand, show an increase in all factors, hence inducing consumption growth and avoiding saturation.

By identifying the factors that influence material consumption, and to what extent, this work contributes to the understanding of human consumption patterns and enables a better approach to problems associated with resource utilization.

Thesis Supervisor: Timothy Gutowski
Title: Professor in Mechanical Engineering

Table of Contents

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Chapter 1

Introduction

Materials, as well as the energy used to process them, are drawn from finite natural resources, such as ore bodies, mineral deposits and fossil hydrocarbons. While supply limits have not been significant threats from early history, the population growth of the last three centuries has generated great concern about resource depletion. The growth of industrialization has increased the human dependence on materials over the last centuries, and consequently, its environmental impact has begun to reach a global level.

Furthermore, the increased consumption of materials has effects on waste generation. Once they have reached end of first life, products may be incinerated, recycled, reconditioned or reused. These alternatives aim to extend the life of the product or material in question. Many products, however, end up in landfill. This option marks the end of life of the product, and presents environmental, as well as health problems.

For these reasons, the historical consumption of materials has been studied extensively. The global consumption of materials has reached approximately 10 billion tons per year. Figure 1 below shows the breakdown of material usage by category. Ceramics is the most widely used family of materials due to the consumption of concrete for construction purposes. In order to avoid scarcity, and maintain a balance between supply and demand, the understanding and foreseeing of material consumption trends is necessary. [1]

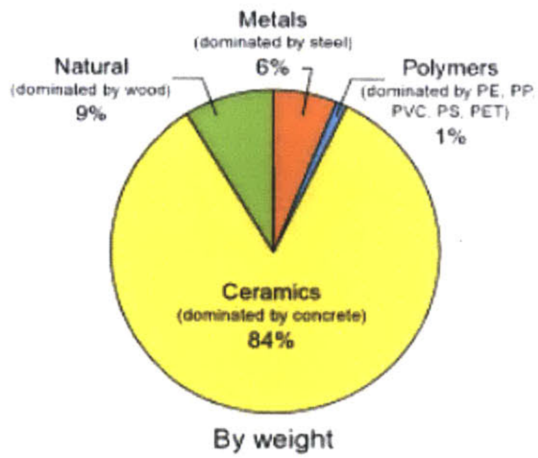


Figure 1 Materials consumption by category (Ashby, 2009)

This study contributes to these efforts. It takes a look at five key materials and analyzes their historical consumption across three nations (USA, China and India) as well as the global trends. The consumption is further broken down into different factors that influence it, and the extent of their contribution to the changes in consumption is quantified and analyzed.

Prior work on material consumption and its drivers, along with material price trends in the United States is presented in Chapter 2. Chapter 3 expands on the methods and analytical tools used to carry out the research and identify the main components of the change in material consumption. The resulting trends for all five materials and four geographic scopes are given in Chapter 4, and are discussed and analyzed. Finally conclusions are given in Chapter 5, along with recommendations for future work.

Chapter 2

Literature Review

2.1 Dematerialization

The concept of *dematerialization* began to be explored by Herman, Ardekani and Ausubel in the 1980s. The term had often been used to describe the decrease in weight of the materials used in industrial end products, or the decrease of "embedded energy" in them. It has also been perceived as the change of the amount of waste generated per product. The question of whether dematerialization is occurring is important from an environmental standpoint as it addresses issues of waste generation and resource availability. However, less material per product may not imply less waste, or less overall consumption, as this may cause more units may be produced due to demand or inferior quality [2]. Furthermore, the interrelation between trends of different materials is important when examining dematerialization from a more macroscopic point of view, as factors such as material substitution play an important role in these trends.

Donald Rogich further studies this point at the level of material categories and individual materials. Material substitution may occur due to improved performance, savings in manufacturing processes, or regulations. The rising consumption of nonrenewable organic materials in the United States after World War II, for instance, is partly due to the increased use of plastics in substitution for other materials on established markets. The presence of plastics in different industries has increased over the 20th century; they compete with paper and glass in the packaging industry, and have replaced traditional agricultural and animal products in the textiles industry as synthetic fibers. The automobile industry, for instance, has turned to plastics due to a demand for lighter and less dense materials, and the construction pipe market, previously dominated by steel, cast iron, and clay, has shifted to the increasing use of plastic, primarily PVC [3].

As the change in the use of different materials over the years may be complimentary, it has been taken into account by several authors studying dematerialization. Wernick et al, have defined dematerialization as *the absolute or relative reduction in the quantity of materials* *required to serve economic functions*. These authors have explored dematerialization in terms of primary resource extraction, industry and industrial products, consumer behavior, and waste generation. [4]

For the purpose of addressing the question of dematerialization, many efforts are being made to understand the historic trends of material consumption and its major driving factors.

2.2 Material Consumption and Material Intensity

The material consumption trends for non-fuel materials in the U.S., for the period of 1900-1989 have been studied by Donald Rogich for six categories: forestry products, agriculture, fishery and wildlife, primary metals, nonmetallic minerals, nonrenewable organic materials, and secondary metals. The consumption trends are studied in terms of both weight and volume. As shown in Figure 2, the historic US consumption by weight shows the domination of nonmetallic minerals (73% of the materials consumed in 1993 was crushed stone, construction sand and gravel) followed by industrial minerals. The trend for metals shows a slight decline at the later decades of the period relative to other materials. As stated previously, this may be due to the use of lighter-weight materials in industries such as the auto industry, as well as substitute materials such as plastics for various applications.

Rogich also studies material consumption in relation to GDP for the time period of 1970-1989 (Figure 3). Material throughput per unit of GDP, which follows the trend for *minerals*, shows a decline during this period. Rogich ascribes this decline to the fact that the United States has already built a large part of its infrastructure such that services contribute to a large portion of the GDP. [3]

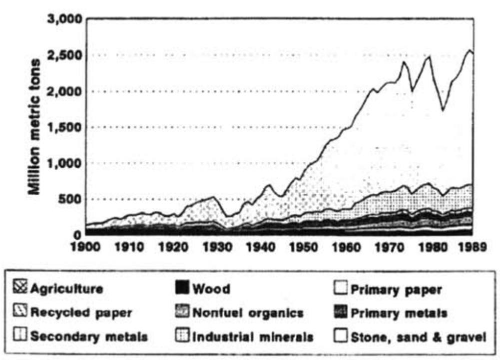


Figure 2 US Consumption of Materials by category (Rogich)

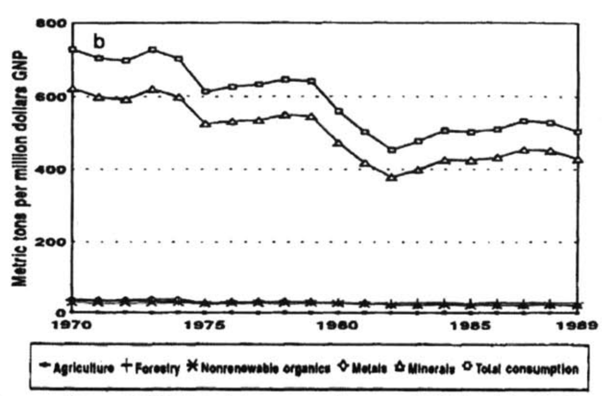


Figure 3 US Material consumption per GDP (Rogich, 1996)

Material Intensity, defined as material consumption per unit of GDP, is also explored by Wernick et al., for plastic, aluminum, potash, phosphorus, paper, timber, copper, steel and lead. Figure 4 shows that while materials such as timber, steel, copper and lead decreased over the last half of the twentieth century, plastics and aluminum increased, while decreasing in slope in the last decades. Paper consumption is also studied (Figure 5), and while absolute paper consumption has risen steeply, consumption per Gross National Product (GNP) has increased from the 1900s, but with a relatively flat slope parting from the 1930s.[4]

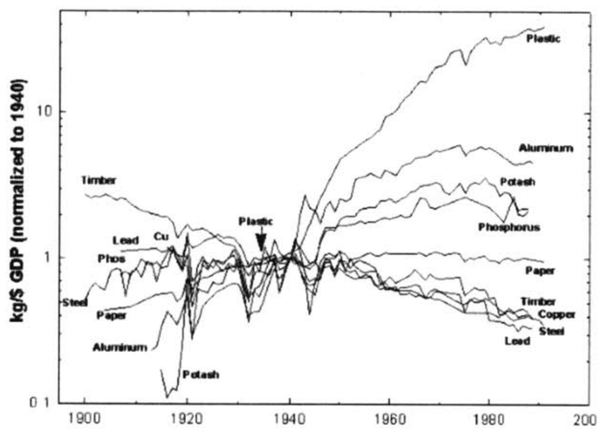


Figure 4 US Material Intensity of use (Wernick et al., 1996)

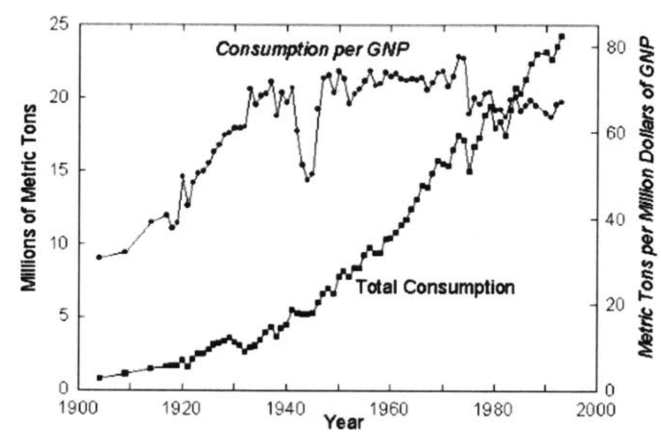


Figure 5 Absolute Paper Consumption and Paper Consumption per unit of GNP in constant 1982 dollars (Wernick et al., 1996)

Another study, by Strout, directly plots consumption and production by weight against GDP per capita for wood pulp, paper and paperboard, chemical fertilizers, hydraulic cement, steel products, primary copper, primary lead, primary zinc, primary aluminum and primary tin, for the periods of 1969-1971, as well as 1979-1980, for several countries. This data is shown in Figure 6. While for the majority of the time period, the materials show a linearly increasing trend, the trend changes at GDP values above $2000 (1970 dollars) [5]. Williams, Larson and Ross expand on this trend and describe the cycle of consumption as one that begins low when the material is first introduced, then grows more rapidly than GNP, which induces advances in processing technology and productivity, which results in lower prices and improved quality, and hence a more efficient use of the material. At this point, the output of material per GNP peaks and begins to decline. Finally, the market for the material becomes saturated and the per capita consumption levels off and may begin to decline. Steel Consumption in the United States exhibits this pattern, both in consumption per GNP and Consumption per capita (Figure 7). It is also shown that by the 1970s, consumption per dollar GNP was declining and consumption per capita was not growing as steeply for steel, cement, paper, ammonia, chlorine, aluminum and ethylene (Figure 8). The trends appear to occur for the aggregated consumption of the following materials: paper, steel, aluminum, petroleum refinery products, cement and a combination of 20 large-volume industrial chemicals (Figure 9). The authors note that these trends may be a result of improvements in material use efficiency, substitution of cheaper or more desirable materials, saturation of bulk markets, and shift in consumer preferences at high income levels to use less material-intensive goods and services [6].

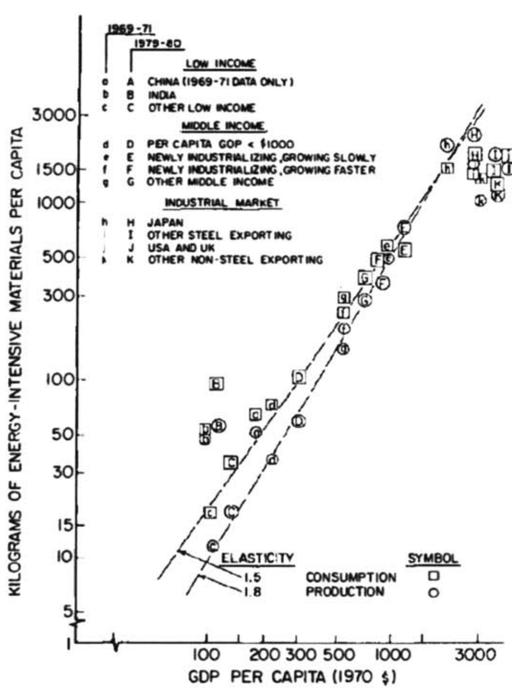


Figure 4 Materials production and consumption per capita by region versus per capita GDP for 10 energy intensive materials. (Strout, 1985)

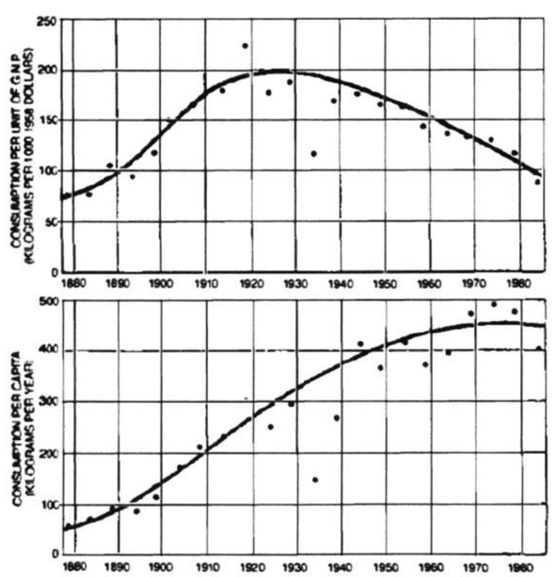


Figure 5 Century data for the Consumption per unit GNP and Consumption per capita of steel for the USA . (Williams et al., 1987)

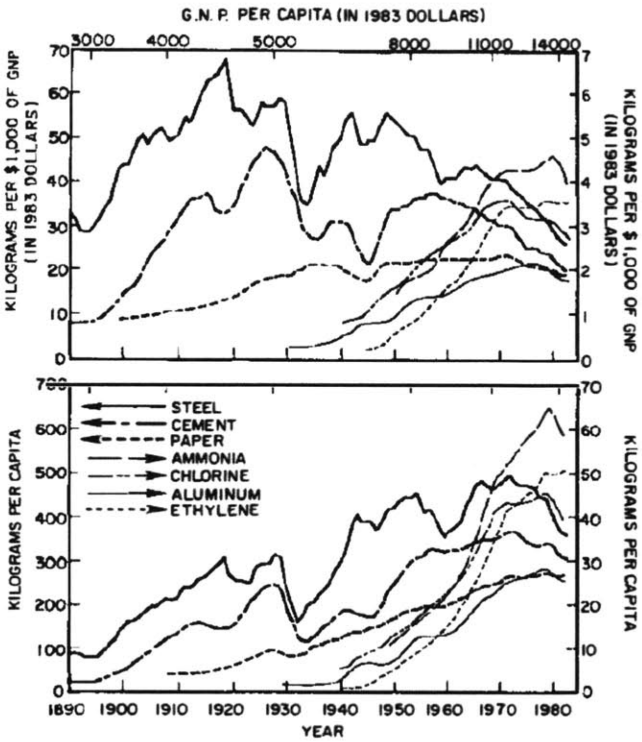


Figure 8 Trends in the apparent consumption of large-volume materials in the United States. (Williams et al., 1987)

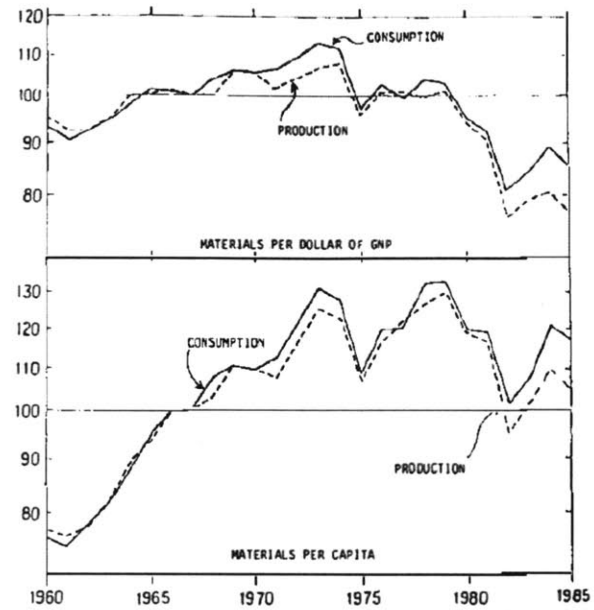


Figure 9 Aggregate Indexes of Apparent Material Consumption and production in the United States.

Material consumption and material intensity at the global level is also visited. Krausmann et al. have compiled data for material consumption for construction minerals, ores and industrial minerals, fossil energy carriers, and biomass, as well as all materials aggregated, for the period of 1900-2005. It is important to note that at the global level, all materials extracted equal all materials consumed. Results show that total material extraction over the century has increased eightfold. The largest increase of consumption is that of construction minerals which increased by a factor of 34 and ores and industrial minerals which increased by a factor of 27. While biomass comprised most of the consumption of materials over the century, it declined throughout the century, and was surpassed by construction minerals in percentage of total consumption in the 1990s. Construction minerals and ores, as well as industrial minerals, experienced a steep growth in the period from 1950 to 1970, and then proceeded with a leveled slope (Figure 10).

Material Intensity is also explored for all materials aggregated at the global level. While Direct Material Consumption (defined as material extracted at the global level) has been declining throughout the century, the trends are driven by biomass consumption. Intensity of mineral materials however, as shown in Figure 11, has increased for most of the century, and has begun to decline in the 1970s.

When taking a closer look at different geographic regions, it has been shown that in industrialized countries such as the USA and various European countries, resource use has been rapidly growing after World War II, and after the oil price peaks in the 1970s, materials use has stabilized at a high per-capita income level. Developing countries such as India, the Philippines, China and many Latin American countries, on the other hand, have seen a rapid growth in material use. [7]

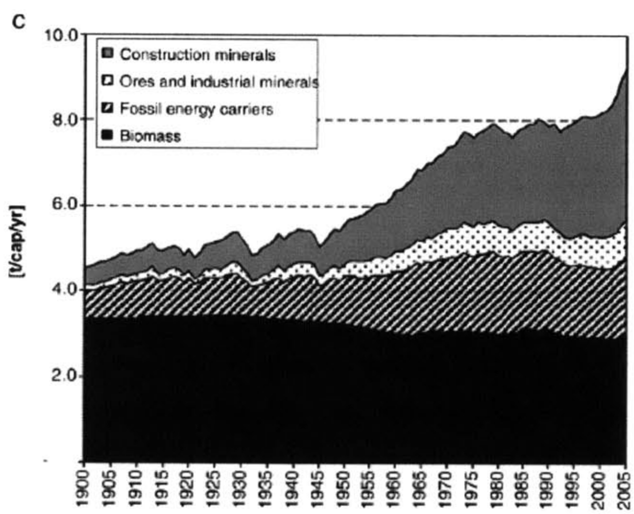


Figure 10 Global materials use per capita by material type from 1900 to 2005 (Krausmann et al., 2009)

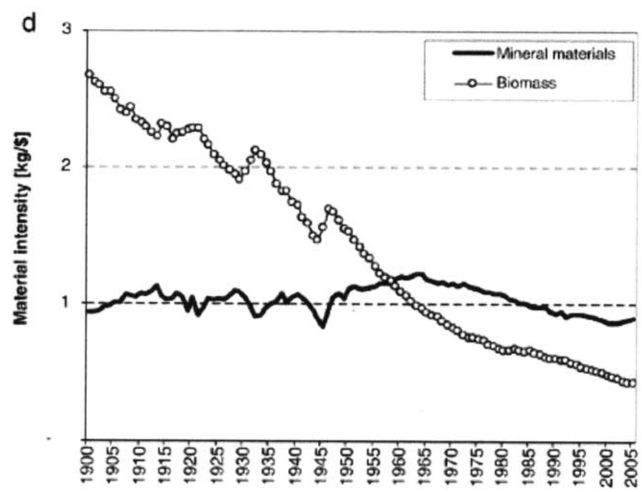


Figure 11 Material Intensity for biomass and mineral materials (Krausmann et al., 2009)

2.3 Price Trends for Materials in the USA

Price trends for specific materials are an important factor when studying the changes in consumption. The trajectory of prices in the United States of America for the main materials included in this study is presented below, along with their respective consumption trends.

2.3.1 Cement

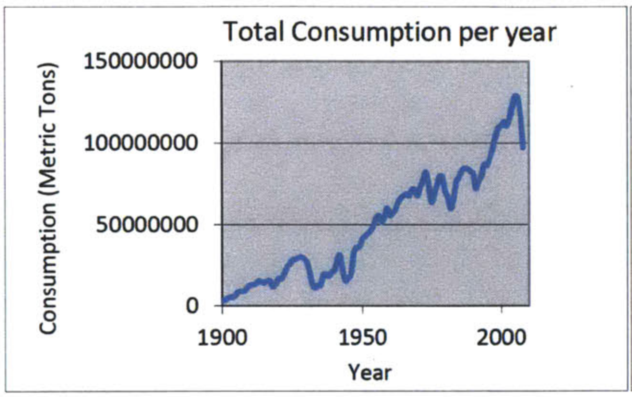


Figure 6

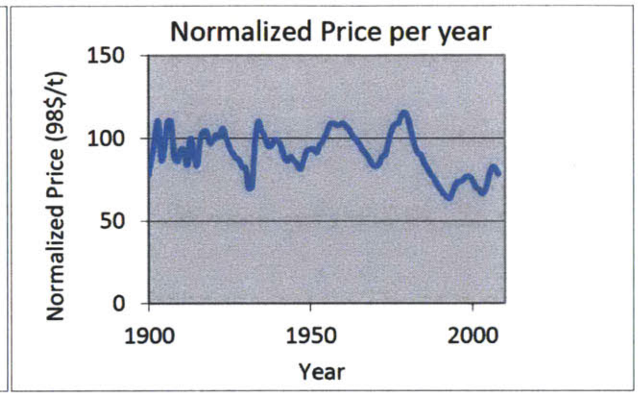


Figure 7

Cement is one of the most widely produced industrial minerals in the United States. It is mostly used for the construction of infrastructure. The figures above show the historic price and consumption trends for this material in the United States. Real price shows a general decline during the 20^{th} century. During 1931 and 1932, the prices declined due to the lack of economic activity. Prices rose during 1934 and 1935 due to large public works projects –such as Hoover Dam- undertaken by the government. Prices declined in 1993, but recovered in the economic boom of the 1990s.

2.3.2 Aluminum

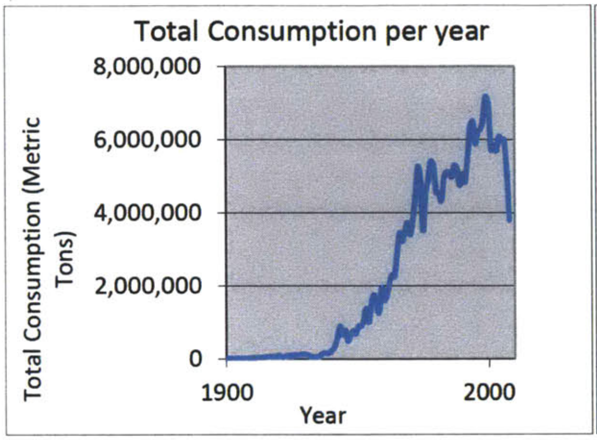


Figure 8

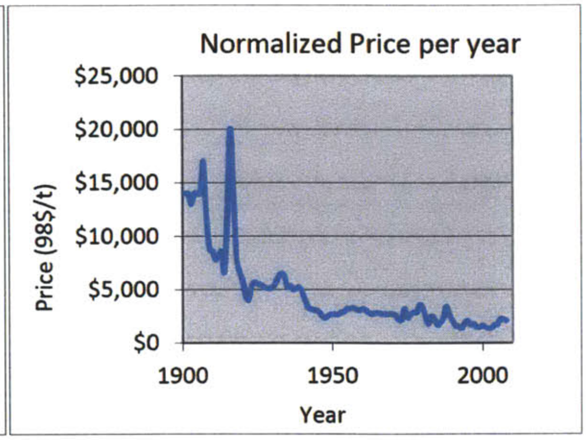
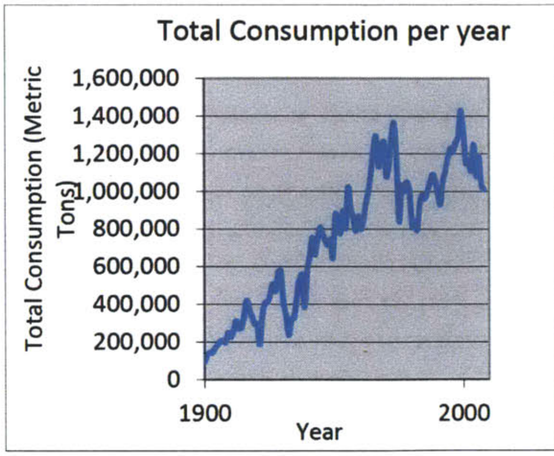


Figure 9

Consumption and price trends for aluminum are found above. The USA does not produce bauxite for aluminum, but it imports bauxite ore (alumina) in order to process it into aluminum. The main uses of aluminum products in the United States are in transportation, building and construction, containers and packaging, electrical, consumer durables, and machinery and equipment. Early in the century, prices were high because producing aluminum was a new process and supply was limited. There was a price peak in 1907 due to increasing demand for railroad cars and automobiles because of aluminum lightweight and strength properties. Additionally, an increase in copper and tin prices encouraged manufacturers to substitute aluminum for these metals, increasing demand for aluminum. A historic high for price occurred in 1916 due to the US participation in World War I and high demand for use in military aircraft and other war materials. During the early 1940s, there was a great increase in domestic bauxite production in order to meet demand for aluminum during World War II. During this time, continuous supply of bauxite from foreign countries decreased due to a short supply of transport ships and the possibility of enemy submarine attacks.

Between World War II and the 1970s there was a major growth for aluminum production, which halted due to the oil crisis in the early 1970s. During this period, there was a downturn in the consumption of aluminum, also due to domestic plant closures, increasing cost of energy, and integration of foreign bauxite mining operations and refineries. Prices have also experienced a strong decline due to new technologies that reduced production costs.

2.3.3 Zinc



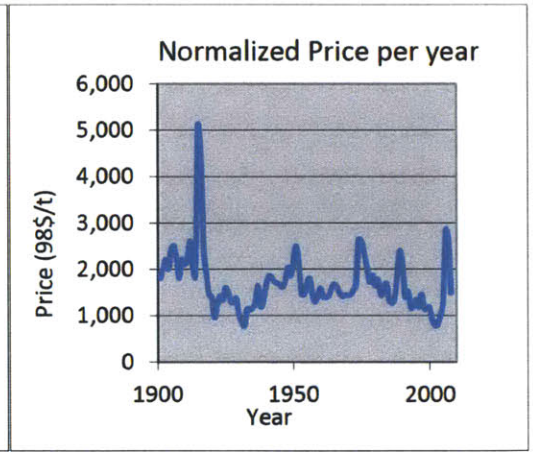
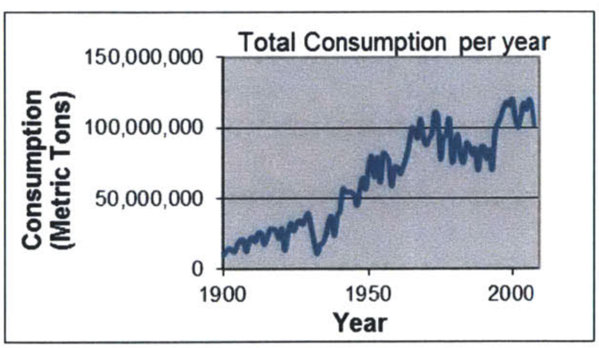


Figure 10 **Figure 11**

Price and consumption trends for zinc are shown above. For zinc, prices rose during WWI due to increased demand. There was an all-time low due to the Great Depression, recovering during World War II. Government policies and price controls let the prices remain stable from 1971 through 1973. There was an increase in late 1980s due to a strong demand and low supply because of strikes, technical problems at smelters, and hurricane- related delays of shipments from Mexico [8].

2.3.4 Steel



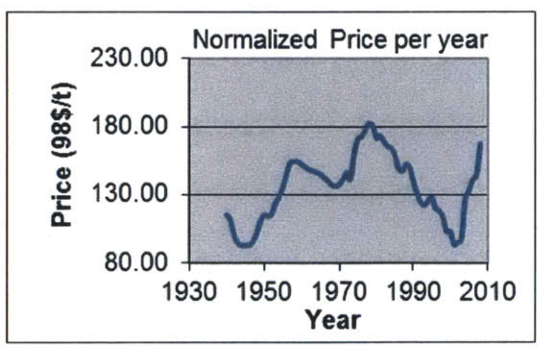
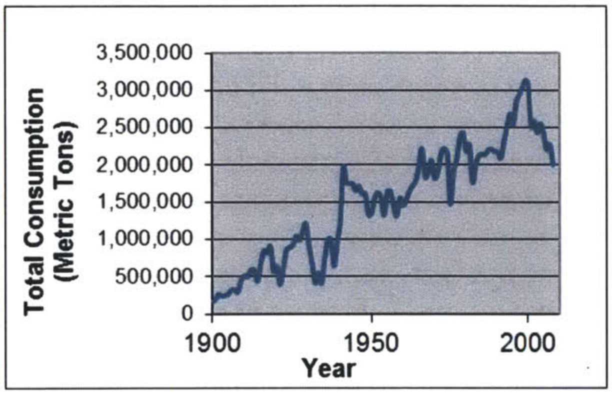


Figure 12 **Figure 13**

During World War II, price controls were implemented on industry for steel due to strong price increases. During the 1960s, prices increased, and the energy crisis of the 1970s resulted with a price escalation due to inflation and the high energy costs of steel companies. Price controls were attempted during this period, but were not effective, and were hence abandoned.

During the 1970s however, new, smaller plants, called minimills, began to perform steel production. These plants did not make use of blast furnaces to process iron ore; instead modern electric furnaces and continuous casters were used. This equipment was used to melt ferrous scrap and cast raw steel into products at a low cost. This new competitive technology contributed to the decrease in prices during the 1980s, along with high domestic demand for steel products during the 1990s [9].

2.3.5 Copper



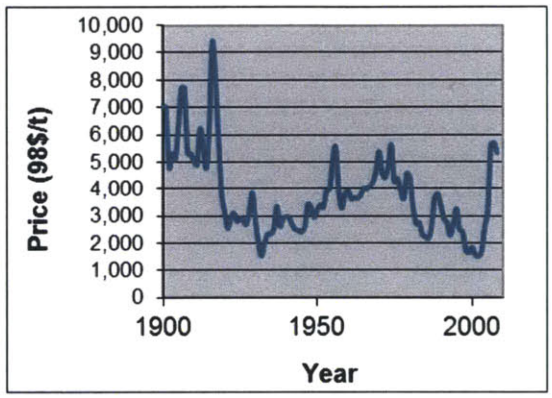


Figure 14

Figure 15

The graphs above show consumption and price trends for copper in the United States. In the United States, the main industries that use copper are construction, electrical and electronic products, transportation, industrial machinery, and consumer products. In the 20th century, the US demand for copper was satisfied using domestic ores, but through the century, ores were imported to help satisfy the economy's need for copper. Prices for copper show a general downward trend for the century. During World War I price increased because there was high demand for copper in munitions and other aspects of the war efforts. There was a low peak during Great Depression in 1932. During World War II, prices were controlled by government, and they rose during the postwar economic boom. Price decreased due to a recession, and then increased gradually due to price controls in order to fight inflation. After controls were lifted, prices declined again resulting in a low peak during the recession of the 1980s [8].

Chapter 3

Materials and Methods

As stated in the Literature Review, a decline in material intensity over the years has been observed for specific materials and geographic regions. For our analysis, a new factor, material price, has been taken into account when analyzing the consumption of materials. Rather than focusing only in material intensity, material consumption has been studied in comparison to $\frac{GDP\ per\ capita}{price}$, which denotes purchasing capability. This method is used by Tsao et al. in their paper *Solid-state lighting: an energy-economics perspective*, which studies lighting consumption, and reveals a linear trend when comparing consumption to:

$$\beta \times \frac{GDP\ per\ capita}{cost\ of\ lighting} \qquad (1)$$

where β represents the fraction of the GDP that is spent on lighting. In the case of illumination, β is empirically found to be constant throughout the years, as its fluctuations are minimal.

The paper studies historical and contemporary consumption patterns and also makes projections for future light consumption. These projections are made from extrapolations of historical trends. For this study, points corresponding to the light consumption (in peta-lumen hours per year) for different countries and years have been compared to the ratio of income per cost of lighting (Figure 22, left). The same method was used for the consumption of associated energy in terms of Petawatt-hours per year versus the purchasing capability in terms of the cost of the energy associated with lighting (Figure 22, right). Both plots result in a linearly increasing trend, showing the proportionality of light consumption to the consumer's purchasing capability. The paper shows that a consequence associated with the increased energy efficiency of solid state lighting, along with increased purchasing capability of consumers, is an increase in light consumption which results in an increase in human productivity. These results imply that consumption of light is not near saturation, as it depends largely on the economic factors, despite technological improvements in energy efficiency. [10]

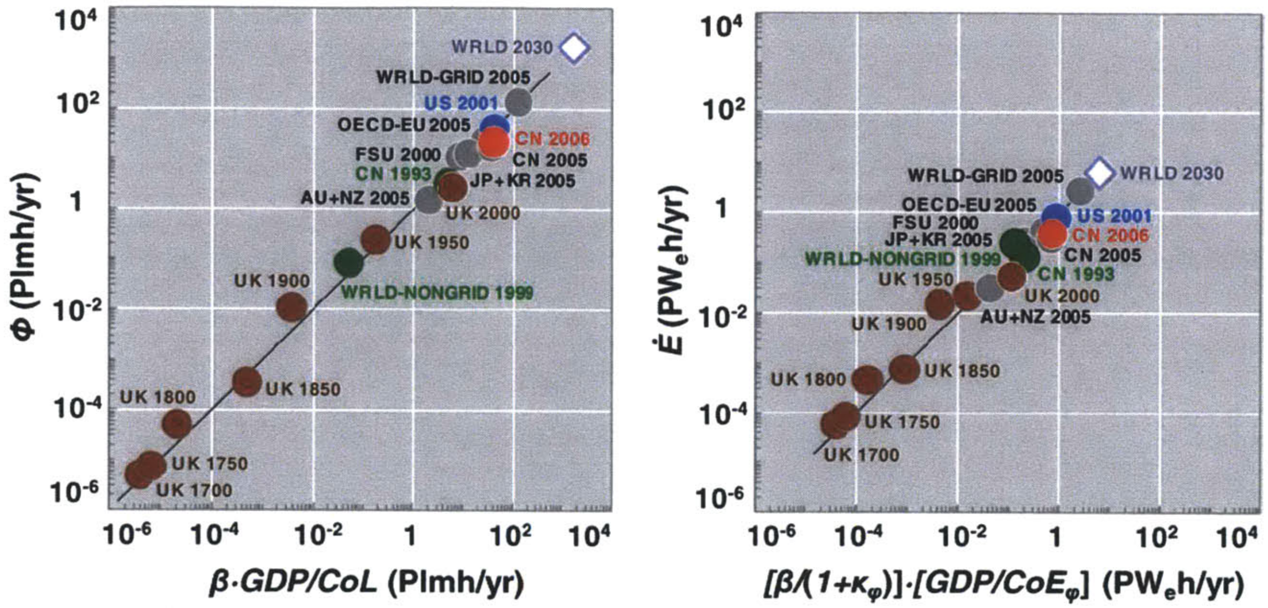


Figure 16 Per capita consumption of light plotted against the product of a constant factor and per capita gross domestic product divided by the cost of light (left). Consumption of associated energy plotted against the product of the respective factor and GDP divided by the cost of energy (right). (Tsao et al, 2010)

A similar approach has been taken for this research, and the cost of materials, as well as material intensity, has been taken into account. Material consumption is naturally different than light consumption as, firstly, material substitution across time affects trends for certain materials, and lastly, the β factor for materials (amount spent on materials as a fraction of the GDP) has not been constant throughout the years.

In order to evaluate the trends of material consumption in relation to purchasing capability of consumers, data was collected for several materials across a century (for most materials) in the United States of America. Data on material consumption (in mass quantities) and yearly price, was retrieved from databases from the United States Geological Survey. National indicators such as population and GDP per capita were collected for the analysis.

For the purpose of comparison, the analysis was also performed for two other nations: China and India, as well as for the global level. The analysis for the United States of America represents that for a developed nation, and the analysis for China and India represents that for developing nations. For this objective however, 5 key materials were chosen. The materials are 4 metals: Aluminum, Copper, Steel and Zinc; and one construction material: Cement. The combination of these materials account for over 50% of industrial material purchases and account for over 30% of global industrial energy and carbon footprint.

In order to identify the main actors behind the observed trends in material consumption, the contribution from different forces to the change in consumption across the years has been evaluated by utilizing the IPAT equation.

The IPAT equation, commonly used to describe the contribution of different factors to environmental impact, is presented in Equation 2 below:

$$I = P \times A \times T \qquad (2)$$

Where I = Impact, P=Population, A= Affluence and T=Technology.

For our application, the equation can be written as:

$$Consumption\ (C) = Population\ (P) \text{x} \frac{GDP}{Population} (\text{A}) \text{x} \frac{Consumption}{GDP} (\text{MI}) \qquad (3)$$

This equation emphasizes the importance of material intensity in the change of material consumption; however, material intensity will be further subdivided in order to evaluate the factors that influence its trends.

Our equation may then be written as Equation (4) below.

$$Consumption\ (C) = Population\ (P) \text{x} \frac{GDP}{Population} (\text{A}) \text{x} \frac{Industry}{GDP} (\text{S})\ x \frac{Material\ Sales}{Industry} (F) x \frac{Consumption}{Material\ Sales} \left(\frac{1}{p}\right) \qquad (4)$$

Consumption of each material is broken down into these factors for each respective country. Consumption (C) is given in mass quantities; Population (P) is given in number of people, Affluence (A) refers to GDP per capita, (S) refers to the Industry Share of the particular region, in other words, the fraction of the GDP that is spent on Industry. The effect of the change in this sector is taken into consideration, given that the other sectors, services and agriculture, consume metals and industrial minerals as final products. This specification does not apply to the consumption of light or fuel, as these are consumed directly by all economic sectors.

$\frac{Material\ Sales}{Industry}$ (F) describes the fraction of the industry that is spent on materials, and (1/p) refers to the mass quantity of material per dollar spent.

In order to evaluate the influence of these elements on the trends of material consumption, their yearly changes are taken into account. For small changes Equation (4) can thus be re-stated in the form below:

$$\frac{\Delta C}{C} = \frac{\Delta P}{P} + \frac{\Delta A}{A} + \frac{\Delta S}{S} + \frac{\Delta F}{F} - \frac{\Delta p}{p} \qquad (5).$$

A complete list of sources for the data used for consumption, prices, GDP, population and industry share of the GDP for all geographic regions can be found on Appendix A.

Chapter 4

Results

4.1 Consumption per Capita and Purchasing Capability

Consumption per capita was plotted against GDP per capita over price for the five chosen materials, for the United States if America, China, India and the global level. Data is presented from 1900 for the United States and the global level, except for the data for steel, and it is presented from 1950 for all other scopes. The plots presented in Figure 24 are used to represent the respective trends of the studied data.

For all materials in the United States, it can be seen that while the consumption per capita vs. purchasing capability shows an initially linearly increasing trend, a drastic slope change occurs posthumously. Similarly, on the global scale, a linear trend is observed initially on all materials, and then it levels off, demonstrating saturation in the per capita consumption with respect to purchasing capability. On the other hand, the graphs for China and India show an increasing trend throughout the full studied period. While for India, some materials, such as aluminum and steel, show a change in slope, the slope does not decrease as significantly as the United States case, rather, it continues as a proportionally increasing trend.

The similarity between the trends for the United States of America and the global level reflects the domination of developed economies on the GDP as well as the consumption of materials for the earlier part of the century. Figure 23 below shows the total consumption of materials by geographic location. After 2000, the consumption of China increases significantly and hence affects global trends.

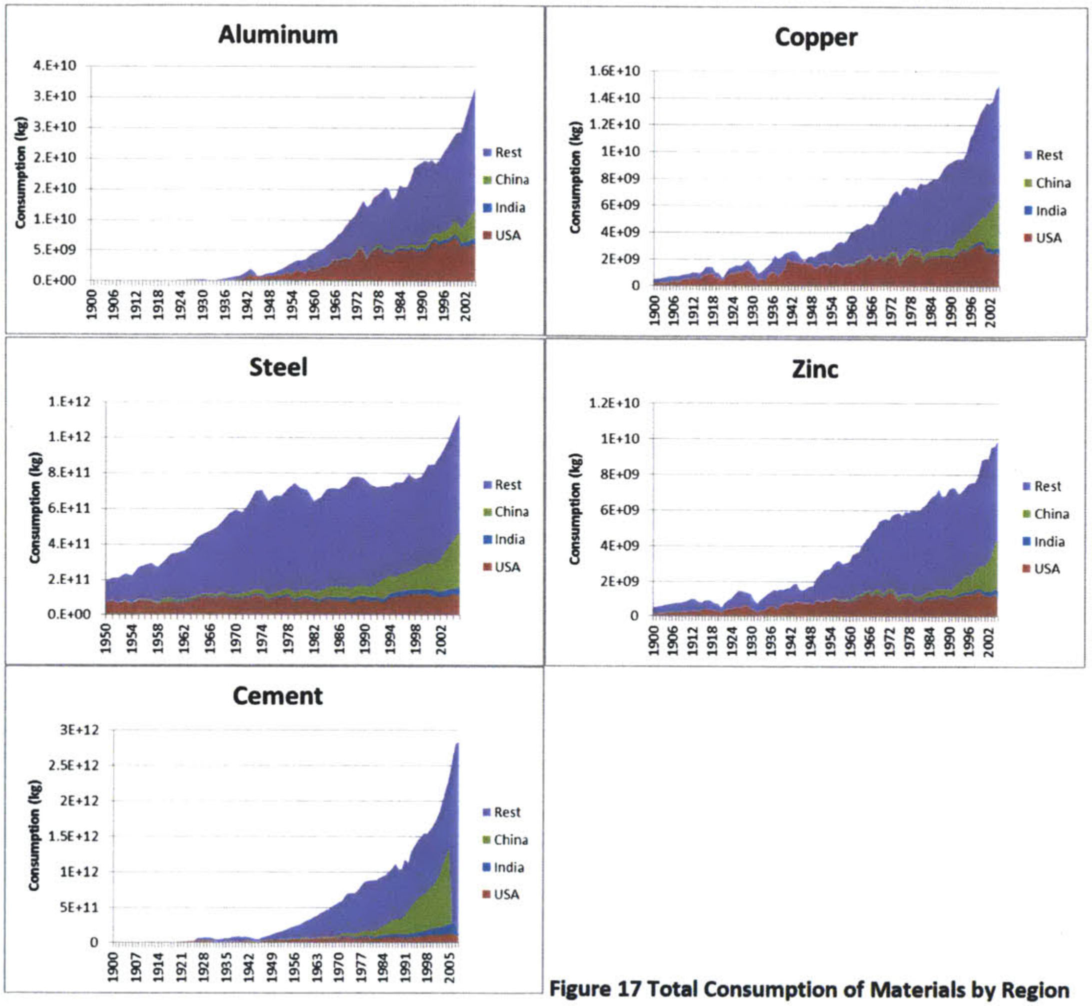


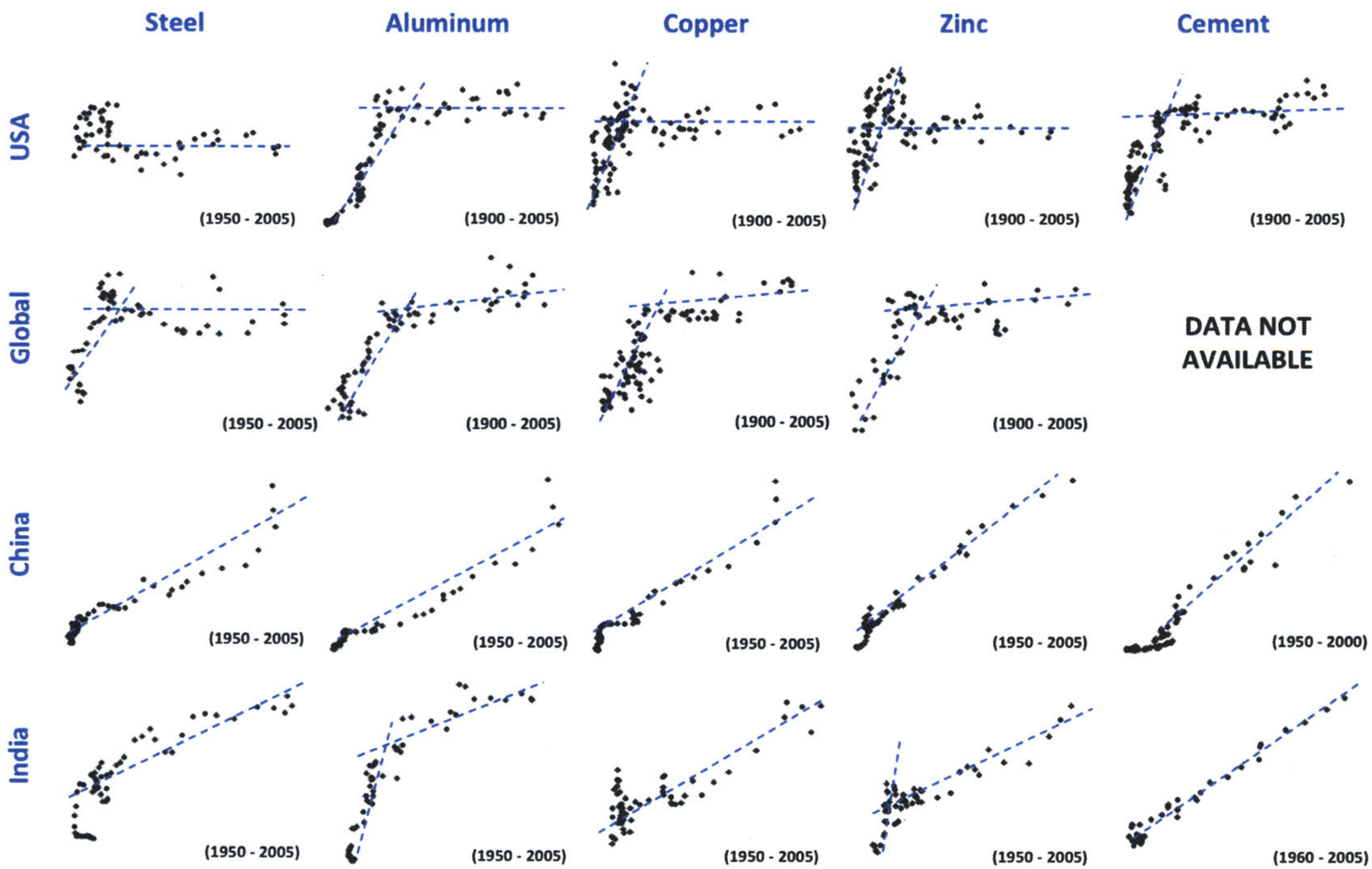
Figure 17 Total Consumption of Materials by Region

4.2 Breakdown of Material Consumption Trends

In order to analyze the observed trends, the consumption of each material was broken down using Equation 5, and the results are displayed in Figure 25 below. Each graph shows the percentage change of consumption from 1950 to 2005 in five year intervals. While the change in consumption trend is shown as a solid line, the percentage change of each factor that composes it is displayed in the color-coded bars in the chart. In this manner the main contributors that drive the change in consumption are portrayed.

The graphs are again arranged by material and geographic region, and they represent data of the second half of the century. The y-axis represents the magnitude of the compounded average growth rates of the percentage changes for a five year interval. The time periods correspond to the years between the labeled year in the x-axis, and the previous five. Axes and scales are the same for all charts, and are shown at the bottom and left of the arrangement of graphs. All of the variables included in Equation 4 are represented in these charts, along with the quantity of material required by industry, which is referred to as "M".

When analyzing these charts, it can be noted that the population has increased continuously for all countries. GDP is another factor that has had a positive change for all countries over the years, with China being the highest increment (5-10%), followed by India, and then United States and the global level. When analyzing the trends for "S", or the fraction of GDP that corresponds to industry, it is observed that industry has positive percentage changes for China and India, while for the United States, it shows mostly negative percentage changes. At the global level, the industry share increased at the first years, and decreased for the rest of the period. Both price and the fraction of industry income spent on materials (F) fluctuate significantly. They also show a strong interrelation which indicates the dominance of material prices on F. M, which indicates the quantity of material used by the industry (or the "material intensity" of industry) has fluctuated for most countries and materials, and has decreased for the last five-year interval for all materials in the United States, except cement, while it has had a positive change for this period in China and India. Furthermore, in the United States, the trends for M and consumption are very close, which reflects the high influence of the material intensity of industry in the United States on the consumption of materials.


Steel
Aluminum
Copper
Zinc
Cement
USA
Global
China
India
(1950 - 2005)
(1900 - 2005)
(1900 - 2005)
(1900 - 2005)
(1900 - 2005)
(1950 - 2005)
(1900 - 2005)
(1900 - 2005)
(1900 - 2005)
DATA NOT
AVAILABLE
(1950 - 2005)
(1950 - 2005)
(1950 - 2005)
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(1950 - 2005)
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(1950 - 2005)
(1950 - 2005)
(1960 - 2005)

Figure 18

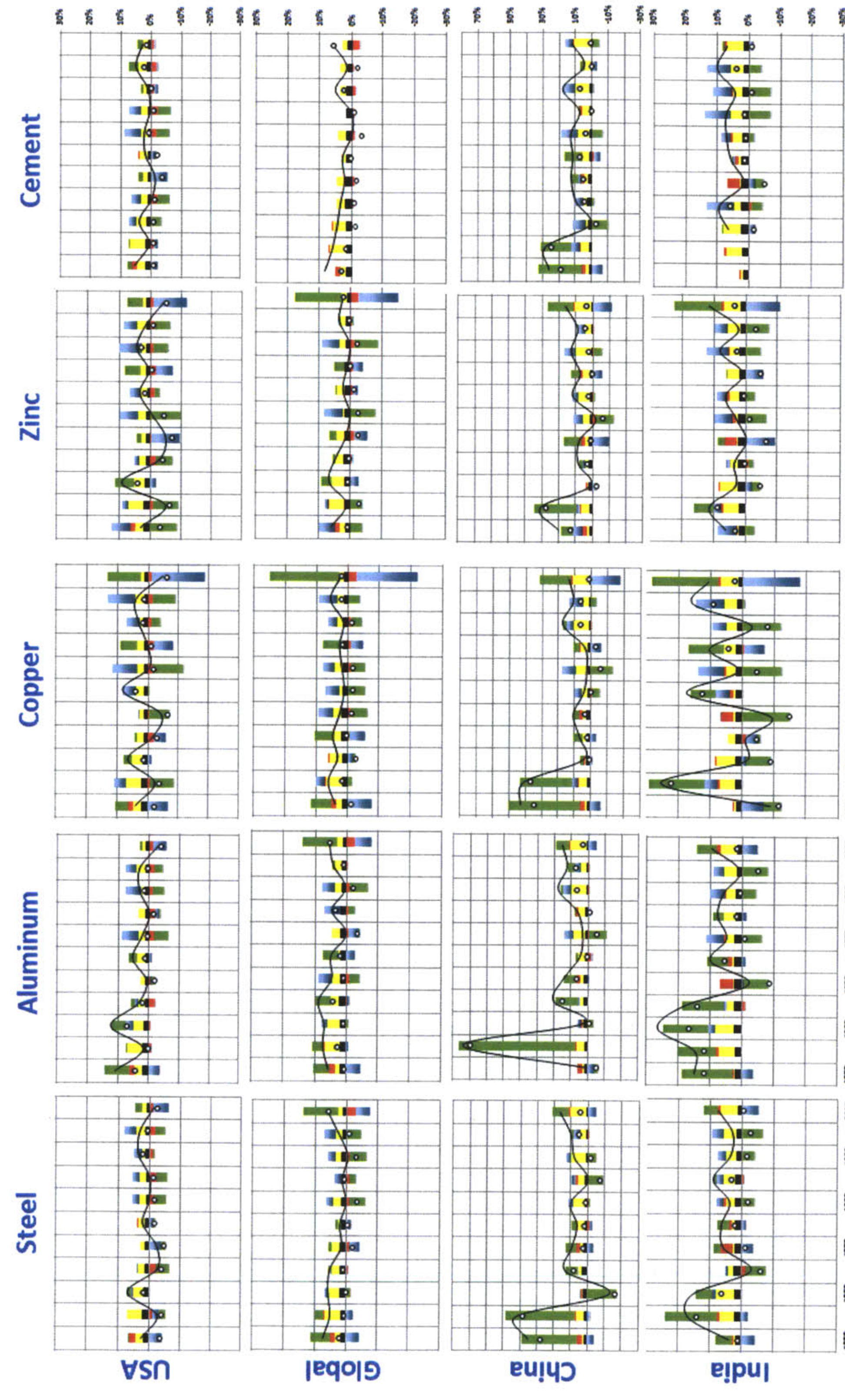
Steel
Aluminum
Copper
Zinc
Cement
USA
Global
China
India
P
A
S
F
1/p
-C
°M

Figure 19

Chapter 5

Discussion

Figure 26 below depicts the summarized results of the breakdown of consumption into the factors mentioned in Equation 4. The table columns show the factors contributing to the change in consumption as the rows show the different geographical scopes under study. As described in the Results section, the factors F and (1/p) are closely interrelated, and have thus been combined in the analysis. The previously discussed factor M is utilized instead, and it represents the quantity (in mass) of materials used within industry. The table should be read as following: the number of starts represents the magnitude of the value of the percentage change *across different countries* (where increasing number of stars indicate larger magnitude); *for each actor* the relative magnitude between countries is represented by these stars along the columns. The color indicates the direction of the change, (where green is positive and red is negative), and the color tone along the rows represents the relative magnitude of the change *within each country* (where a darker color indicates a larger magnitude and a lighter color indicates a smaller magnitude. These magnitudes were determined by taking the averages of the percentage changes across all years.

Analyzing the table and focusing on the later time period (1955-2005), it can be noted that population and affluence have been positive changes for all geographic regions, with population being a more influential factor for India, and Affluence for India and specially China. When looking across countries though, the difference between each is evident. For the United States, while population and affluence increase, the industry sector, as well as the amount of materials used in the industry sector, decreases significantly, as shown by the bright color red. This highly contrasts the reality for India and China, as in both of these countries, all actors are *increasing*. In both of the countries, the industry sector, while increasing, is the lowest influence, while affluence presents the largest percentage change, along with the amount of materials spent in Industry for the case of China.

At the global level, for the period starting from the 1970s, we can notice that the pattern resembles that of the United States even more, as the industry sector and the material spent per dollar output are both decreasing with a larger magnitude. Furthermore, in the *first* half of the twentieth century, the factors for material consumption In the United States were increasing, with the largest influences corresponding to the affluence, and the quantity per dollar output. At this earlier stage, the United States resembled the patterns exhibited by India and China for the later part of the century. These increasing factors explain the increasing trends of consumption in the United States which correspond to the earlier part of the century. This period corresponds to one in which industry was crucial to the economy as the United States was developing in terms of infrastructure. As the economy of India and China develops, the industry attains increasing importance and material use within the industry sector shows an increasing trend, as did the United States at the earlier part of the century. The linearly increasing trend of material consumption vs. purchasing capability for materials in China and India reflect the positive changes in the actors that are presented.

Actor / Country	Population (P)	GDP per cap (A)	Industry Share (S)	Kg/industry (M)
USA [1955-2005]	*	**	**	*
Global [1955-2005]	**	**	*	*
China [1955-2005]	**	****	*	*******
India [1955-2005]	***	***	**	**
Global [1975-2000]	**	*	**	*
USA [1905-1955]	*	*	**	***

Colors are comparing different actors for same country -> darker is larger magnitude, green is positive, and red is negative

** are comparing different countries for same actor with more '*'s referring to a larger magnitude*

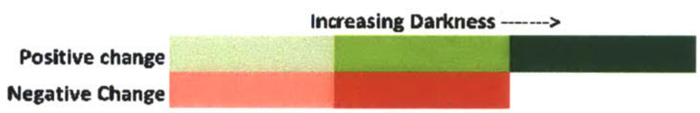

Figure 20

Chapter 6

Conclusions

The present investigation shows a correlation between consumption per capita of studied materials and the purchasing capability of the consumer for that material. It is shown that for the United States and at the global level, the consumption per capita of materials increases with purchasing capability from the beginning of the century. After the second half of the century, however, a change in the trend is observed for all five materials under study and the growth rate for the consumption per capita values decreases significantly, reaching a plateau in for most materials. The progression is different for China and India, as consumption per capita is found to increase with purchasing capability for the second half of the century in a linear fashion, and for some materials, the slope increases at the very end of the period. The analysis of consumption by the composing factors reveals that the size of the industry sector and the material intensity of the industry sector in each country are essential in the trends of material consumption.

The decrease in industrial material intensity for developing nations for the studied materials may be caused by a lower dependence of these materials of the industry sector itself. This may be due to material substitution, as described in the literature review, or a shift within industry to less material consuming products. Another potential influence on the decrease of material used by industry could be improvements on material efficiency. Improvements on material processing and manufacturing efficiency within the industrial sector to meet demand may be important agents that affect the change in material intensity of this sector.

In terms of consumption per capita trends, and growth rates for industry share and industrial material intensity, the trajectory of the United States for the first half of the century resembles that of China and India for the second half of the century. This does not necessarily indicate a repetition of the saturation tendencies in the future of these countries for these materials. In order to make forecasts regarding material consumption trends, the studied contributing factors must be taken into account, and projections for each of should be studied. Recommendations for future work on this subject include analyzing these actors individually and developing projections for the future of material consumption. Furthermore, the decrease in industrial material intensity for developing nations may be studied, taking into account the effects of material demand and material efficiency.

This work discloses the saturation of material consumption per capita for the United States and shows the contrasting trends for the economies of India and China. It also studies the agents that play an important role in the course of those trends and makes comparisons between diverse economies. The analysis sheds light on resource consumption patterns and provides key elements to target when aiming to reduce overall consumption of materials.

Appendix A

Sources for data on all materials and countries are given below. Full references can be found in the references section.

		USA	China	India	Global
Aluminum	Price	[USGS]	[USGS]	[USGS]	[Grilli and Yang]
	Consumption	[USGS]	[Nishiyama] and [Menzie et al.]	[Nishiyama] and [Menzie et al.]	[USGS]
Steel	Price	[USGS]	[USGS]	[USGS]	[USGS]
	Consumption	[USGS]	[Nishiyama] and [Pauliuk et al.]	[Nishiyama] and [World Steel]	[USGS]
Copper	Price	[USGS]	[USGS]	[USGS]	[Grilli and Yang]
	Consumption	[USGS]	[Nishiyama] and [Menzie et al.]	[Nishiyama] and [Menzie et al.]	[USGS]
Zinc	Price	[USGS]	[USGS]	[USGS]	[Grilli and Yang]
	Consumption	[USGS]	[Nishiyama] and [Fortis Bank Nederland]	[Nishiyama] and [Streifel]	[USGS]
Cement	Price	[USGS]	[Deckers and Yuansheng] and [OECD]	[RBI] and [OECD]	-
	Consumption	[USGS]	[Chinese Statistical Yearbook]	[Cembureau] and [CRISIL] and [Matos]	-
GDP		[Johnston and Williamson]	[Maddison]	[UN] and [Bah]	[Krausmann]
Population		[Johnston and Williamson]	[Johnston and Williamson] and [UN, 2006]	[World Bank] and [Maddison]	[Krausmann]
Industry Share		[Bah]	[Bah]	[Bah]	[Bah]

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