Consumption-based accounting of U.S. CO2 emissions from 1990 to 2010

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Consumption-based Accounting of U.S. CO_2 Emissions from 1990 to 2010

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Abstract: To tackle global climate change, it is desirable to reduce CO_2 emissions associated with household consumption in particular in developed countries, which tend to have much higher per capita household carbon footprints than less developed countries. Our results show that carbon intensity of different consumption categories in the U.S. varies significantly. The carbon footprint tends to increase with increasing income but at a decreasing rate due to additional income being spent on less carbon intensive consumption items. This general tendency is frequently compensated by higher frequency of international trips and higher housing related carbon emissions (larger houses and more space for consumption items). Our results also show that more than 30% of CO_2 emissions associated with household consumption in the U.S. occur outside of the U.S. Given these facts, the design of carbon mitigation policies should take changing household consumption patterns and international trade into account.

Keywords: CO_2 emissions, household consumption, income group, carbon intensity

JEL classification: E01, F18; C67; F64, H23

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Introduction

As the world largest economy and the second largest CO2 emitter, the United States (U.S.) plays a crucial role in both global economic development and climate change mitigation. In the past two decades, the U.S. experienced an average annual increase of 1% in population from 250 million in 1990 to 319 million in 2014. During the same time period, its GDP increased from 8.2 trillion constant 2005 US$ to 14.8 trillion, by an average annual growth rate of 2.5% (see Figure 1). The steady growth in population and relatively fast growth in GDP led to a significant increase in U.S. household consumption of goods and services. However, as many other developed countries, the increasing consumption of goods in the U.S. has largely relied on the production in less developed countries, such as China, India, Thailand and many others, thus outsourcing environmental impacts to foreign countries.

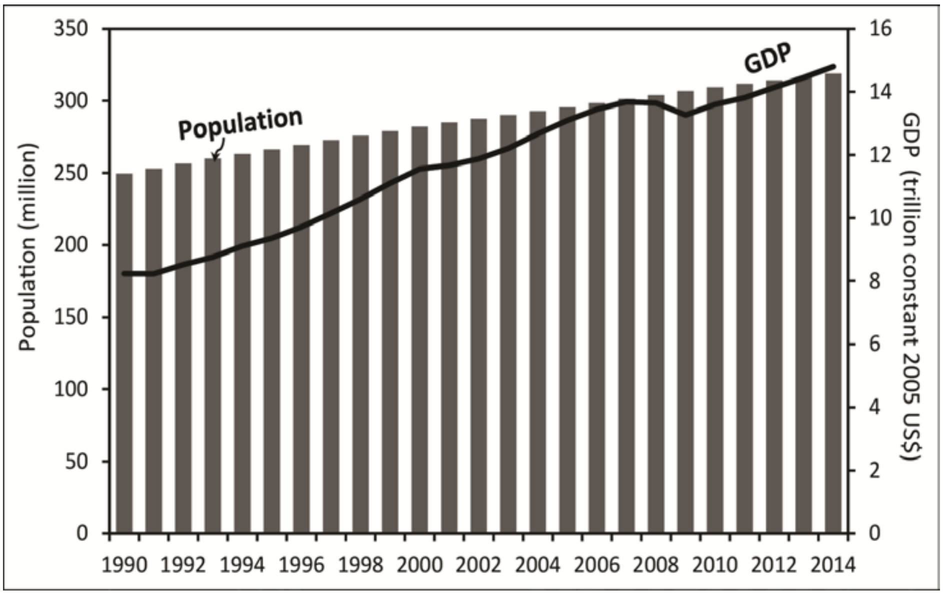

Figure 1: Population and GDP in the United States. *Data sources: the World Bank.*

Assessing energy and emissions associated with household consumption has been one of the most studied aspects in environmental sustainability research for many years (e.g. Druckman and Jackson, 2009; Girod and De Haan, 2010; Tukker et al., 2010; Weber and

Matthews, 2008). At the same time, studying the environmental impacts of globalization and international trade based on a multi-regional input-output analysis (MRIO) have become very popular (e.g. Barrett et al., 2013; Lenzen and Peters, 2010; Liu et al., 2015; Minx et al., 2009; Peters and Hertwich, 2008; Wiedmann, 2009a, b). MRIO analysis provides a consistent analytical and modeling framework to link household consumption to global commodity chains and is able to capture the environmental impacts in upstream supply chains for the production of household consumption items. With fast growth of international trade, it becomes important to recognize the differences in production structure, energy use efficiency, and fuel mix across nations and regions when assessing total environmental impacts of consumption activities in a country (Peters and Hertwich, 2008; Weber and Matthews, 2008). However, there are very few studies on assessing environmental impacts of household consumption through tracing the entire global supply chains due to the lack of global input-output data capturing international trade. Missing the link between household consumption and global production via international trade may significantly underestimate the environmental impacts associated with household consumption, in particular in developed countries including the U.S., as a large proportion of their consumptive goods are imported from other countries. In addition, to meet national environmental targets, countries may move their emission intensive industrial production to other countries; a fact that has been observed in numerous studies (e.g. Barrett et al., 2013; Peters et al., 2011; Weber and Matthews, 2007; Wiedmann et al., 2010).

Consumption-based carbon accounting assigns responsibility to final consumers which is distinct from the production-based accounting assigning responsibility to producers (Peters, 2008). In the past, consumption-based carbon emission analysis has often focused on the average impacts of household consumption within a country/region (e.g. Feng et al., 2013; Feng et al., 2014b; Hertwich and Peters, 2009; Lenzen et al., 2004; Lenzen and Peters, 2010; Wilting and Vringer, 2009). However, households belonging to different income groups may have very different carbon emissions associated with their consumption. For example, lower income household may spend most of their money on the products that meet their basic needs, such as food, clothes, and utilities, while higher income household may spend a larger share of their income on luxury goods and services, such as hotels and restaurants and vacations, which are also carbon intensive when accounting for indirect emissions. The big gap between the rich and poor households in terms of carbon footprint led to a recent popular discussion of environmental inequality (e.g.Golley and Meng, 2012; Hubacek et al., 2015; Yu et al., 2014). In this paper, we assess embodied CO2 emissions in the U.S. trade through applying global MRIO analysis based EORA MRIO database (EORA, 2012). In addition, we analyze total CO_2 emissions of U.S. households across 13 U.S. income groups through connecting global MRIO model with U.S. consumer expenditure survey data.

CO_2 emissions embodied in U.S. trade

In the past few decades, the U.S. had rapidly expanded its trade, in particular emerging economies, such as China, India, Brazil, and South Africa. Figure 2 shows that US was a net carbon exporter in 1990 with net export of 123 million tons (Mt) CO2 emissions. However, this situation changed rapidly after 1993 when the embodied emissions in import overtook embodied emissions in export which led the U.S. to be a net CO_2 emissions importer. The embodied emissions in U.S. import sharply increased by 2.1 times in eight years, from 585 Mt in 1992 to 1,243 MT in 2000. After a slight decline between 2000 and 2002 due to the "Early 2000s recession" which mainly occurred in developed countries (Kliesen, 2003), the embodied emissions in import kept increasing again to 1,474 Mt by 2007. During the great recession 2008-2009, the emissions embodied in import of the U.S. declined back to the 2000 level, a decrease of 20%. However, the emissions quickly increased again by 9% in 2010 when the U.S. economy started recovering from the recession. In contrast, embodied emissions in the U.S. export significantly decreased by 40% from 1992 to 1999 and there was only a slight increase of 11% (about an average 1% increase per year) from 1999 to 2010.

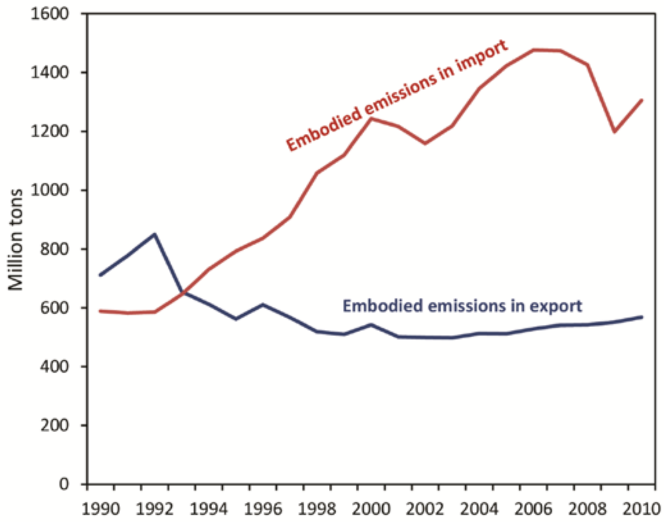

Figure 2: Embodied emissions in U.S. import and export.

The big gap between embodied emissions in import and export was not only due to the increasing gap between the trade volumes of import and export, but also caused by the changing trade patterns. For example, it has been widely discussed that U.S. increasingly imports carbon intensive but less value-added manufacturing goods from developing countries (Prell et al., 2014). Figure 3 shows the U.S. import and export in monetary value from 1990-2010. From Figure 2 and Figure 3 we can see that the changing trend of embodied emissions in import coincide with the changes in the import volume during this study time period, while there was also a rapid increase by more than 3 times in the U.S. export, according to the U.S. Census Bureau, but the embodied emissions in export decreased by 20% over this time period. The opposite trend in embodied emission in export and export volume is due to the change in the U.S. export structure towards high tech and value-added but low emission intensive goods and services. Although the U.S. still export a large amount of carbon intensive manufacturing goods, such as transport equipment and office machinery, but the most energy and carbon intensive production processes in the upstream supply chain often occur outside of the U.S. (Davis et al., 2011).

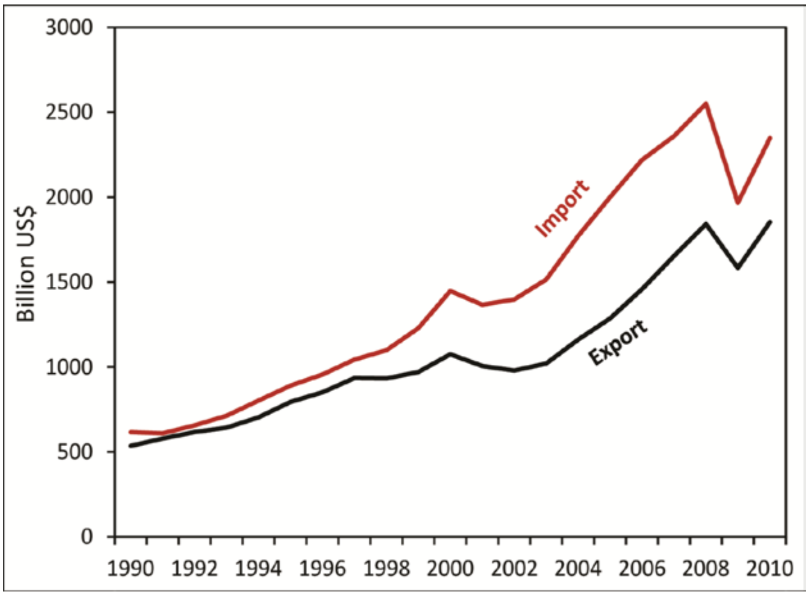

Figure 3: U.S. import and export 1990 – 2010. *Data source: U.S. Census Bureau*

Figure 4 shows the total consumption-based CO_2 emissions of the U.S. from domestic and import production. From the figure we can see that consumption-based CO2 emissions of the U.S. peaked around 2005 and remained almost unchanged until 2007 right before the global recession. Over this time period, the CO_2 emissions associated with U.S. consumption increased by 35% or 1,771 Mt. In 2007, U.S. consumption contributed about 6.4% of global CO2 emissions. From Figure 4 we also can see that the increasing consumption-based CO_2 emissions over this time period were largely contributed by the increase in embodied emissions in import. The share of imported emissions in total consumption-based emissions of the U.S. increased from 12% in 1990 to 22% in 2007, an increase of 10 percentage points. The global recession largely contributed to the decline in the U.S. consumption-based CO_2 emissions from 2007 to 2009 (Feng et al., 2015), but the emissions immediately bounced back by about 3% in 2010 as the U.S. economy started recovering the recession. The share of imported emissions in total consumption-based emissions declined slightly by 2 percentage points during the recession, but went back by 1 percentage points in 2010 with a share of 21% of total emissions.

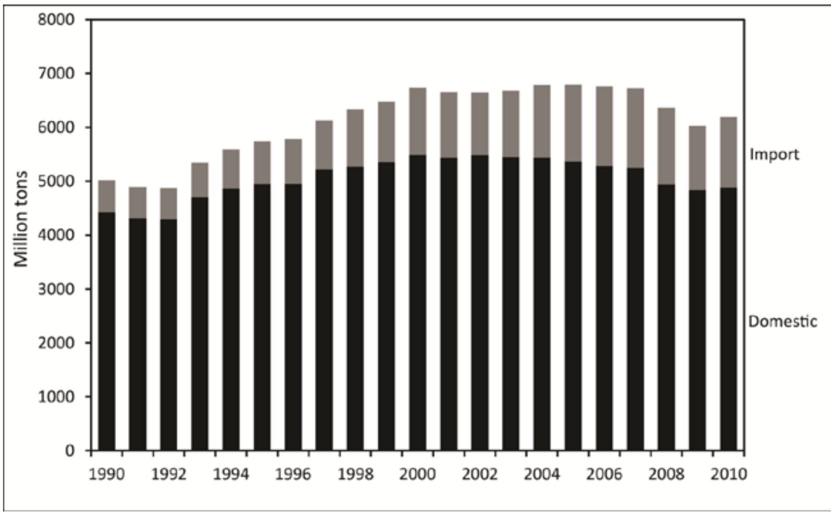

Figure 4: Consumption-based CO_2 emissions from domestic and import production.

From above analysis we see that embodied emissions in import played a vital role in the increase of U.S. consumption-based emissions in the last two decades. However, it is also important to quantify where the emissions came from. Figure 5 shows embodied emissions in the U.S. import from different countries or regions. From the figure we can see that U.S. imported a huge amount of CO_2 emissions from less developed but high carbon intensity countries, such as China, India, and Southeast Asian countries. China is ranked the top embodied emissions exporter to the U.S.; embodied emission in import from China accounted for 31% of the total imported emissions of the U.S. In fact, the increasing CO_2 emissions embodied in U.S. import were largely driven by the increasing trade with China. For example, embodied emissions in import from China to the U.S. grew rapidly by 4.7 times from 1990 to 2010 and the share of embodied emission in China's export to the U.S. in the total imported emissions was about 14% in 1990 compared with 31% in 2010. It is also important to highlight that China's emissions intensity (CO2 emissions per unit of GDP) is approximate 6 times of the intensity in the U.S. The high emissions intensity in China is largely due to less advanced technologies in industrial sectors and coal dominated fuel mix in China's electricity sector (Feng et al., 2014a; Guan et al., 2014; Liu et al., 2015). Therefore, shifting consumption from domestic production to imported goods and services from China ultimately increased U.S. consumption-based CO_2 emissions and the overall global CO2 emissions. Apart from China, the U.S. also imported a large amount of emissions from other less developed but high emission intensity countries, such as India (75 Mt) and Southeast Asian countries (66 Mt), but their exported emissions to the U.S. were relatively small compared with the emissions from China. EU countries are the second largest CO_2 emissions exporter to the U.S. and accounted for 11% of the total imported emissions. Although the emissions intensities in the EU countries are relative small compared with the emissions intensities of less developed countries and the U.S., the large volume of trade with the U.S. traditional trade partners in the Europe led to the large amount of carbon flows from the EU. As U.S. neighbors and important trade partners with the North American Free Trade Agreement (NAFTA), Canada and Mexico produce a significant amount of goods and services and associated CO_2 emissions for U.S. consumption. These two countries' exports accounted for about respectively 9% and 5% of the total CO_2 emissions embodied in the U.S. import.

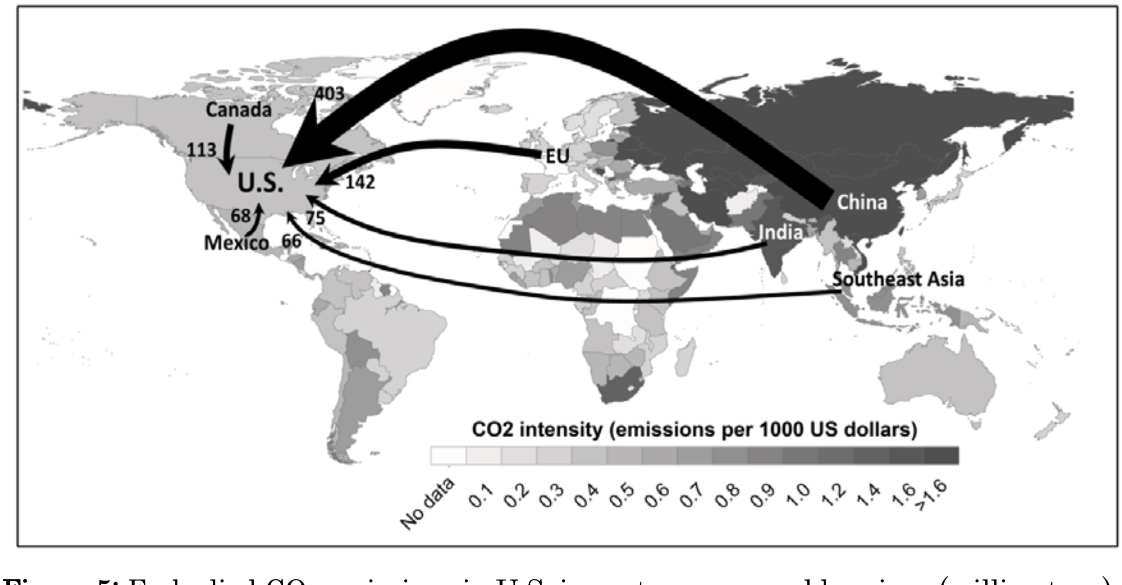

Figure 5: Embodied CO_2 emissions in U.S. imports across world regions (million tons).

US household consumption and associated CO_2 emissions

Final consumption is usually distinguished into four sectors including household consumption, governmental expenditure, capital formation and changes in inventories. In the US, household consumption accounts for the largest share (86%) of the total consumption-based CO_2 emissions. Thus, household consumption in the U.S. may have significant impact on both domestic and foreign CO2 emissions.

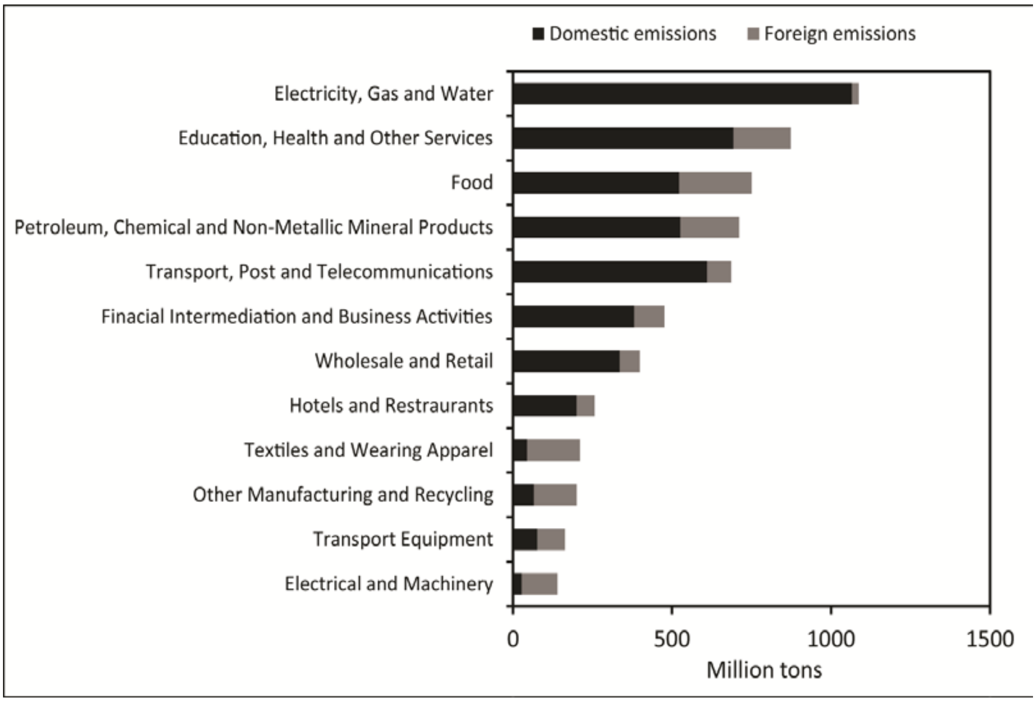

Figure 6: Embodied emissions in 13 aggregate household consumption categories from domestic and foreign emissions.

From Figure 6 we can see that foreign emissions embodied in different consumption categories vary considerably ranging from 2% to 80%. For example, Electrical and Machinery and Textiles and Wearing Apparel have a much higher share of foreign emissions with close to 80% of the total emissions. While, almost all utilities, e.g. Electricity, Gas, and Water, are produced domestically, thus emissions occurring in the U.S. In addition, more than half of CO2 emissions associated with Transport Equipment and Other Manufacturing and Recycling are produced in foreign countries. The U.S. has very large-scale car manufacturing industry; however, car parts and materials used for assembling are heavily relying on production abroad, thus most emissions are emitted in the producing countries. Results also show that about 30% of emissions associated with Food products in the U.S. came from foreign countries. This results reflect that the

U.S. is one of the largest agricultural importers in the world importing coffee, fruits, vegetables and nuts from tropical countries. It is interesting to highlight that 21% of emissions embodied in Education, Health, and Other Services are imported from other countries. This relatively large share of foreign emissions is due to the bid share of imported goods as inputs to these services sectors. For instance, the equipment used in these sectors may be produced abroad.

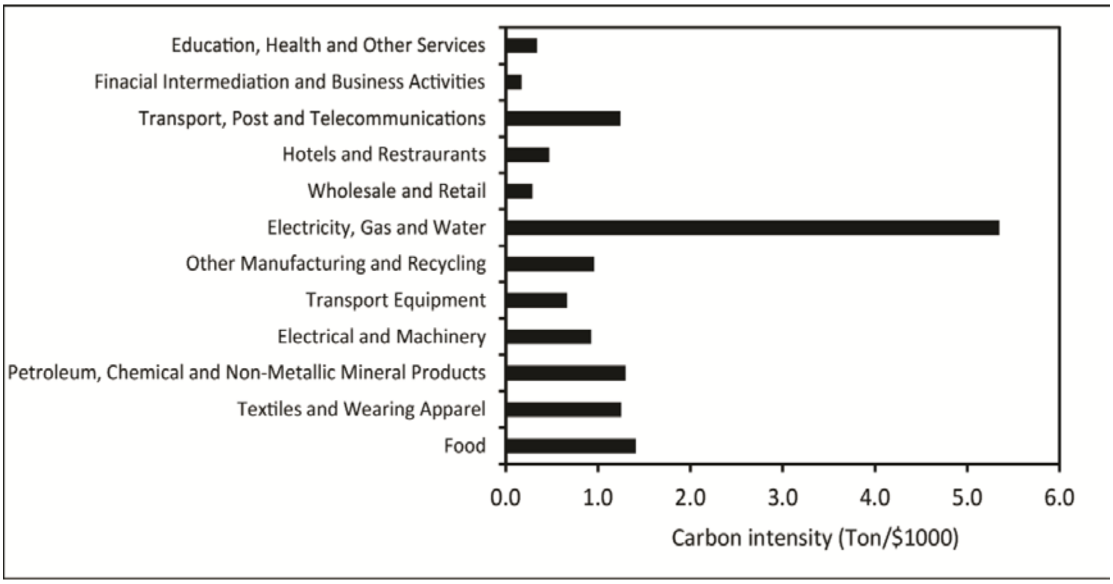

Figure 7: Carbon intensity of goods and services in the U.S.

Consumption choices impact household's CO_2 emissions as carbon intensity varies significantly across goods and services; thus reducing consumption of carbon intensive goods and services is an important way to reduce CO_2 emissions. From Figure 7 we can see that Electricity, Gas and Water is the most carbon intensive sector (5.3 tons per $1,000) compared with other goods and services. Food, Textiles and Wearing Apparel, Petroleum, Chemical and Non-Metallic Mineral Products, and Transport, Post and Telecommunications are having very similar carbon intensity around 1.2 tons of CO_2 emissions per $1,000 consumption. Services are the least carbon intensive, for instance, Financial Intermediation and Business Activities only cause 0.2 ton of CO_2 emissions with consumption of $1,000. However, the total embodied emissions in financial and business activities are fairly large (476 Mt and 8.5% of total household emissions) due to the large amount of consumption.

Inequality of U.S. CO2 emissions across income groups

The focus of this section is on household carbon footprint, the total embodied emissions in consumption of goods and service for a household. It is a widely accepted fact that the inequality in the U.S. is historically high amongst developed countries (Norton and Ariely, 2011) and has been on the increase again (). Different income groups have very different consumption patterns, thus have different responsibility for the CO_2 emissions and associated impacts on global climate change. The average carbon footprint of the U.S. household is 20 tons per person. However, there is a great variation in carbon footprints of different income groups.

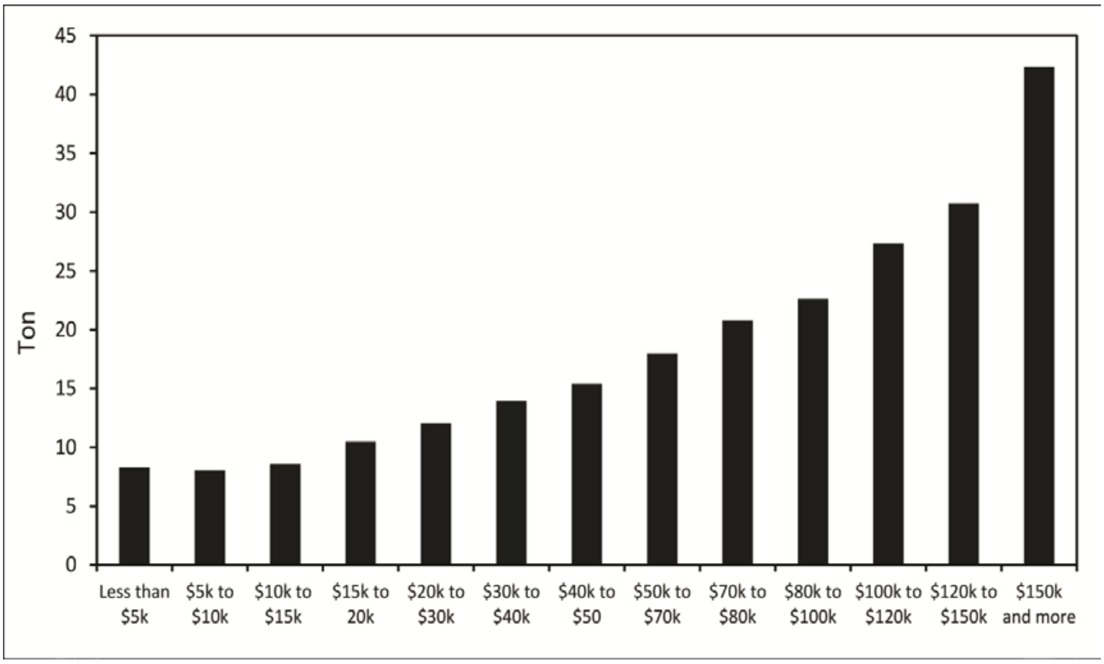

Figure 8: Per capita household carbon footprints by income groups.

From Figure 8 we can see an exponentially increasing trend in per capita household carbon footprint along with income growth. Carbon footprint of the highest income group ($150 or more per year) is 42 tons per person, which is more than 5 times of the carbon footprint (less than 8 tons per capita) for income group earning less than $5k per year. Households earning less than $15k per year have very similar carbon footprint around 8 tons per person. When household earn higher than $15k per year, their per capita carbon footprints increases rapidly with growth of their income. There is also a big gap between the households earning $120k - $150k and more than $150k. Per capita carbon footprint for household with more than $150k annual income is 37% higher than the footprint for the household earning $120k - $150k per year.

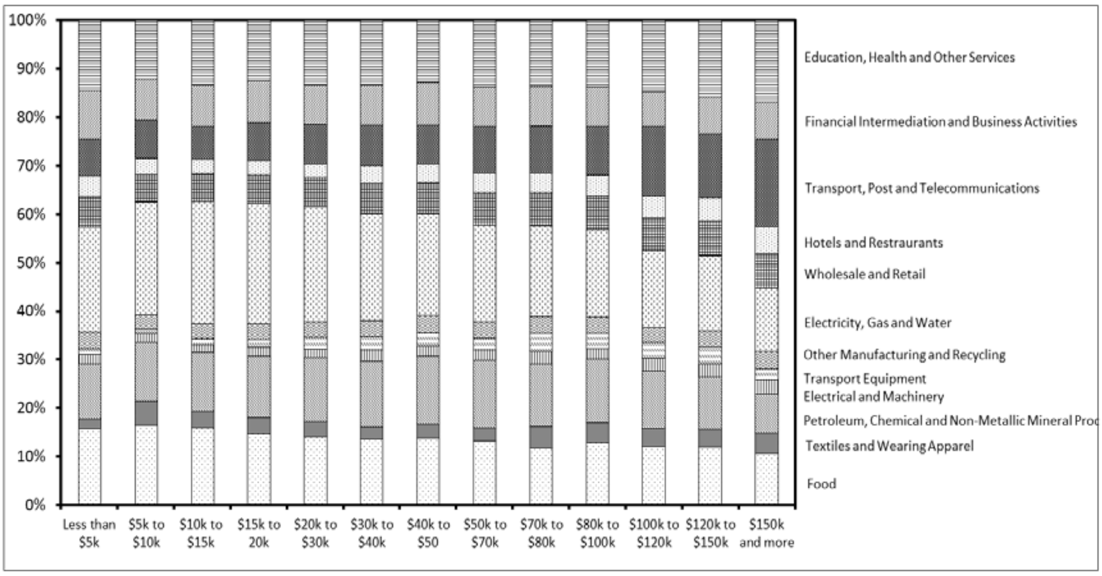

Figure 9: Structure of carbon footprint by 13 consumption categories for different income groups

Different income groups may have very different lifestyle and consumption patterns. It is clear from Figure 9 that lower income and expenditure groups tend to have a larger share of their carbon footprint from consumption categories, such as food, utilities, and petroleum products for personal transportation, to meet their basic needs. While the household carbon footprint associated with these consumption categories increases with growth of household income and expenditure, there is a diminishing returns effect, and the share of household carbon footprint associated with these categories drops as other consumption categories become more important including transportation, communications, hotel and restaurant, education and other services. For example, CO_2 emissions associated with transport, post and communications accounts for 18% of total household footprint for high income group (e.g. $150k or more per year), which is higher than the share of the emissions from utilities (13%). In contrast, share of emissions from utilities is the highest (around 23%) for the low income groups, while the share of emissions from transport, post and communications is only 8%. It is important to note that the most CO_2 intensive consumption categories, such as utilities, fuels, transport, and food) are categories which make up the bulk of low-income consumption bundle. When income increases, household are able to choose either more of the high carbon intensive categories (e.g. bigger houses or cars, increased international air travel) or to spend more on previously unaffordable consumption categories such as leisure goods, better health care, or increased communication services.

In addition, imports associated with the production of low income consumption is much lower for household's basic needs items than for many of the categories associated with higher consumption levels. Therefore, the international share of household carbon footprint tends to increase with income. This result implies that high income households cause more CO_2 emissions in foreign countries, thus have more responsibility for overall global climate change.

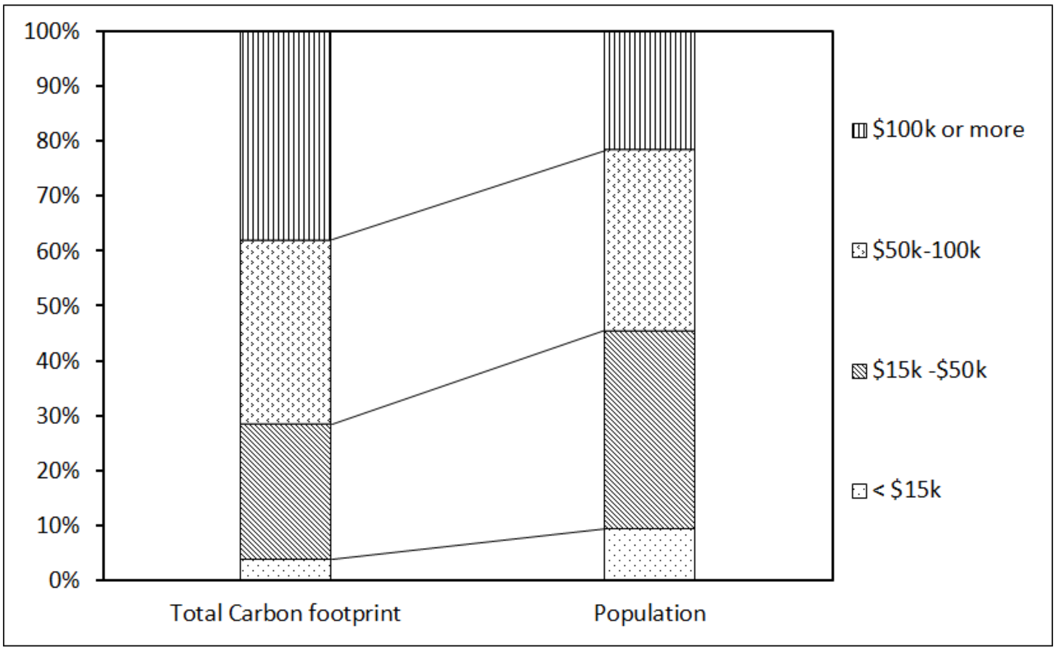

Figure 10: Share of total carbon footprint and population by income groups

The large inequality in per capita carbon footprint leads to a disproportional share of total carbon footprint and population across income groups. Figure 10 shows that the high income group ($100k or more) share about 40% of the total US household carbon footprint but only share about 20% of the population, while the low income group (less than $15k) shares about 10% of population but only 4% of the total household carbon footprint. The lower middle income group ($15k - $50k) share 24% of total household carbon footprint and 36% of population. These shares are almost equal for the upper middle income group ($50k-$100k). If each person in the U.S. has the same carbon budget, the high income group largely displace the carbon budget of low and lower middle income group.

Discussion and Conclusion

To tackle global climate change, it is desirable to reduce CO_2 emissions associated with household consumption in particular in developed countries which tend to have much higher per capita household carbon footprints than less developed countries (Davis and Caldeira, 2010). Per capita consumption-based emissions of the U.S. household is about 20 tons, which is higher than most of other countries in the world (Davis and Caldeira, 2010). Therefore, there is a big potential to reduce the U.S. household carbon footprint and contribute to global carbon emissions mitigation. Three options have been frequently discussed in the past studies including reducing the overall consumption, improving production efficiency of goods and services, and change consumption patterns towards a more sustainable lifestyle (Feng et al., 2009; Hertwich, 2005; Hubacek et al., 2007; Weber and Matthews, 2008). Most mitigation policy and research efforts have focused on production efficiency and changing consumer preferences to less carbon intensive goods and services due to the political undesirability of reducing overall consumption (Hertwich, 2005). Our results show that carbon intensity of different consumption categories varies significantly and with increased income spending additional income on less carbon intensive services, such as education and service for leisure activities, may help to prevent a fast growth of household carbon footprint. Transport, such as international trips, has much higher carbon intensity which is increased rapidly with increased income, thus should be discourage for emission mitigation.

As most of carbon emissions mitigation policies, such as carbon taxes and cap and trade system, would take place at the national level, knowing where CO_2 emissions occur is important for policy design to increase production efficiency and influence consumer preferences towards low carbon alternatives. Our results show that more than 30% of CO_2 emissions to meet the household consumption in the U.S. occur outside of the U.S. If there is no carbon tax adjustments for imported goods, a significant portion of the impacts on CO_2 emissions from the U.S. household consumption would be excluded. Thus, the CO_2 emissions mitigation policies would be less effective since an increasing trend of carbon intensive industries moving to foreign countries due to the increased cost and the production in foreign countries may use more carbon intensive and less efficiency technologies. Given these facts, the design of carbon mitigation policies should take changing household consumption patterns and international trade into account.

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