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Embedded Carbon Footprint of Chinese Urban Households: Structure and Changes

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Abstract: Reducing environmental pressure is a major concern for China but despite the improvements in energy efficiency, its gross carbon dioxide (CO_2) emissions have maintained an upward trend, consistent with the Jevons Paradox. A fundamental shift is thus needed at all levels, including the household.

This paper explores the embedded carbon footprint (ECF) of Chinese urban households associated with activities, such as food, personal transport, communications, education, recreation, health and hygiene. It uses an input-output model for carbon emissions and 2003-2009 urban household data. The results show that the total ECF emission intensity increases when an individual's consumption is higher than 10000 Yuan (¥). Structural changes are further observed with consumption expenditure above ¥10000: food, clothing and other survival-oriented emissions intensities as well as education, health and development-oriented emissions intensities reduce; transport, recreation, housing and enjoyment-oriented emissions intensities increase or remain stable; and the total emissions intensity increases. Currently per capita consumption expenditure of Chinese urban residents exceeds ¥10000 and as income continues to rise, China will remain on a high carbon track. There is a need for better policies, management and behavioural change and the study provides some policy suggestions, including a carbon quota system to guide individual consumption.

Keywords: *Input-output model of carbon emissions, Life style, Urban residents, Carbon quota system*

1. INTRODUCTION

It is well known that increase in consumption is the main factor behind the serious environmental deterioration across the globe, including constantly growing greenhouse gas (GHG) emissions (Lenzen and Shauna, 2001). Technological improvements in energy efficiency, for example, have not decreased energy use (which is predominantly fossil fuel based) as per capita consumption has continued to grow (Rood et al., 2003). Strong concerns are currently being raised about the increase of wealth in developing countries, such as China and India, which is likely to aggravate the ecological situation even further (Pearce, 2008). In fact, China is already the top GHG emitter, largely caused by the production sector of its economy, but what are we to expect as the country's population becomes richer?

Since the 1990s it has been increasingly acknowledged that reducing household carbon emissions can be a starting point for developing strategies aimed at environmental protection (Boxall, 2006). In Canada, for example, households are estimated to generate 45% of the country's GHG emissions (Statistics Canada, 2011). Household carbon dioxide (CO_2) emissions however are largely associated with the provision of certain functional needs, such as shelter, food or recreation (Druckman and Jackson, 2009). The carbon footprint of a household is represented not only through the direct consumption of energy, petrol and gas but also in the carbon embedded in the products it uses or consumes. Driving a car or heating a home, for example are direct generators of CO_2 emissions while purchasing goods and services, such as television sets, furniture, food or holidays contribute to GHG emissions indirectly through the embedded carbon emissions of production, distribution and disposal (Kerkhof et al., 2009).

Without having a clear understanding as to what a household consumes, what carbon emissions this generates and what are the likely changes to be expected, it is impossible to see a shift in consumer behaviour towards a sustainable society. This is particularly the case for China's growing and fast urbanising economy contributing to improving household consumption levels. A good description of the impacts the components of urban consumption have can also inform policy making by government as well as industry when it comes to the development and adoption of cleaner products.

This paper is focused exclusively on CO_2 emissions as the primary indicator of negative environmental externalities. The main aim of the study is to provide an overview of the embedded carbon footprint (ECF) of Chinese urban households and the specific objectives are: (1) to develop a methodology to analyse the ECF; (2) to apply the developed methodology to analyse data on Chinese urban households; (3) to understand emerging trends in the Chinese households ECF in relation to changing income levels; and (4) to put forward policy recommendations that can potentially encourage a reduction in the carbon footprint.

The paper is organised as follows. Section 2 reviews the existing literature related to this topic. The methodologies adopted for the analysis are introduced in Section 3 and the trends in ECF are presented in Section 4. In the concluding Section 5, we synthesise the salient findings and comment on their relevance for policy-makers. Finally, this paper puts forward the personal carbon quota concept as a new path for the realisation of the Porter Hypothesis which claims that environmental regulation can induce efficiency and encourage innovation producing a win-win situation for increased social welfare and net commercial benefits for private companies (Porter and van der Linde, 1995).

2. HOUSEHOLD EMBEDDED CARBON FOOTPRINT

The use of fossil energy resources remains one of the main sources of CO_2 emissions (IPCC, 2007). According to China's Statistical Bureau (NBSC, 2010), fossil fuels accounted for 92.2% of the total energy consumption in China in 2009. As the country remains heavily dependent on this energy source, its contribution to the increase in the on-going atmospheric concentration of CO_2 and its corollary of climate change continues to grow. Rapid urbanisation has been associated with increases in both per-capita income and GHG emissions (Zheng et al., 2011). This is particularly visible in direct energy consumption for purposes, such as transportation, electricity use, heating and domestic fuels. Despite the fact that as of 2009 a household in China's "dirtiest" city Daqing emits only one-fifth of the carbon produced by a household in USA's "greenest" city San Diego (Zheng et al., 2011), the stable increase in household income is likely to see these emissions rise. In fact Zheng et al. (2011: 763) warn that "if China invests in infrastructure and changes its urban forms so that China looks more like the United States, then emissions of both China and the world will increase dramatically".

Since the 1990s, there has been a growing understanding that economic development does not need to necessarily be opposed to the environment. Stringent environmental standards can trigger innovations that not only offset the costs of the development of the new technologies but also lead to competitive advantages for those who develop them (Porter and van der Linde, 1995). Known as the Porter hypothesis, this link between environmental regulations and innovation argues that it is in fact profitable for companies to deal creatively with environmental issues and regulatory pressure motivates new technology development and economic progress. What products are available on the market is largely determined by a country's standards and regulations, and households as direct consumers of these products may have some choice between products but very little control over the availability of environmentally friendly options.

A household not only consumes energy directly in the form of gas, electricity and petrol, but it also uses indirect energy that is embedded in the production, transportation and disposal of consumer goods and services. We define the embedded carbon footprints (ECF) of a household as the CO_2 emissions resulting from the whole lifecycle of products and services for the household including those associated with their manufacturing and eventual breakdown. This indirect energy use can be regarded as being as important in the cities as direct energy use (Lenzen et al., 2004). In European countries, approximately half of the average household energy use is estimated to be indirect energy use (Reinders et al., 2003; Benders et al., 2006). One way of reducing GHG emissions is to decrease household energy requirements by making changes in consumption patterns. However, indirect energy requirements are much more difficult to calculate and address and have rarely been a subject of reduction targets (Benders et al., 2006). The indirect energy use may be reduced by changing the behaviours and decisions of producers and distributors, but also by changing the behaviours of consumers (Steg, 2008). Factors that encourage such behavioural changes include knowledge and understanding of the issue, motivation and ability to engage in energy conservation (Steg, 2008). However, in order to see any effective changes in consumer behaviour, such efforts should be based on a good familiarity with the energy consumption patterns of households. For example, emission intensities were found to decrease with increasing income in the Netherlands and UK but the opposite was the case for Sweden and Norway (Kerkhof et al., 2009).

Analysing household consumption and its environmental impacts remains one of the most active topics in sustainability research. Vringer and Blok (1995, 2000) analysed the changes in consumption patterns of Dutch households in order to find out whether these changes have influenced the energy intensity of society, which showed that, due to the rise in consumption, the total energy intensity of households fluctuated but on average changed from 5.6 to 6.3 MJ/NLG (megajoules per one Dutch guilder), an increase of 0.25% per year. Reinders et al. (2003) evaluated the average energy requirement of households in 11 EU member states, and found that the indirect energy requirement is linearly related to the total household expenditure. Lenzen et al. (2004) used input–output analysis and detailed household expenditure data to yield comprehensive energy use breakdowns for the 14 Statistical Subdivisions of Sydney, and drew clear correlations between energy use and income, household size, age and degree of urbanity.

At the same time, there has been increasing interest in studying the environmental effects of globalisation and international trade at the national level. Based around a quasi-multi-regional input–output (QMRIO) model, Druckman and Jackson (2009) took into account all CO_2 emissions that arise from energy used in production of goods and services to satisfy UK household demand which showed that recreation and leisure are responsible for over one quarter of CO_2 emissions in a typical UK household in 2004. Using consumer expenditure surveys and multi-country life cycle assessment techniques, Weber and Matthews (2008) analysed the global and distributional aspects of American household carbon footprint, and found that due to the recently increased international trade, 30% of the total US household CO_2 impact in 2004 occurred outside the US. Differences between the European and Chinese production systems can lead to substantial increases in the carbon footprint of the traded products (Herrmann and Hauschild, 2009). Consequently, if a country has more stringent environmental regulations, this will affect positively the traded products, irrespective as to where on the globe they are being consumed. As Porter and van der Linde (1995: 116) argue, economic success these days "must involve innovation-based solutions that promote both environmentalism and industrial competitiveness".

Benders et al. (2006) developed a web-based tool for households on the subject of energy conservation. The research was carried out as a field experiment with a group of 300 households in the Dutch city of Groningen. It showed a direct energy reduction of about 8.5% compared to the control group, however, there was not a statistically significant reduction in indirect energy. Similarly, the study of Abrahamse et al. (2007) showed that the Groningen households exposed to the tailored interventions (such as information, goal setting and individual feedback), saved significantly more direct energy than the households in the control group, but no difference in indirect energy savings emerged (Abrahamse et al., 2007). Indirect energy use was positively associated with income and household size, and indirect energy savings could be significantly explained by treatment, attitude and perceived behavioural control (Abrahamse and Steg, 2009).

Households can be considered an important target group for energy conservation. In China research of the ECF of urban residents is in its infancy. To help us understand the link between the attempted satisfaction of human needs and desires and CO_2 emissions, and to understand the scale of emissions reductions that are required, we ask the following questions: What are the current trends of carbon emissions in China? To what extent is coupling occurring between household expenditure and CO_2 emissions? What policy interventions can encourage better environmental behaviour by Chinese urban residents?

3. METHODOLOGY AND DATA SOURCES

The use of different methodologies to assess a carbon footprint is likely to result in different estimation outcomes (Dias and Arroja, 2012; Plassmann et al., 2010). In the case of the embedded carbon footprint, there have been at least two alternative approaches for its estimation. One is based on estimating the "apparent consumption" of each type of energy resource, along the line of the methodology proposed by Wackernagel and Rees (1996) and its later development. The other, proposed by Bicknell et al. (1998) is based on the monetary values of products that are delivered to domestic final demand, the information recorded in an input–output table.

The first approach centres on the amounts of energy used in a defined economy, not on the products consumed by the given human population (Ferng, 2001). When the defined economy is a big exporter of finished products produced using large amounts of imported resources, the deficiencies in such calculations are obvious. In the case of China, it is estimated that 33% of its carbon footprint is associated with exports (Weber et al., 2008). On the other hand, a study by Weber and Mathews (2008) estimated that 30% of the American households' 2004 carbon footprint occurred outside the US. Therefore, such an approach will overestimate China's carbon footprint as far as local consumption is concerned. Alternatively consumer activities can be linked to input–output patterns in the economy and hence to the accompanying energy requirements due to these economic activities (Benders et al., 2006). The primary advantage of the input–output assessment framework is that it provides a standard method of analysis that can be updated or applied to alternative populations in a uniform manner (Bicknell et al., 1998). Based on the product flows recorded in an input–output table, the monetary value of the energy available for domestic final consumption can be approximately traced and calculated using input–output analysis. This is the approach adopted in the analysis to follow.

3.1. Carbon Dioxide Emissions Input-output Model

Bicknell et al. (1998) were the first authors to propose the use of generalised input–output analysis as a method for calculating the ecological footprint. Their 1998 article contains an instructive introduction into the principles of the input–output method. In recent years there have been a number of further contributions attempting to use input–output techniques to calculate the ECF of particular products, regions or similar indicators (Ferng, 2001, 2009; McDonald, 2004; Rawshan, 2009). Some studies have also addressed issues related to the accuracy of the ECF estimates obtained by the input–output analysis, such as suggesting the use of a multi-regional input–output modelling framework to improve the calculation of embedded resources and CO_2 emissions in trades (Turner et al. 2007; Druckman and Jackson, 2009).

Given that the focus of the ECF is to capture the total CO_2 emissions embedded in final consumption in an economy, input–output would seem to be a well-suited accounting framework. In the present study we use a closed-economy framework where imports are exogenously given and the direct and indirect CO_2 emissions coefficients of these imports are assumed to be identical to those in China. No distinction is made for the origins of the intermediate inputs used by the producing sectors in those exporting countries. This is obviously an assumption to simplify the model. In 2005, China was the world’s biggest net CO_2 exporter (DSTI, 2011). Being an emerging economy with high energy dependence on fossil fuels, the carbon footprint of its products is on average higher than that of comparable goods produced in the developed world. The overall impact on the world of China’s production sector through international trade is much higher than any imports have on Chinese domestic consumption. Tracking the emissions components of all imported goods is a difficult task. However taking into consideration that only 1-2% of China’s consumption is of imported goods (DSTI, 2011), the impact of the model simplification is not that significant.

The model we develop takes into account the amounts of ECF that are used to support the various activities that make up modern lifestyles, or, in other words, we attribute ECF to functional uses, namely: housing, food and catering, clothing and footwear, health and hygiene, recreation and leisure, education, communications and commuting (Weber and Matthews, 2008; Druckman and Jackson, 2009). The total ECF, measured in kilograms CO_2 emissions (kg CO_2), is determined as：

$$ECF_{total} = \sum_{i=1}^{M}\sum_{j=1}^{N}\{\sum_{j}[diag(B)(I-A)^{-1}]\}Y_{ij} \tag{1}$$

Where B is a 1 x N vector, with elements b_j, representing the average CO_2 emissions per monetary unit of gross output for each stage in sector j. A stands for the direct requirements (or input–output coefficients) matrix. Y represents final demands, measured in Yuan (¥). $\sum[diag(B)(I–A)^{-1}]$ is the emissions multiplier of sector j, where i=1,…, M (M is total number of stages in economic sector j) for consumption category i, j =1,…, N, for each economic sector j and N is the total number of economic sectors. Consumption categories cover expenditures, such as for food, clothing, housing, recreation, health and hygiene, education, telecommunications, transport and others.

In 2006 the Intergovernmental Panel on Climate Change (IPCC) published the latest Guidelines for National Greenhouse Gas Inventories (IPCC, 2006). These and many more GHG emission factors can be found on IPCC's Emission Factor Database (http://www.ipcc-nggip.iges.or.jp/EFDB/main.php). The conversion between fossil fuels usage and CO_2 emissions is straightforward while the conversion between electricity usage and CO_2 emissions is considerably more complicated. The average CO_2 emission factors for electricity generation can be estimated as：

$$\rho_9 = \frac{\sum_{j=1}^{3}\sum_{i=1}^{8}\omega_{ij}\rho_i}{Q} \quad (2)$$

Where ω_{ij} is the use of fossil fuels *i* by power plants *j*, such as thermal, hydropower and nuclear power plants, measured in hundred thousand tons (10^5 t) of standard coal; ρ_i is the emission factors for fossil fuels, measured in kilograms CO_2 emissions per kilogram standard coal, *Q* is power generation, measured in billion kilowatt hours (10^9 kWh).

The CO_2 emissions in economic sector *j*, measured in kilograms (kg) is:

$$\Phi_j = \frac{\pi_j}{\sum_{i=1}^{9} q_{ij}\varphi_i / \lambda_i}\left(\sum_{i=1}^{8} q_{ij}\rho_i + q_{9j}\rho_9\lambda_9\right) \quad (3)$$

where π_j is the consumption of total energy by economic sector *j*, measured in hundred thousand tons of coal equivalent (10^5 tce) , φ is conversion factors from physical unit to coal equivalent (kgce), q_{ij} is final energy consumption for category *i* by sector *j* measured in hundred thousand tons of coal equivalent (10^5 tce) and λ is the efficiency of energy transformation.

The average CO_2 emissions per unit of gross output in sector *j*, measured in kilograms per Yuan (kg/¥) is:

$$b_j = \frac{\Phi_j}{X_j} \quad (4)$$

where X_j is the gross output in sector *j*, measured in Yuan (¥).

3.2. Data Sources

The CO_2 emission factors for coal, coke, crude oil, gasoline, kerosene, diesel, fuel oil and natural gas can be found on IPCC's Emission Factor Database. China's 2006 Energy Statistical Yearbook (NBSC, 2007) gives the consumption of total energy by economic sector, conversion factors from physical unit to coal equivalent, final energy consumption by sector and the efficiency of energy transformation. The latest available estimates of the International Energy Agency show that global GHG emission of urban activities accounted for more than 67% of total emissions in 2008 (IEA, 2008). Hence, it is important to be able to estimate the contribution of Chinese urban households. China's Urban Life and Price Yearbook (NBSC, 2003-2009) was used as the source for household expenditure data over the 2003–2009 period and China's input-output statistics were available for the year 2005.

4. RESULTS AND DISCUSSION

4.1. Trends in China's Carbon Dioxide Emissions

The importance of being able to estimate the Chinese urban household embedded carbon footprint can be understood within the context of China's constantly raising total CO_2 emissions. Despite a small decrease between 1997 and 2000, the overall trend is upwards (see Figure 1). In fact, the 2005 level was 48% higher than that in 1995. Between 1995 and 2002, due to the economies of scale achieved through the replacement of small energy generation units with large ones, CO_2 emissions decreased at a faster rate than energy use in China; however, since then carbon emissions and energy use have been increasing at about the same rate.

Emissions intensity, on the other hand has an overall downward trend, from 2.65 tons of CO_2/ton of standard coal in 1995, down to 2.38 in 2005. This shows that China's energy efficiency has been constantly optimised, but the country's gross CO_2 emissions have maintained an upward trend. This is consistent with the Jevons Paradox which states that technical efficiency improvement in energy use leads to higher energy consumption if it is not accompanied by adjustments in people's lifestyle (Adua, 2010). Hence, China's growth of CO_2 emissions should be attributed to growth in final consumption, including exports, in line with the findings by Lenzen and Shauna (2001) that the main factor driving emissions growth is an increase of per-capita consumption.

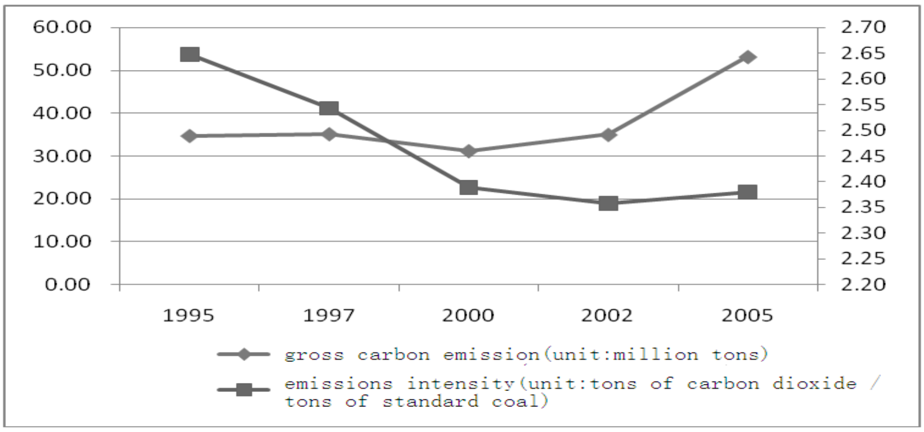

Figure 1. Carbon Dioxide Emission Trends in China, 1995-2005
Source: Authors' calculations through equations (2) and (3)

4.2. Emissions and Consumption

At the household level, the different consumption categories are responsible for very different shares of both expenditure and ECF. This breakdown also varies largely between countries and comparisons are generally difficult to make. For example, OECD countries, such as Australia, Germany, Japan and US, have much higher emissions associated with transport and consumption of imported goods than emerging economies, such as China (DSTI, 2011). This is due to big differences between consumption patterns, energy sources used, living standards, level of urbanisation, to name a few. An additional complication in comparisons arises from the lack of directly compatible research data. We have however endeavoured to provide some international context where possible to put the findings about Chinese urban households into perspective. Despite the multitude of economic, social, cultural and geographic differences, most of the references we use relate to US as this is the only country with an economy larger than that of China.

On average, the Chinese urban household consumption totalled ¥7942 in 2005 and resulted in 2007 kg of CO_2, with an average CO_2 intensity of consumption of about 0.25 kg CO_2/¥. By comparison, in 2003 an average US household spent US$1115 on non-energy related goods and services resulting in 12950 kg of CO_2 (Shammin and Bullard, 2009) and an average intensity of 11.6 kg CO_2/US$ or 1.4 kg CO_2/¥ (at 2005 conversion rates). As households in rural areas have around 17% higher emissions (Shammim, 2012) and with 80% of the US population urbanised (UN, 2004), we estimate that the average American urban household in 2003 was responsible for 12524 kg of CO_2 or 6 times more than its Chinese counterpart in 2005.

Some consumption categories, such as education, recreation and food have carbon intensities much lower than the average while others, such as housing and personal transport, have much higher intensities. For example, Shammim (2012) estimates that in the US the CO2 intensity of public transportation is the highest at 1.38 kg/US$ compared to telephone services at 0.17 kg/US$, reading and education at 0.21 kg/US$ and food at 0.41kg/US$.

Figure 2 shows the distribution of the various categories of ECFs as shares against the total annual expenditure of households. Several interesting trends can be noted. For example, the lower income/expenditure groups tend to generate a larger share of their CO_2 burden from what could be referred to as ‘necessities’, namely food. This is not dissimilar to the US where the share of food expenditure drastically decreases with higher levels of expenditure – from 23% for the lowest to 5% for the highest group (http://laborsta.ilo.org/). While the ECF from this category grows with increased expenditure, there is a diminishing returns effect, and the share of ECF associated with food drops continually as other consumption categories, such as housing, recreation and personal transport become more important. It is important to note that the most CO_2 intensive categories, namely transport and housing, are precisely the items which make up the bulk of the high-income consumption bundle. These trends are not dissimilar from the ones observed in the US, where transport also becomes more prominent and the share of housing remains relatively stable, both contributing to higher CO_2 emissions. The actual share of transport however is by far larger for American households and in 2003 it was responsible on average for more than a half of their ECF.

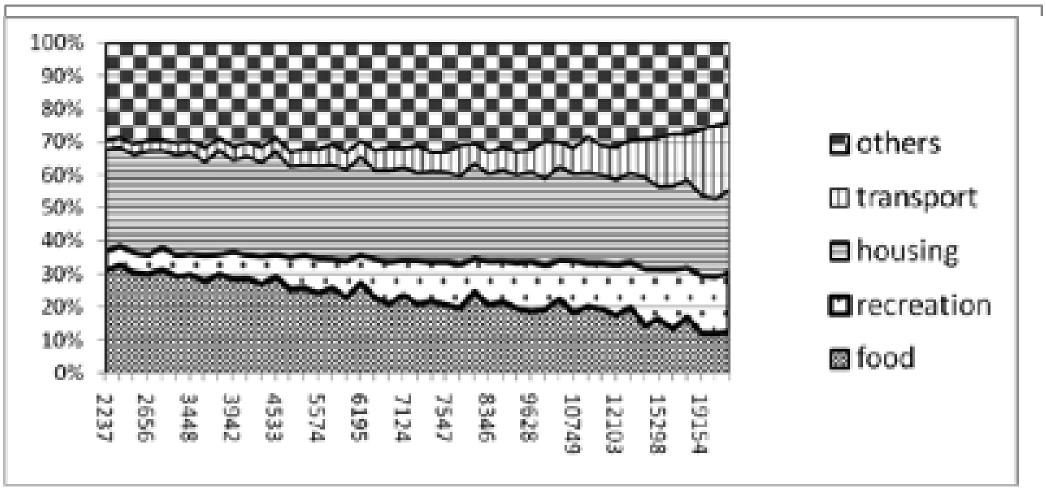

Figure 2. Breakdown of Carbon Dioxide Attributable to Chinese Households by Expenditure Category (% of Total) according to Consumption Expenditure (¥)
Source: Authors’ calculations through equation (1)

The ECF and its shares are closely related to consumer expenditure. With the consumption expenditure per capita increasing from ¥2200 to ¥27000, i.e. 11 times, accordingly, the ECF per capita increases from 540 kg to 7000 kg, i.e. 15 times. In other words, the ECF per capita grows faster than consumption expenditure, and the emissions intensity increases with the rising expenditure levels. Figure 3 shows that when the consumption expenditure is less than ¥6000, the ECF structure is relatively stable. When consumer expenditure reaches ¥8000 or higher, the portion of ECF associated with personal transport and recreation tends to rise.

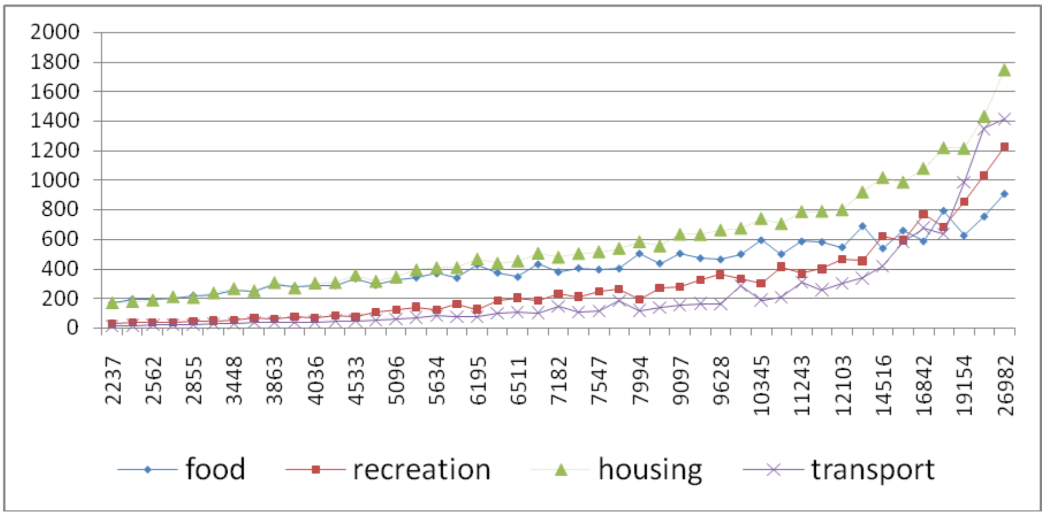

Figure 3. Absolute Amounts of Carbon Dioxide Emissions (kg) Attributable to Chinese Households by Expenditure Category according Consumption Expenditure (¥)

4.3. Structure of the Embedded Carbon Footprint

Below is some more analysis of the observed changes in the main components or categories of the urban households' ECF.

Food ECF

As the level of consumer expenditure rises from ¥2200 to ¥27000, the share of the food ECF becomes smaller and smaller from 30% to 13% (Figure 2). In absolute terms, the food ECF is relatively stable, which shows that the food-type ECF generates what we refer to as survival emissions (Figure 3). Compared to US households, where the average share of food's ECF is 9% (Shammim, 2012), food remains a very important component in the Chinese households' ECF (even the top expenditure group in China has a higher share than the US average).

Housing ECF

The breakdown of the total ECF into consumption categories shows the dominance of the housing ECF — ranging between 24 and 31% of the overall ECF (Figure 2). In contrast, the average American housing ECF is 12% (Shammim, 2012). In absolute terms, the housing ECF increases rapidly with the upward moving consumption levels. In China, this reflects the implementation of the urban housing system reform by the government whereby the in-kind welfare housing was abolished and a fully commercialised and monetised housing system is being advocated and implemented. As a consequence, housing and buying a house have become a hot spot for the improving living standards in China.

Other ECFs

The shares of transport and leisure and entertainment ECF rise with increasing consumption, respectively from 3% and 6% to 20% and 18%. When consumption expenditure per capita reaches ¥8000, these shares rapidly rise. The proportions of health and hygiene, clothing, education and communication ECFs are relatively small and remain stable. A major difference is that the share of transport alone is more than 50% in the case of US household emissions (Shammim, 2012), while it is still much lower even for the richest urban Chinese households.

4.4. Evolving Trend in ECF's Structure

In order to describe the evolution of Chinese urban residents' ECF, we construct an ECF function with respect to expenditure, as presented in equation (5). It includes a dummy variable – when the expenditure is lower than the value of the inflection point, the dummy variable is set to 0, otherwise its value is 1. By testing whether the product of the dummy variable and expenditure is significant, we can determine the existence of an inflection point.

$$ECF = \alpha + \beta D + b_1 Dx + b_2 x + \varepsilon \tag{5}$$

where D is the dummy variable, x is consumption expenditure (the unit being thousand Yuan), α and β are linear coefficients and ε is the error term.

Fang (2006) argued that the structure of household consumption will change rapidly during the 10 years after the GDP per capita exceed US$1000. It is in 2003 that the GDP per capita of China exceeded this amount for the first time and the per capita consumption expenditure of urban residents surpassed ¥6000 in that same year. Therefore, from the perspective of consumption, we assume that ¥6000 per capita is the inflection point in the the evolution of Chinese urban residents' ECF and this is tested below.

When $\begin{cases} D = 0, x < 0.6 \\ D = 1, x \geq 0.6 \end{cases}$, the coefficients b_1 and b_2 are both significant (Table 1), and ¥6000 is the inflection point of the gross per-capita ECF. Hence there is a non-linear relationship between emissions intensity and consumer spending. Table 1 shows that the coefficient b_1 is positive, so the emissions intensity will increase when the expenditure passes the inflection point which further validates the former conclusions.

Table 1. Regression Results of ECF per Capita

	b_1		b_2		**Adjusted R^2**
	Coefficient	**Significance**	**Coefficient**	**Significance**	
ECF	0.009*	0.046	0.253*	0.000	1

* p < .05.

According to Lescaroux (2011), energy consumption follows an S-curve when income per capita increases, and energy intensity follows a bell-shaped curve. The ¥6000 inflection point is still in the left half of the bell-shaped curve, leaving room for emissions intensity to increase even more. To further analyse the structural changes in the ECF, we construct an ECF function with respect to consumer expenditure as shown in equation (6):

$$ECF_i = \alpha_i + \beta_i D_i + b_{i1} D_i x + b_{i2} x + \varepsilon_i \tag{6}$$

where i stands for consumption categories, such as food, housing, clothing and so on.

We investigate the changes occurring in the ECF as consumption expenditure rises with the view to analysing how various expenditure categories and hence associated emission patterns are affected as the inflection point (threshold income level) changes.

- Assume ¥6000 to be the inflection point

With ¥6000 as the inflection point of the total ECF per capita, we can define a dummy variable that:

$$\begin{cases} D_i = 0, x < 0.6 \\ D_i = 1, x \geq 0.6 \end{cases}$$

As shown in Table 2, it is in the equations for food, clothing, recreation, communication, and education ECFs that the coefficients b_{i1} and b_{i2} are both significant. This indicates that ¥6000 is the first inflection point for those ECFs equations. In other words, the emissions intensity of those ECFs will change significantly when the expenditure exceeds the ¥6000 inflection point.

The b_{i1} coefficient is negative in the food and clothing ECF equations, which means that the emissions intensity of food and clothing will decrease when the expenditures are beyond the ¥6000 inflection point. This can be explained with the fact that in the presence of overall gradual upward trend in consumer demand, the relative shares of basic, subsistence consumption items, such as food and clothing, will reduce. In other words, the proportion of those consumptions with low income elasticity of demand will be significantly reduced with increasing income.

Table 2. Regression Results of ECF per Capita (Inflection Point=¥6000)

	b_{i1}		b_{i2}		
	Coefficients	**Significance**	**Coefficients**	**Significance**	**Adjusted R^2**
Food ECF	-0.027*	0.009	0.050*	0.000	0.931
Clothing ECF	-0.008*	0.018	0.029*	0.000	0.987
Housing ECF	-0.005	0.335	0.067*	0.000	0.995
Transport ECF	0.049*	0.002	0.018	0.232	0.954
Recreation ECF	0.019*	0.005	0.033*	0.000	0.989
Health and hygiene ECF	-0.009	0.055	0.029*	0.000	0.978
Communication ECF	-0.006*	0.017	0.017*	0.000	0.977
Education ECF	-0.005*	0.001	0.011*	0.000	0.976

* $p < .05$.

The b_{i1} coefficient is positive in the recreation ECF equation, namely, the emissions intensity of leisure and entertainment will increase when the expenditure are beyond the ¥6000 inflection point. As recreation is enjoyment-oriented consumption, when the GDP per capita reaches US$800 to 1000, consumption for leisure and entertainment will enter a period of rapid growth. Moreover, the Chinese government reformed the leave system in the country. The ratio of working days and holidays has reached 251:114, compared to 305:60 previously; leisure days now account for 31% of the year, generating demand for leisure and entertainment products and services.

The b_{i1} coefficient is negative in the communication ECF equation, which shows that communication is a basic demand in China nowadays with the country's information industry rapidly developing. The supply of information products and services is sufficient and the prices are low. Telephones, including mobiles, the Internet and other communication services have become household necessities for urban residents. Chinese also pay attention to "favour association" – the formal and informal communications between people are frequent.

The education ECF is generally linked to development and any associated emissions are expected to rise with increase of income. However this is not the case for China and the b_{i1} coefficient in this equation is negative. China has always had a fine tradition of emphasis on education and people believe that education is the last thing to sacrifice. The intense competition in the employment market urged further spending on education in recent years. Especially for low-income households, it can change a family's fate. In addition, the one-child policy made people to concentrate on this child's education. For high-income families however the emissions intensity of education will be relatively lower.

- Assume ¥8000 to be the inflection point

We let the inflection point move forward, and the redefinition of the dummy variables is as follow:

$$\begin{cases} D_i = 0, x < 0.8 \\ D_i = 1, x \geq 0.8 \end{cases}$$

In addition to the equations of the food, clothing, recreation, communication and education ECFs, ¥8000 is the inflection point of the transport ECF and health and hygiene ECF equations (see Table 3). The emissions intensity from the last two is of particular interest as an inflection point is obtained for the first time.

The b_{i1} coefficient is greater than zero in the transport ECF equation, which indicates that the emissions intensity will increase when the expenditures are beyond ¥8000. With the acceleration of the pace of life, modern transport rapidly becomes essential for households. The growing middle and the rich class have a strong desire to own cars, as the car is a status symbol and manifestation of prestige in China.

Table 3. Regression Results of ECF per Capita (Inflection Point=¥8000)

	b_{i1}		b_{i2}		Adjusted R^2
	Coefficients	**Significance**	**Coefficients**	**Significance**	
Food ECF	-0.023*	0.000	0.044*	0.000	0.937
Clothing ECF	-0.007*	0.000	0.028*	0.000	0.988
Housing ECF	-0.005	0.066	0.066*	0.000	0.995
Transport ECF	0.053*	0.000	0.022*	0.000	0.974
Recreation ECF	0.014*	0.000	0.038*	0.000	0.989
Health and hygiene ECF	-0.012*	0.000	0.030*	0.000	0.987
Communication ECF	-0.006*	0.000	0.016*	0.000	0.982
Education ECF	-0.004*	0.000	0.010*	0.000	0.976

* $p < .05$.

The health and hygiene ECF accounts for 10% of the total ECF and remains more stable. This relatively higher inflection point value indicates that the consumption of health and hygiene requires households to reach higher incomes. As living standards improve, people's health consciousness increases and various healthcare equipment and medical services enter the household. In addition, the healthcare system reform shifted the burden of medical expenses to the individuals.

- Assume ¥10000 to be the inflection point

We let the inflection point to move further up, and the dummy variables are redefined as follows:

$$\begin{cases} D_i = 0, x < 1.0 \\ D_i = 1, x \geq 1.0 \end{cases}$$

Table 4. Regression Results of ECF per Capita (Inflection Point=¥10000)

	b_{i1}		b_{i2}		Adjusted R^2
	Coefficients	**Significance**	**Coefficients**	**Significance**	
Food ECF	-0.022*	0.000	0.041*	0.000	0.940
Clothing ECF	-0.007*	0.000	0.027*	0.000	0.988
Housing ECF	-0.006*	0.014	0.065*	0.000	0.996
Transport ECF	0.055*	0.000	0.025*	0.000	0.978
Recreation ECF	0.012*	0.000	0.042*	0.000	0.988
Health and hygiene ECF	-0.013*	0.000	0.030*	0.000	0.989
Communication ECF	-0.006*	0.000	0.016*	0.000	0.981
Education ECF	-0.003*	0.000	0.010*	0.000	0.977

* $p < .05$.

Table 4 shows that ¥10000 is the first inflection point of the housing ECF equation, in addition to being an inflection point for the former seven equations. The value of the first inflection point of the housing ECF equation is the highest among all equations. The consumption or investment in housing involves a wide range, with long duration and large impacts. The total value of housing consumption is large. It takes long for urban residents to accumulate funds to be able to own a home, consequently the improvement in housing penetration is slow. In addition, its b_{i1}coefficient is less than zero, indicating that to some extent the housing reform policy has released a pulling effect of basic housing needs. We forecast that the improvement-oriented housing purchase will become a consumption hotspot in the near future. However, the absolute value of b_{i1} accounts only for 10% of b_{i2}, indicating that the household emissions intensity will remain stable.

- Expenditure elasticity of ECFs

In previous research, expenditure and income have been found to be the strongest predictors of household energy requirements or environmental impacts (Lenzen et al., 2004; Reinders et al., 2003). Here we test a common model form to estimate the expenditure elasticity, ε_i (dimensionless), of ECFs, defined as:

$$\varepsilon_i = \frac{\bar{x}}{\overline{ECF_i}} b_i \qquad (7)$$

where $\bar{x}$ is average consumption expenditure, measured in Yuan (¥) and $\overline{ECF_i}$ is average ECF for category i, measured in kilograms CO_2 emissions; b_i refers to coefficient b_{i2} (as defined earlier).

Table 5. Expenditure Elasticities of ECFs

	ε_i<¥10000	**ε_i>¥10000**
Food ECF	0.677	0.463
Clothing ECF	1.191	0.875
Housing ECF	0.925	0.893

Transport ECF	1.768	2.122
Recreation ECF	1.607	1.341
Health and hygiene ECF	1.003	0.644
Communication ECF	1.243	0.792
Education ECF	0.766	0.762

All expenditure elasticities of ECFs are greater than zero. When the expenditure is below the ¥10000 inflection point, the expenditure elasticities of clothing, transport, recreation, health and communication ECFs are greater than 1, indicating that those ECFs are "luxury" emissions. When the expenditure is beyond the inflection point, the expenditure elasticity of the transport, recreation and housing ECFs is larger, with the former two more than 1; hence transport and recreation ECFs belong to "luxury" emissions. In all consumptions, only the transport ECF expenditure elasticity beyond the ¥10000 inflection point is larger than that below the inflection point. This shows that the "luxury" emissions are relative to income and therefore, we need to focus on these "luxury" emissions beyond the inflection point.

The above analysis shows that the emission intensities of Chinese urban residents' consumption still have room for growth, which stems from changes in the consumption structure. Two types of consumption emissions are particularly important: first, when the value of the first inflection is larger, and second, the "luxury" emissions beyond the ¥10000 inflection point. Accordingly, transport, housing, and recreation consumptions are these areas of focus.

5. CONCLUSION

The Chinese urban households are no longer satisfied with the provision of basic needs and are fast adopting Western lifestyles (Hubacek et al., 2009) which has significant implications for their overall ecological footprint. This study sheds some light on how their embedded carbon footprint evolves with the increasing levels of household income.

The above analysis shows that the ECF structure is stable. The food and housing ECFs are dominant when consumption expenditure is below the ¥6000 inflection point, while the rest ECFs account for a smaller proportion. When consumption expenditure is beyond the ¥10000 inflection point, the ECF structure changes significantly: food, clothing and other survival-oriented emissions intensity, and education, health and other developmental-oriented emissions intensity reduce; transport, recreation, housing and other enjoyment-oriented emissions intensity increases or remains stable, and the total emissions intensity increases. Thus the increase in emissions intensity stems from structural change in consumption. Income and other economic factors, housing reform, education reform, medical reform and other policy factors, and the inner law of consumer demand play a leading role in these trends.

The current per-capita consumption expenditure of Chinese urban residents has exceeded ¥10000, and the expenditure of low-income class has also entered the ¥6000 range. China is gradually moving towards the road of high-carbon consumption. Therefore, appropriate restricting and control policies need to be developed.

5.1. Recreation-oriented Consumption

The share of the housing ECF is larger, accounting for 30% of the total ECF, and is relatively stable. The value of the first inflection point of housing ECF is the largest. Therefore, housing consumption should be the focal point in reduction policies. The expenditure elasticity of transport ECF is more than 1 below and beyond the ¥10000 inflection point, and the latter is larger than the former. As the current expenditure per capita of urban residents in China has entered the ¥10000 range, transport consumption should be at the core of carbon-reduction policies.

Leisure and entertainment consumption is generally considered “green”, but the calculations of the ECF show that recreational consumption also generates a lot of “invisible” carbon emissions. In particular, when the expenditure level reaches ¥6000, the emissions intensity of recreational ECF rapidly rises. Hence, carbon emissions produced by recreational consumption also require full attention.

5.2. Consumption-based CO_2 Emissions Quota System

The study showed that there are close relationships between personal emissions and consumption patterns and a gap between consumer classes. This is not surprising in the presence of similar disparities in the developed world where the debate about personal carbon allowances has been in existence since the 1990s (Fleming, 1997 and 2007). In the UK, for example, support for personal carbon quotas is strong among civil society groups and is also being taken seriously by government (Seyfang et al., 2007; Hyams, 2009). The moral value of such a distributive principle is argued on the basis of social justice (Hillman and Fawcett, 2004; Monbiot, 2007; Hyams, 2009). Governments in developed countries are urged to develop methods that can help achieving this (Hyams, 2009). Similar arguments are being raised within an international context where different countries should be allowed different carbon quotas depending on the level of their development and contribution towards atmospheric pollution (Vanderheiden, 2008; Garnaut, 2008). Militaristic parallels are drawn for the urgency for action in the “war against climate change” (Cohen, 2011).

A fair consumption-based CO_2 emissions quota system can also be built in China whereby each person is given a certain quota of CO_2 emissions, and CO_2 emissions credits can be traded in the secondary market. Aggregate emissions targets can determine the sum of rights to emit. The manufacturers of goods and providers of services will generally be encouraged to lower the carbon footprint of their products so that consumers can fit within their allocated quotas. Also, in such a system each commodity can have an ECF tag and it is likely that goods with a lower footprint will be priced higher. This will allow people to understand the direct results of their consumption and to a certain degree, internalise the social costs of their actions. The poor whose expenditures are low and who cannot afford more expensive goods, could buy the cheaper products even if their ECF is relatively higher as their overall carbon emissions will be low. The rich, in order to consume more goods and services, will have to buy the more expensive products with lower ECF as their total emissions will be high. Research from the UK based on computer simulation of people’s behaviour when personal carbon allowances are introduced, indicates that positive outcomes from such a measure can be expected (Capstick and Lewis, 2008).

The use of personal carbon quotas is not a simple policy option as it requires “setting the national carbon budget, setting individual allowances and surrendering allowances”, the use of “smart cards” and essentially represents a new form of currency (Seyfang et al., 2007: 3). The costs for running such a system will have to be included in the market price of goods or borne by the government. There is also a range of issues related to what represents a fair entitlement and whether governments are prepared to embark on such a brave political act. China has entered the total emissions control era, and in many ways, it is better positioned to deal with the complexity of issues than western democracies. Establishing a consumption-based carbon quota system can assist the government in its desire to cut down emissions this but further studies are required for determining its viability and possible successful implementation.

Personal carbon quotas is just one available policy option in cutting household emissions. Proper environmental labelling of household products is another easy avenue for informed customer decisions. There are also speculations that China may consider introducing a carbon tax and is trialling emission trading schemes (Lin and Yang, 2012).

However, the strengthening of environmental regulations is certainly the most needed measure for the Chinese economy. It can be expected that in order to obtain higher profits, the manufacturers will increase investment in technological innovation, research and development to produce more low-carbon products so that they could achieve effective control of any carbon quotas or restrictions from consumption to production areas. Such environmental regulations will provide a new implementation path for the Porter hypothesis as far as Chinese companies are concerned.

A possible implementation of a carbon quota system will involve calculating the ECF of specific products and the allocation of personal carbon quotas, and this needs further investigation and development of management mechanisms. In the meantime, environmental policy regulations can offer some continuity and stability, particularly if China's central and local governments become more effective in introducing, monitoring, controlling and policing their implementation.

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