Household Energy Use and Carbon Emissions in China:

A Decomposition Analysis

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Abstract

Although its per capita carbon emissions are still relatively low, China's aggregated carbon emissions have grown by nearly 4-fold in the last three decades, and now it is the biggest CO2 emitter in the world. There are many reasons for this emissions growth, and much emphasis has been placed on industrial development, but previous research has estimated that 40% of the growth in Chinese CO2 emissions over the 15 years to 2007 can be attributed to household energy consumption. In this paper, we conduct a decomposition analysis to show that in the period from 1978 to 2008 nearly 60% of the growth in Chinese household emissions can be attributed to the increasing number of households and 40% to increasing emissions per household. We also show that over this period emissions growth in urban households has been six times that of rural households. These results have important implications for policy makers seeking to promote reductions in China's CO2 emissions, relating for example to family planning and urbanization.

Keywords: households; population; Responsibility; decomposition; carbon emissions; China; Policy

1 Introduction

The history of developed countries shows that industry is the major source of new carbon dioxide (CO_2) emissions in the development process. However, a considerable proportion of industrial emissions are released in order to satisfy the demand from households for consumption. If these industrial emissions are attributed to household consumption, then household consumption becomes one of the major sources of CO_2 emissions. For example, more than 30% of CO_2 emissions in U.S. are directly related to household consumption (Vandenbergh et al., 2010) and 40% of the emission growth in China in the period from 1992-2007 can be attributed to households for consumption (Minx et al., 2011). The important role of household consumption should not be overlooked by policy makers since there is potential for energy policies – and numerous other policies - to change household consumption behavior to reduce energy consumption and associated emissions. Better understanding of household energy use and decision-making processes is therefore necessary if effective policies and programs are to be introduced (Dietz et al., 2013).

China has achieved rapid economic development by adopting the reform and opening-up policy since 1978 and it is now the second biggest economy in the world. With the steady growth of population and levels of urbanization, average living standards in China have been improved continuously. However, energy consumption and the associated carbon emissions have increased considerably over the past three decades so that China has become the biggest aggregate CO2 emitter in the world (Le Quéré et al. 2013).

Since 2007, the Chinese central government has started to publish key policies to control emissions in China's National Climate Change Program. In the 2012 report on policies and actions for addressing climate change (NDRC, 2012), the general public is encouraged to reduce carbon emissions in daily life by means of knowledge dissemination activities, but no specific policies or actions targeting energy use in households have yet been adopted. In 2012, household consumption accounted for 36% of Chinese GDP (NBSC, 2013) and it is expected to increase further in the future. Considering the high share of household consumption in the economy, it is necessary to explore the important role of households in carbon emission abatement.

There is an argument that the family planning policy adopted in China since 1970s has helped carbon emissions reduction with estimates of the impacts varying between 100 million (Wang and Cai, 2010) and 400 million births prevented (Li, 2009). Currently the debate on the policy is going on and the strict policy has been relaxed slightly as part of the response to an ageing society and this could have important implications for energy use and carbon emissions. However, Satterthwaite (2009) shows that the growth in population does not necessarily drive the growth in greenhouse gas (GHG) emissions but rather that the growth in consumers and in their levels of consumption does. Since members of a household often make consumption decisions as a joint unit, it seems more plausible to consider the growth in households rather than population as one of key drivers of the emission growth.

Rapid economic growth in China has also been accompanied by rapid urbanization in the past three decades, leading to more households living in cities and less in rural areas. The share of urban population has dramatically increased from 18% in 1978 to 53% in 2012 (NBSC, 2013) and is expected to keep increasing in the near future. The movement of a person from a rural to an urban area implies significant change in lifestyle, and this has important implications for energy consumption. Leaving out self-produced energy – for instance from burning firewood - the commercial energy (i.e. purchased fuel and electricity, which are included in the official statistics system) use per capita of urban households in China was nearly 1.5 times of rural households in 2011 (NBSC, 2012a), but it is important to note that the average income of urban households was more than three times that rural households at this time (NBSC, 2012b).

In this paper, we examine the contribution that the changing level and composition of household energy consumption makes to Chinese carbon emissions so that the impacts of various types of households on emission growth in China can be estimated. Firstly, we estimate the contributions to emission growth of households in China in the period from 1978-2008. After the impact of the increasing number of households is separated from impact of changing emissions per household, we further explore impact of reducing household size and other determinants of emissions growth from rural and urban households respectively.

The remainder of the present paper is organized as follows. The next section justifies the methodology adopted in this study. Section 3 briefly describes the time series data used in the analysis, and Section 4 offers results and analysis on the contributions to emission growth of households. Section 5 offers discussions on the policy implications and sensitivity analyses of our study, and the last section concludes the paper.

2 Methodology

In order to estimate the impacts of changes in both the number and the size of households on emission growth, we adopt a complete two-stage decomposition approach that Hoekstra and van den Bergh (2003) call the refined Divisia method. As with other decomposition approaches, the two-stage approach assumes the proportional effects of each determinant on carbon emissions, other things being equal.

Decomposition approaches in environmental studies can be dated back to the widely applied IPAT accounting model that was first proposed in the early 1970s to analyze important determinants of anthropogenic environmental impacts (Ehrlich and Holden, 1971, 1972). The IPAT model categorizes three determinants of environmental impact (I) as population size (P), affluence (A) represented by per capita consumption or production, and technology (T) to capture the effects of all the other factors and assumes that each has a proportional effect on the environment. The IPAT model is a good starting point to help understand the impacts of human behavior on environment, and it is also the basic equation behind our research.

Previous research has conducted decomposition analyses to examine the determinants on carbon emissions in China. At least four studies focus on changes in lifestyles. Wei et al. (2007) quantify the impacts of the lifestyles of urban and rural residents on China's energy use and the related CO2 emissions during the period 1999–2002 based on the application of a consumer lifestyle approach (CLA).They find that 30 per cent of CO2 emission are consequences of residents' lifestyles and related economic activities. Feng et al. (2009) use the IPAT model to analyze the impacts of changing levels of income and urbanization and changing lifestyles on the growth of CO_2 emissions of five regions in China over the period of 1949-2002. They find that technological improvements have not been able to compensate fully for the increase in emissions due to population growth and increasing wealth. Minx et al. (2011) adopt a structural decomposition analysis (SDA) approach to study the explanatory factors behind the rapid growth of carbon emissions in China. They conclude that "Urbanization and the associated changes in lifestyle are shown to be more important than other socio-demographic drivers like the decreasing household size or growing population". Hubacek et al. (2012) find that the contribution of population growth to emissions in China has been relatively small since the late 1970s, and there is a huge disparity between urban and rural households in terms of changes of lifestyle and consumption patterns.

Other studies focus on energy use. Zhang (2000) decomposes China's CO_2 emissions during 1980-1997 to explore the historical contributions of fuel switching, energy conservation, economic growth and population expansion over time, and includes that China has made a significant contribution to reducing global CO_2 emissions in terms of continuous decrease in energy intensity. Wang et al. (2005) focus on the impacts of energy-related determinants using time series from 1957 to 2000, and indicate that China has achieved a considerable decrease in its CO_2 decrease mainly due to improved energy intensity, moreover, fuel switching and renewable energy penetration also contribute to CO_2 reduction. Zhang et al. (2009) also focus on energy-related determinants even though they adopt a different decomposition method using time series from 1991 to 2006. In their study, energy intensity effect is confirmed again as the dominant contributor to the decline in CO_2, in addition, economic structure and CO_2 emission coefficient effects are found to contribute little to the changes in CO_2 emission. Zha et al. (2010) estimate and compare the CO_2 emissions in China from urban and rural residential energy consumption from 1991 to 2004 by applying the index decomposition analysis (IDA) approach, and find that the population effect contributes to the increase of residential CO_2 emissions with a rising tendency in urban area, while it keeps decreasing since 1998 in rural China. Ma and Stern (2008) investigate China's carbon emissions during 1971–2003 with a particular focus on the role of biomass using the logarithmic mean Divisia index (LMDI) method. They include that a shift from biomass to commercial energy increases carbon emissions, and the positive effect of population growth has been decreasing over the observed period.

In all of these studies, the share of emissions attributed to households is typically associated with household consumption, directly or indirectly. The emissions related to investments and exports are not taken as contributions of households. In our study, we argue that all emissions should be attributed to households for current and future consumption. Total emissions are generated to meet demand from households for current consumption and non-households for investments and exports. For example, 27% of total Chinese emissions in 2007 can be attributed to exports to satisfy foreign demand (Minx et al., 2011). Consumption-based approaches would attribute responsibility for these emissions not to Chinese producers but instead to foreign consumers(Munksgaard and Pedersen, 2001). However, Chinese households receive income from satisfying the export demand that will be used for consumption and future investments that aim to create income for future consumption. Therefore, emissions related to current exports and investments can be seen as contributions to future household consumption. Hence, all emissions can be attributed to domestic households since the emissions are released for either current or future consumption of the households.

In order to indicate the tradeoff between current and future consumption made by households at the aggregate level, we use the inversed consumption-GDP ratio since GDP can be taken as a proxy for the income of all households and income generated from investments and exports that will be used for future consumption. In our analysis, the income corresponding to the governmental expenditure is linked for future consumption even though part of the income is used for current consumption. The higher the consumption-GDP ratio, the more is the current consumption and vice versa. Hence, the inverse of consumption-GDP ratio indicates the income level (GDP) by assuming current consumption to be 1 and that the income is always greater than 1. The higher the inversed ratio, the higher share of income is saved for future consumption.

In our decomposition approach, we highlight the role of households and consider five determinants or impact factors shaping carbon emissions, these are the number of households, household size, household consumption, gross domestic product (GDP) and the carbon intensity of GDP in mainland China from 1978 to 2008. Each of these determinants or impact factors is broken down into urban and rural households to highlight the differences between the contributions from the two household groups. The details of the decomposition approach are described further in the Appendix.

3 Data description

The data used in our study address the determinants or impact factors outlined above. Carbon emissions from fossil fuels are derived from the data center of the Carbon Dioxide Information Analysis Center of Oak Ridge National Laboratory, USA (CDIAC., 2011). Data on household size, consumption, GDP and population, which is used to derive the number of households, are directly taken from a series of China Statistical Yearbooks, annually updated by National Bureau of Statistics of China. Both GDP and consumption data are comparable since they are adjusted on the basis of 2000 constant prices.

The urban population used to derive the number of urban households is defined as total permanent residents who live in cities and towns in China. More specifically, the urban population includes both registered residents in an urban area and the migrants who have lived in that urban area for more than half a year but have not registered as permanent residents in urban area.

The development paths of variables in the IPAT identity (Eq. 1) are presented in Figure 1, indexed against 1978 values. During the period, per capita GDP (A) presents the fastest growth of nearly 12.5 times, followed by the carbon emissions (C, nearly 5 times), and population size (P, less than 1.4 times). The only decreasing variable is carbon intensity (T), which in 2008 becomes less than 30 percent of the 1978 level. If we look into the shapes of the curves, we find that the curve of per capita GDP (A) becomes steeper over time, indicating an exponential trend. On the contrary, carbon emissions grow smoothly until 1995, then level out until 2002, and then speed up again to 2008 when the rate of growth slows again.

Insert Figure 1 about here.

The number of urban households in 2008 is more than 5 times that of 1978, but the number of rural households is only 1.3 times higher in 2008 than in 1978. On the other hand, average household size is continuously shrinking for both rural and urban households. Urbanization plays an important role in the process since an urban household generally consists of fewer members than a rural household. According to the data sources, if there are members of a rural household who work in cities, they are counted as members of the urban household if they have stayed in the cities for over half a year.

Per capita GDP is divided into per capita consumption and the inverse of consumption-GDP ratio. During the period, per capita consumption increases rapidly. In 2008, it is 33 times and 27 times of the 1978 level for urban and rural households respectively. The inversed consumption-GDP ratio is decreasing at the beginning of the period and increasing after 1985. By the end of the period, it is more than 1.3 times of the 1978 ratio. This indicates that although residential consumption level grows dramatically, its share of GDP exhibits a decline tendency due to export and investment increase at a faster speed over this period.

4 Results and analysis

Urban households dominate emission growth

By deploying the complete two-stage decomposition described in the Appendix, we calculate the cumulative changes in carbon emissions attributed to households as a whole (Figure 2). Cumulative emission growth keeps increasing in all years except slightly decreasing in 1998 and 1999, when Asia financial crisis happened. At the beginning of the period, urban households contributed almost the same emissions as rural households even though in most years total emission growth was dominated by the contributions of urban households. However, particularly since the 1990s, urban households have contributed much more to emissions growth than rural households. The tendency becomes more obvious after 2000 with the rapid development of the housing market in urban areas. As a result, during the whole period, urban households contribute 1300 million metric tons (MMT) to emission growth, accounting for 85% of the total and six times that of the contribution of rural households. However, we may overestimate the contributions of rural households since they have a lower saving rate and a lower carbon intensity due to less use of fossil fuels[1]. If the principle of Common but Differentiated Responsibility is applied at the household level, then urban households would have to take the major responsibility to reduce emissions in the future. Urban households should be responsible for 85% of future emission abatement if the emissions during 1978-2008 are criteria for distribution of the emission abatement responsibilities. Notice that emissions from bioenergy are not considered in the study and rural households use more bioenergy in daily life for

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[1] Our decomposition approach assumes the same saving rates and carbon intensity for both urban and rural households.

cooking and heating. Even though bioenergy are considered to be renewable and carbon neutral, the bioenergy use also produces emissions of black carbon, which is a short-lived greenhouse gas but might have considerable impacts on local climate (Berntsen et al., 2006; Joos et al., 2012).

Insert Figure 2 about here

Number of households and emissions per household

To further examine the role of households, we consider the impact that both the number of households and emissions per household have on emissions growth. As shown in Figure 3, emission growth attributed to the number of total households are gradually increasing over time and reach a level of 858.8 MMT in 2008, thereby accounting for 56.5% of total cumulative emission growth during 1978-2008. The effects of emissions per household are negligible before 2003 but started to speed up until 2008.

In Figure 3, we also list the contributions of the number of urban households and emissions per urban household respectively. Both of them follow the same pattern but are slightly lower than total households, indicating the dominant role that urban households have on emissions growth in the period. Conversely, the contribution of the number of rural households keeps increasing until the middle of 1990s achieving the peak of 100 MMT and then slightly deceases until 2008. Emissions per rural household are almost stable before 2000 and then speed up sharply, the same as urban households, achieving a level of nearly 150 MMT in 2008.

Insert Figure 3 about here

Household size

Shrinking household sizes in both rural and urban households result in less emission growth per household (Figure 4). This seems contradict the observation that smaller household size always leads to more emission growth. However, if we focus only on one household, the intuition would be the smaller household size, the less energy use. Our positive effect of household size coincides with the expectation and can be understood as direct effect of the household size. The indirect negative effect of household size is then captured by the impacts of an increasing number of households in our analysis. In addition, the positive effect of household size is also consistent with the widely accepted assumption that less population implies less carbon emissions, other things being equal.

As a whole, we find that the decreased emission growth due to the shrinking household size reaches a level of 280.8 MMT in 2008, a level that is 18.5% of total observed emission growth during the period. The contributions of urban households are slightly more than that of rural households until the early 1990s and then the gap between the two groups gradually enlarged. However, the dominant role of urban household size is not marked compared to the effects of the number of households and emissions per household.

Insert Figure 4 about here

Consumption per capita

We find that the cumulative contributions from consumption per capita of all households keep increasing to a level of 1602 MMT or 105.5% of total observed emission growth, slightly more than the total observed emission growth in 2008 (Figure 5). This implies the effects on emission growth of all other determinants almost cancel each other out, i.e., the positive effects of the number of households and the inverse of consumption-GDP ratio are almost cancelled out by the negative effects of household size and carbon intensity.

At the beginning of the period, rural households contribute more than double the amount of urban households to emission growth due to faster increasing consumption per capita alone. This reflects the fact that the original reform in China was initiated from rural area and farmers benefited from it earlier. However, urban households continuously increase their contribution at a faster speed than rural households so that by end of the period urban households contribute double the emission growth of rural households. This also suggests greater responsibility should be given to urban households to reduce carbon emissions in the future.

Insert Figure 5 about here.

The tradeoff between current and future consumption

The inversed consumption-GDP ratio is used to indicate the tradeoff between current and future consumption made by households at the aggregated level. During the period, the inversed consumption-GDP ratio tends to increase over time since more and more income has to be saved to meet the demand for investments and exports. As a result, the cumulative contributions from the inversed ratio tend to increase so that they achieve a level of 349.7 MMT carbon emission growth or 23.0% of total observed emission growth in 2008 (Figure 6). The increased emissions due to the inversed ratio are expected to be reduced or even to decrease in the near future when households spend greater share of their income on current consumption.

Insert Figure 6 about here.

Carbon intensity

Carbon intensity represents a generalized concept of technology, including at least three determinants: the energy consumption level per unit output, the energy mix, and the associated emissions per unit energy. Carbon intensity tends to be decreasing over the period and is the major determinant leading to a considerable reduction in emissions (Figure 6). During the period, the cumulative effects of carbon intensity result in more than 1010.8 MMT carbon emissions reduction or 66.5% of the total observed cumulative emission growth.

The carbon intensity increased slightly only in 2003 and 2004. This leads to the inversed U-shape curve during 2002-2008 in Figure 6. This is mainly the result of changes in energy intensity, i.e., energy use per unit GDP. A possible reason could be the changes in industry structure that resulted from the rapid development of construction sector in China since 2002.

5 Discussion

We find that urban households are the main driver of emissions growth in China in the past three decades, implying that these households should have greater responsibility for emission reduction in the future. Nowadays China is at a demographic turning point, changing from an agricultural society into an urban one, and from a society attached to the land to a more floating one (Peng, 2011). Urbanization in China is expected to continue in the next decades, and the dominant role of urban households will be enhanced. Even though household size may continue to shrink for a long period due to the influence of urbanization and a floating population, a continuation of the trend from 1978-2008 will mean more households are expected to remain in cities and to contribute more to emission growth in the future. Therefore, the dominant role that urban households play in shaping emissions growth will continue and more policies targeting at urban households have to be made to reduce carbon emissions in the future.

However, the improvement of rural households' energy use should not be forgotten. Due to the specialized urban–rural dualistic structure, a significant disparity exists between urban and rural areas in China and per capita expenditure of urban households has been 3.5 times that of rural households for the past decade (Zhu and Peng 2012). The decomposition analysis of our research also shows that the contributions to emission growth of rural households are much smaller than urban households. Considering the social and economic inequality between rural and urban households, more financial and technological support should be provided to spread the application of clean energy in rural areas, so that rural residents' basic right to survival and development can be well respected and protected. This provision would also be an embodiment of the principle of Common but Differentiated Responsibility at the household level.

The effects of both the changing number of households and reductions household size can be summed up to the effect of population increase. From 1978 to 2008, population increases contribute 578 MMT or 38.1% of the total observed emission growth. A conservative estimate of the impacts of the family planning policy in China is that it prevented about 100 million births (Wang and Cai, 2010). According to our rough approach, if the unborn population were added to create more households with household size and consumption per capita kept the same as the historical data, then we would have additional 65 MMT of emission growth. If, on the other hand, the unborn population were to increase household size while the number of households and consumption per capita are kept at the same historical level, then we would have additional 21 MMT emission growth. Hence, the effect of changing the family planning policy in the near future is quite uncertain.

In fact, the natural growth rate of population in China has declined for nearly three decades, with a yearly increased population from more than 17 million in the mid-1980s decreasing to less than 7 million in recent years. Meanwhile, the continuous reduction in household size rapidly increases in the total number of households. Even if the population stops growing, the number of households will increase for some time. Considering that the strict family planning policy in China has already been relaxed to some extent, population growth will continue to influence China's carbon emissions for one or two decades. According to our approach, with other things being equal, the impacts of population change on emission growth in China will mainly depend on the tradeoff between the effects of the increasing number of households and the decreasing level of average household size. However, such dependence does not necessarily mean that the growth in population accelerates emissions growth. As our results suggest, the positive effect of more population in the near future might not be an issue at all, assuming less consumption growth per capita, less income saved for future consumption, and even the stronger negative effect of carbon intensity that might result from the ambitious national target on emissions reduction (UNFCCC, 2010).

In the past three decades, the inversed consumption–GDP ratio of China has markedly fluctuated upward, indicating that China has saved a larger share of income for future consumption. This observation is supported by the export-oriented industrial structure and the large-scale investments dominated by the government. The positive effects of the inversed consumption–GDP ratio during this period indicate that the increased shares of export and investment in China’s economy have driven the growth of emissions. However, it is impossible to always save for the future without spending and the situation could not continue forever. Changes may happen in the near future given changes in the world economy that may reduce exports from China. Furthermore, the investments dominated by the government have been so strong that it becomes difficult to invest more in the economy in the near future. China has noticed this situation and has already started to encourage domestic consumption by various policies and measures. Conceivably, China might become a net importer in the future, meaning reduction of domestic emissions and their replacement with emissions embodied in the imported products. Hence, we would expect that greater share of GDP will be used for current consumption. The inversed consumption-GDP ratio will decrease in the near future and its effects on emission growth will decline gradually, even possibly be negative instead of positive.

Moreover, consumption per capita might grow at a lower rate and contribute less to the emission growth in the near future. As mentioned above, net exports and investments may not necessarily serve as the key drivers of the economic growth any more. At the same time, domestic consumption is difficult to speed up in the short term since a thorough all-inclusive social security system has not yet been established, and the preferences of consumers may not change dramatically overnight when they have to face the uncertain risks of illness, unemployment and high housing prices. In addition, China is experiencing fast and profound population ageing with rapidly declining fertility and increasing life expectancy. Both the size and share of the working-age population have decline since 2012, indicating that the window of opportunity for China's "demographic bonus" is closing. These observations all suggest a possible lower economic growth rate in the near future.

Peters et al. (2007) have concluded that the carbon emission growth is a race between increasing consumption and technology or efficiency gains since other determinants are relatively stable over the period. In this context, *consumption* is represented by GDP, which is the product of consumption and the inversed consumption-GDP ratio in our analysis. Hence, the contribution of consumption in our analysis should be less than those in Peters et al. (2007). Consumption per capita in our analysis contributes to emission growth at almost the same rate as the total observed emission growth. This allows us to say that the effects of technology represented by carbon intensity are almost cancelled out by effects of population growth and the tradeoff between current and future consumption represented by the inversed consumption-GDP ratio. With less income saved for future consumption and better technology expected, there would be more room for population growth provided emission growth is coupled with changing consumption per capita.

The change in carbon intensity exerts a significantly negative effect on emission growth during this period. It is naturally deemed one of the most critical points in terms of energy conservation and emission reduction. The contributions of carbon intensity equal the sum of the effects of both energy intensity and the carbon emission factor. Therefore, two main approaches are generally used to reduce carbon intensity: one is to reduce energy intensity by promoting technological progress and increasing energy efficiency and the other is to reduce the carbon emission factor by improving the energy mix. However, we should not overlook that industry-wide carbon intensity can also be reduced by adjusting the economic structure.

To check whether our results are strongly influenced by the assumptions we have made in this study, we conduct some sensitivity analyses to test the significance of the assumption. The uncertainty of our findings might be associated with the assumption on the links between GDP and household consumption. As mentioned above, we used the inversed consumption-GDP ratio to indicate roughly the trade-off between current and future consumption made by households at the aggregate level, assuming all the income corresponding to the governmental expenditure to be future consumption. However, the inverse consumption-GDP ratio might underestimate current household consumption due to overlooking the part of the government income used for current consumption. To test the sensitivity of this assumption, we consider an extreme case where all the governmental expenditure is treated as current rather than future consumption. The governmental expenditure is then allocated into household consumption proportional to urban and rural populations and their consumption patterns over this period. In the extreme case, the cumulative contributions from current household consumption from 1978 to 2008 are increased by a further 3.2% of total observed emission growth (or 49.3 MMT carbon) compared with that based on our original assumption. Correspondingly, the cumulative contributions from the inversed consumption-GDP ratio are reduced by the same amount of carbon emissions growth. Hence, the deviation caused by the original assumption would be less than 3.2% of the total observed emission growth, which we consider is within acceptable limits, and our original assumption would not lead to a substantial misjudgment regarding the contributions of carbon emissions of households in China.

6 Conclusions

By adopting a complete two-stage decomposition approach, the current study quantitatively illustrates the contributions households to the growth in carbon emissions in China. The growth of carbon emissions from fossil fuels is decomposed to consider the effects of five impact factors, i.e., the number of households, household size, per capita consumption, inversed consumption–GDP ratio, and carbon intensity. The effect of each these impact factors is then broken down to consider the influence of urban and rural households. Our key results are as follows:

(1) From 1978 to 2008, nearly 60% of emission growth can be attributed to the increasing number of households and the other 40% due to increasing emissions per household.

(2) Decomposition of emissions per household suggests that reduced household size decreases emissions by less than 20%.

(3) The contribution urban households to emission growth is six times that of rural households.

(4) The cumulative contributions from the inversed consumption–GDP ratio increase and achieve 23% of the total observed emission growth in 2008.

(5) Consumption per capita contributes to emission growth by almost the same amount as the total observed emission growth.

(6) The cumulative effects of carbon intensity result in reducing nearly 70% of total observed cumulative emission growth.

Some of the possible policy implications of these results have been discussed. We point out that urban households should take the major responsibility for emission abatement in the future due to their dominant historical contributions to emission growth. Meanwhile, the basic right to survival and development of rural households has to be respected and protected. The principle of Common but Differentiated Responsibility can be extended to the household level by, for instance, taking urban households as “developed countries” and rural households as “developing countries.” We also point out that the effect of family planning policy on emissions is uncertain given the high interdependence between the key determinants of emissions. Hence, the relaxation of the family planning policy may not result in more emissions, but this is not clear.

The policies to encourage domestic consumption in China can increase the share of GDP for current consumption and lower domestic emissions growth in the near future since less investment, less exports and more import are expected. In the near future, increasing consumption per capita may contribute less to emissions growth given slower economic growth in the rest of the world and the challenges of economic structural change in China. The ambitious national target on emissions reduction (UNFCCC, 2010) may keep carbon intensity continuously as the key driver of emission abatement.

Acknowledgments

This study was supported by the Research Council of Norway (grant 209701/E20) and the National Natural Science Foundation of China (grant 71333010). The final version was completed during Zhu Qin's visit at CICERO supported by China Scholarship Council and the Research Council of Norway (grant 230606/E10). Zhu Qin is also grateful for the financial support from the Humanities and Social Sciences Project of Ministry of Education of China (No. 11YJCZH260), and the Fundamental Research Funds for the Central Universities of China.

Appendix. The decomposition approach

We start our two-stage decomposition approach from the IPAT model, which can be expressed by

$$C_t = P_t A_t T_t, \qquad \textbf{(1)}$$

where t denotes a year between 1978 and 2008, C_t the annual national carbon emissions to replace the impact on the environment (I) in IPAT, P_t the population size, A_t per capita GDP, and T_t carbon intensity defined as carbon emissions per unit GDP. Based on the IPAT identity, we develop our decomposition model as follows.

P in IPAT is replaced by two demographic factors: number of households $(N_t^u \quad N_t^r)$ and household size $\begin{pmatrix} S_t^u & 0 \\ 0 & S_t^r \end{pmatrix}$ in order to focus on the impacts of households instead of population. In the two expressions above and expressions below, the superscript u indicates urban households and r rural households. Notice that the inversed household size has been included as a determinant (Minx et al., 2011). However, in our opinion, if less population in a country implies less emissions, which is widely accepted, it is not plausible to assume less members of a household (household size), on the contrary, imply more emissions in the same context.

The A in IPAT represented by GDP is decomposed to be two terms:

(1) Residential consumption (represented by expenditure) per capita in urban and rural area $\begin{pmatrix} e^u = \frac{E^u}{P^u} \\ e^r = \frac{E^r}{P^r} \end{pmatrix}$, where E^u is total consumption of urban households and E^r total consumption of rural households. This term captures different consumption levels between rural and urban households.

(2) The inverse of consumption-GDP ratio $R = \frac{GDP}{E}$, where E is total households consumption, i.e., the sum of consumption of both rural and urban households. If GDP is taken as a proxy of total income of all households

represented by the country, this term captures the difference between current consumption and savings for future consumption. In other words, if a country is taken as a representative consumer, the higher the ratio (R) implies the more income saved for future consumption. In this sense, this ratio can be taken as a patience indicator for future consumption.

We still keep T as the carbon intensity, representing a generalized concept of technology, including at least three determinants: the energy consumption level per unit output, the energy mix, and the associated emissions per unit energy.

Notice that we do not distinguish rural households from urban households for the inversed consumption-GDP ratio. This implicitly assumes the same saving rate for both rural and urban households. The assumption may lead to overestimate the contributions of rural households if they have a higher saving rate. In addition, the assumption of the same carbon intensity (T) for both types of households may also lead to overestimated contributions of rural households since they use less fossil fuels and have a lower emissions intensity, which can be defined as carbon emissions per unit income of a household.

Hence, the IPAT identity is modified to become:

$$C_t = \begin{pmatrix} N_t^u & N_t^r \end{pmatrix} \times \begin{pmatrix} S_t^u & 0 \\ 0 & S_t^r \end{pmatrix} \times \begin{pmatrix} e_t^u \\ e_t^r \end{pmatrix} \times R_t \times T_t. \tag{2}$$

This equation can be rewritten as the sum of two terms: one is related to urban households

$$C_t^u = N_t^u \times S_t^u \times e_t^u \times R_t \times T_t. \tag{3}$$

and the other is related to rural households

$$C_t^r = N_t^r \times S_t^r \times e_t^r \times R_t \times T_t. \tag{4}$$

At the first stage, the logarithmic mean Divisia index (LMDI) decomposition approach is adopted for both terms respectively to obtain the effect of each determinant from one year t to the next year *t*+1. We sum up to obtain effects on emission growth of rural and urban households respectively. At the second stage, we sum up the effects of the same determinants to obtain the effects of the six determinants on the right hand side of Eq. (2).

In the first stage of the decomposition, we obtain

1. Effect of the number of households

Rural
$$\Delta C_n^r = \frac{C_{t+1}^r - C_t^r}{lnC_{t+1}^r - lnC_t^r} \times ln\frac{N_{t+1}^r}{N_t^r} \tag{5}$$

Urban
$$\Delta C_n^u = \frac{C_{t+1}^u - C_t^u}{lnC_{t+1}^u - lnC_t^u} \times ln\frac{N_{t+1}^u}{N_t^u} \tag{6}$$

2. Effect of household size

Rural
$$\Delta C_s^r = \frac{C_{t+1}^r - C_t^r}{lnC_{t+1}^r - lnC_t^r} \times ln\frac{S_{t+1}^r}{S_t^r} \tag{7}$$

Urban
$$\Delta C_s^u = \frac{C_{t+1}^u - C_t^u}{lnC_{t+1}^u - lnC_t^u} \times ln\frac{S_{t+1}^u}{S_t^u} \tag{8}$$

3. Effect of per capita consumption

Rural $$\Delta C_e^r = \frac{C_{t+1}^r - C_t^r}{lnC_{t+1}^r - lnC_t^r} \times ln\frac{e_{t+1}^r}{e_t^r} \tag{9}$$

Urban $$\Delta C_e^u = \frac{C_{t+1}^u - C_t^u}{lnC_{t+1}^u - lnC_t^u} \times ln\frac{e_{t+1}^u}{e_t^u} \tag{10}$$

4. Effect of the inversed consumption-GDP ratio

Rural $$\Delta C_R^r = \frac{C_{t+1}^r - C_t^r}{lnC_{t+1}^r - lnC_t^r} \times ln\frac{R_{t+1}}{R_t} \tag{11}$$

Urban $$\Delta C_R^u = \frac{C_{t+1}^u - C_t^u}{lnC_{t+1}^u - lnC_t^u} \times ln\frac{R_{t+1}}{R_t} \tag{12}$$

5. Effect of carbon intensity

Rural $$\Delta C_T^r = \frac{C_{t+1}^r - C_t^r}{lnC_{t+1}^r - lnC_t^r} \times ln\frac{T_{t+1}}{T_t} \tag{13}$$

Urban $$\Delta C_T^u = \frac{C_{t+1}^u - C_t^u}{lnC_{t+1}^u - lnC_t^u} \times ln\frac{T_{t+1}}{T_t} \tag{14}$$

Hence, total changes in carbon emissions are the sum of the above five terms:

Rural $$\Delta C^r = \Delta C_n^r + \Delta C_s^r + \Delta C_e^r + \Delta C_R^r + \Delta C_T^r \tag{15}$$

Urban $$\Delta C^u = \Delta C_n^u + \Delta C_s^u + \Delta C_e^u + \Delta C_R^u + \Delta C_T^u \tag{16}$$

In the second stage of decomposition, we sum up across households to get effects on emission growth of total and each determinant for all households. In addition, to sum up for each determinant over time, we obtain cumulative effects on emission growth of the determinant. We can also sum the effects across determinants up to effect of an aggregated determinant. For instance, the contributions of emissions per households can be calculated as the sum of effects of household size, consumption per capita, the inverse of consumption-GDP ratio, and carbon intensity.

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Figures

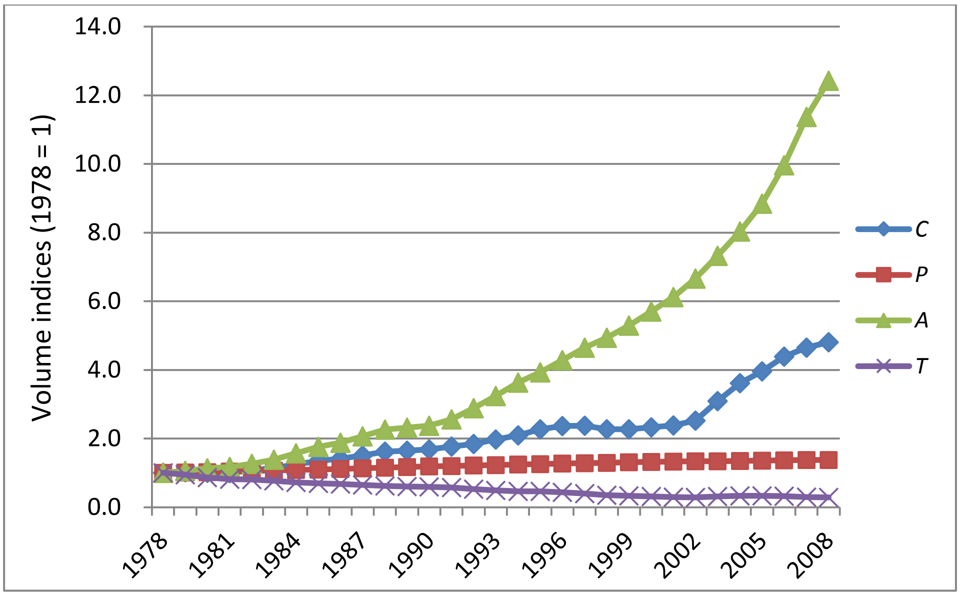

Figure 1. Development paths of carbon emissions (C) and key determinants (P: population size; A: per capita GDP; T: carbon intensity) compared with 1978

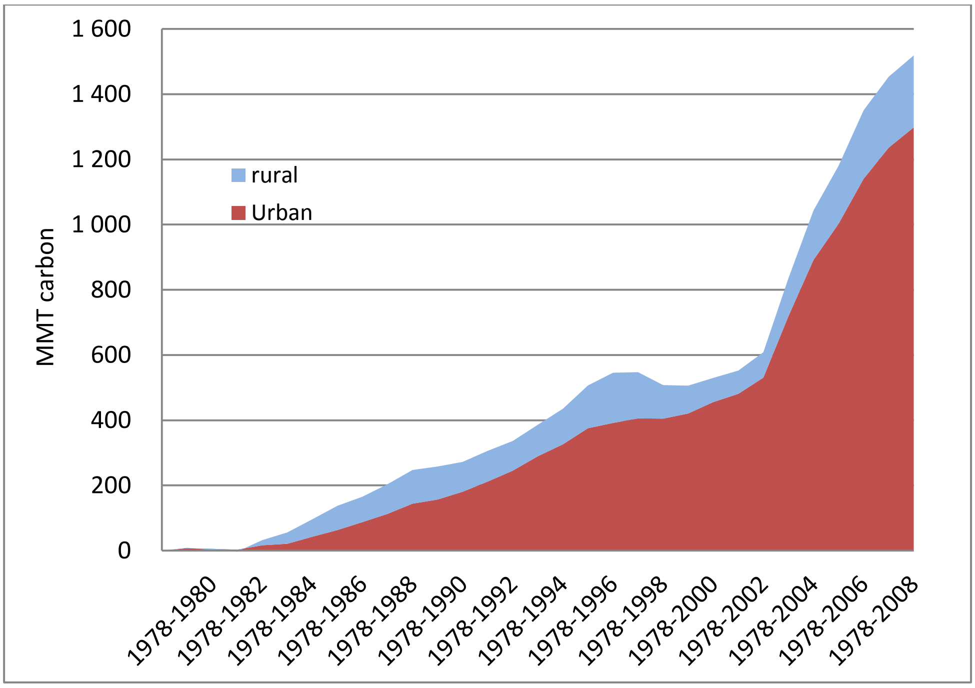

Figure 2. Cumulative contributions to carbon emission growth of households

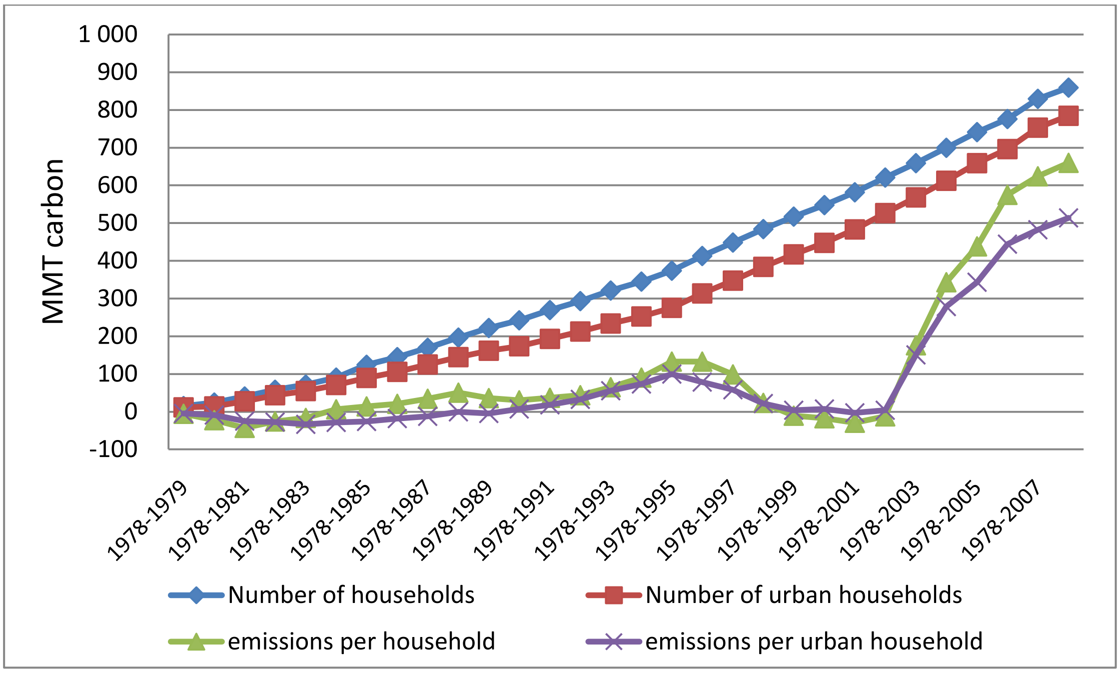

Figure 3. Cumulative contributions to emission growth attributed to the number of households and emissions per household

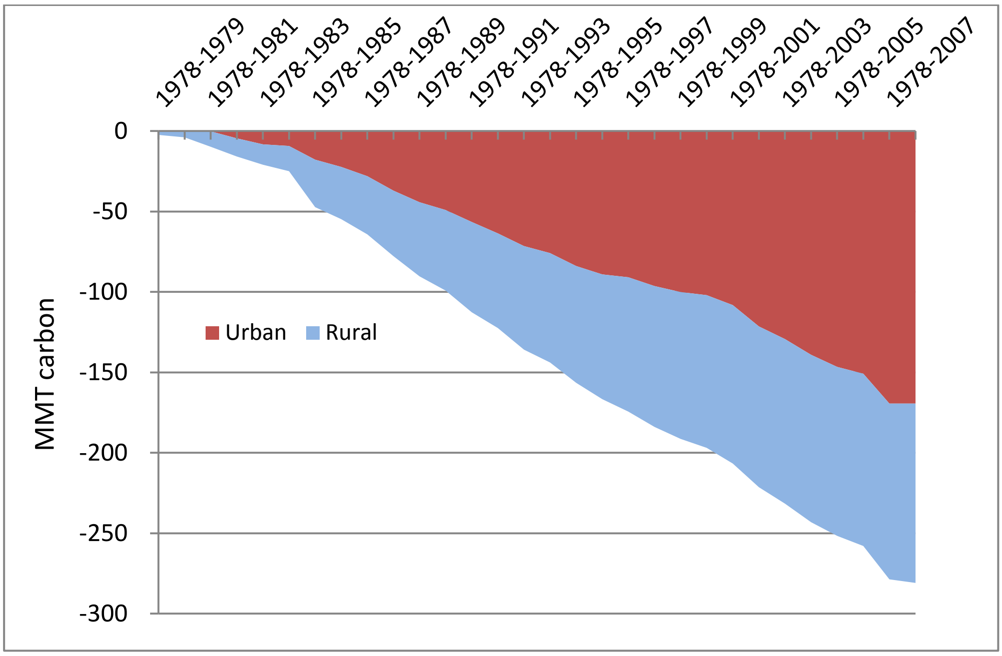

Figure 4. Cumulative contributions to emission growth due to household size

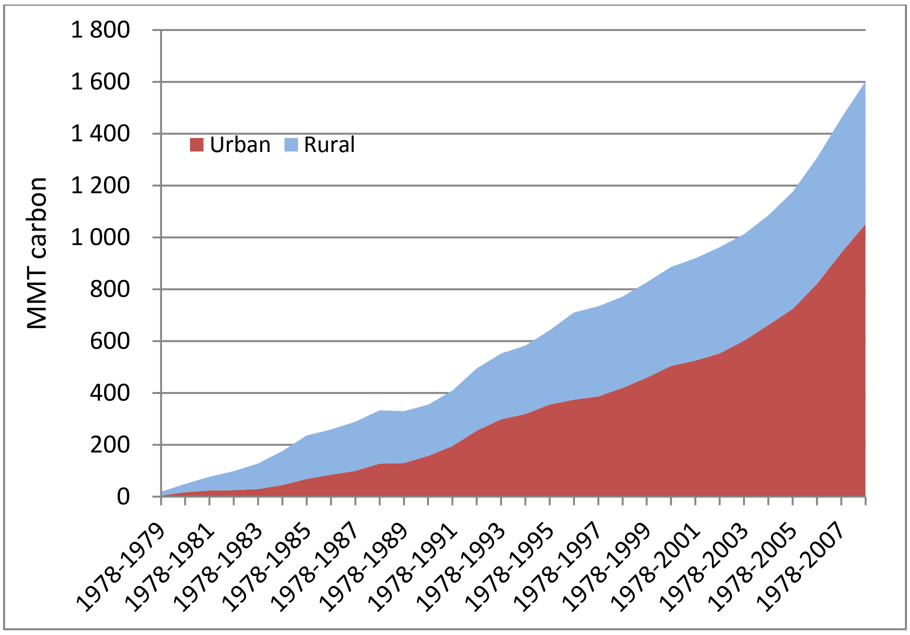

Figure 5. Cumulative emission growth due to consumption per capita

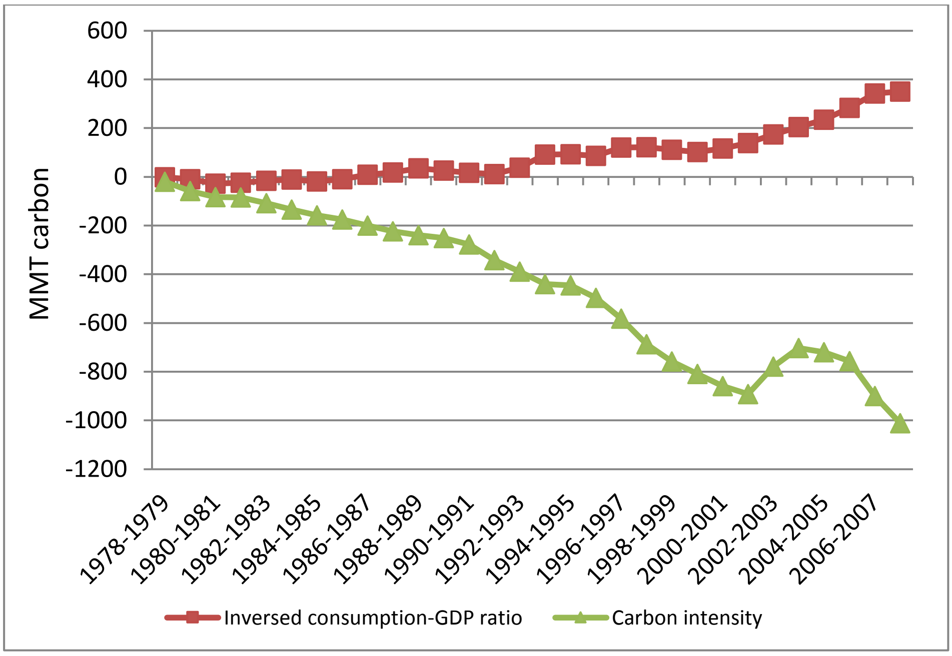

Figure 6. Cumulative contributions to emission growth attributed to the inverse of consumption-GDP ratio and carbon intensity