The dynamics of consumption activities by income level in Mexico and CO_2 emissions[1]

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Abstract.

The overall purpose of this paper is to emphasize that consumption activities –which are considerably different among income levels– are drivers of CO_2 emissions and particularly studying this picture of Mexico from 1965 to 2015.

Although from the economic science most of the climate change studies have been based on the conventional approach focused mainly on the supply (activities and actors related with production sectors), some alternative approaches focused on the demand (activities and actors related with final consumption of goods and services) have already been developed, and some of them take into account economic inequality. The “consumption-based emission inventories” –which consider emissions embodied in products of consumption, whether locally produced or imported– are an option to estimate the impact of consumption activities of a country on CO_2 emissions. However, consumption activities are not homogeneous within a country, so including in this scenario internal economic inequality allows allocating emissions among individuals and suggests an extreme carbon inequality between rich and poor people.

From these alternative approaches, CO_2 emissions of Mexico during 1965-2015 are analyzed by applying a simple expenditure-CO_2 emissions elasticity model in order to allocate carbon responsibilities among income groups within the country. This top-down analysis uses consumption-based CO_2 inventories and elasticities from 0.7 to 1.0 (based on estimates of previous bottom-up studies) and points out there has been a big carbon inequality among income groups all through this period. If an average of 0.9 elasticity is considered, in 2014 the poorest decile emitted 2.4 tons of CO_2 per capita, while the richest decile emitted 13.3 tons, and the richest percentile 38.2 tons.

This kind of studies –non-existent for Mexico– leads to rethinking the weight of income distribution and consumption patterns on climate change, as well as the allocation of mitigation responsibilities among both countries and individuals, thus opening up complementary options to design mitigation strategies and policies.

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[1] This paper presents the state of the art and the first results of the ongoing doctoral thesis of the author, which is developed at Postgraduate Studies in Economics, National Autonomous University of Mexico (UNAM), into the seminar “Energy, Natural Resources and Sustainable Development” led by Angel de la Vega Navarro.

1. Introduction.

Since *Our common future* (WCED, 1987) established in a "formal" way the concept of "sustainable development"[2], this term has gained great strength, and given its flexibility, it has been applied to almost all environmental problems[3], including climate change. *Our common future* is an optimistic proposal to conciliate the economic, environmental and social dimensions of the development. From this, the limits of development are imposed by the present state of technology and social organization on environmental resources and by the ability of the biosphere to absorb the effects of human activities. So, according to the WCED, managing and improving technology and social organization can make way for a new era of economic growth, an indispensable element to alleviate poverty, the major cause, and effect of global environmental problems.

Most of the climate change studies and mitigation strategies and policies have been based largely on these ideas. Generally, economic science studies mitigation climate change by "the conventional approach" named herein, a kind of "extended mainstream" based on neoclassical theory but recognizing the existence of market failures and relevant government intervention[4]. From the conventional approach, climate change mitigation is focused mostly on the supply (activities and actors related with production sectors) and only a little on the demand (when attending direct energy consumption), and it is characterized by the underlying idea that technological development, adequate funding and public policy (if it is necessary) enable compatibility between economic growth and climate change mitigation.

Schemes as eco-efficiency, clean production, green economy, and recently deep decarbonization[5] are just some examples of the conventional approach influence on designing and implementation of strategies to mitigate carbon emissions[6]. All of these point to a rising production of goods and services and simultaneously a falling use of resources and less environmental impacts. According to this approach, decoupling economic growth from CO_2 emissions can be achieved by energy efficiency and substitution from fossil fuel toward clean energies, in order to reduce energy intensity and carbon intensity, respectively$\left(\frac{CO_2}{GDP} = \frac{Energy}{GDP} * \frac{CO_2}{Energy}\right)$. For which, the confidence on technology, funding, and public policy is truly extensive and for many authors, it is quite arguable (Brey, 1999; Dubois & Ceron, 2015; Duchin & Lange, 1994, quoted in Suh & Kagawa, 2009; Trainer, 2007, and 2011).

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[2] Development that meets the needs of the present without compromising the ability of future generations to meet their own needs (WCED, 1987).

[3] Some authors suggest "sustainable development" is ambiguous and even contradictory; but its flexibility and possibility to be interpreted in many ways, turn it into in a powerful tool of consensus. See, for example, Lélé (1991) and Mebratu (1998).

[4] The term "extended mainstream" is based on De la Vega (2015).

[5] For further reference of these schemes consult, e.g., Leal (2005), PNUMA (2011), and DDPP (2015).

[6] Given the availability of information, the analysis of this paper is focused on CO_2 emissions –mainly from fossil fuel combustion– to mitigate climate change, but the author does recognize the existence of others greenhouse gasses different from CO_2, as well as CO_2 emissions from non-fossil elements.

Not including an analysis of the total demand has overlooked the influence of consumption activities on CO_2 emissions, e.g., a probable energy demand so high (induced by a high demand for goods and services) that it is not feasible to satisfy with clean energies, which present several difficulties to expand massively their use (Álvarez Maciel, 2009; Bird, Cowie, Cherubini, & Jungmeier, 2011; Fargione, Hill, Tilman, Polasky, & Hawthorne, 2008; Guijarro, Lumbreras, Habert, & Guereña, 2009; IPCC, 2012, and 2014; Ledec, Rapp, & Aiello, 2011; Patzek, *et al.*, 2005; Searchinger, *et al.*, 2009; Simms, Johnson, & Chowla, 2010; Trainer, 2007; WEC, 2015); or increasing energy demand as an adverse effect of energy efficiency (Jevons paradox) either as a direct or indirect effect (IPCC, 2014; García Ochoa, 2010; Simms, Johnson, & Chowla, 2010; Trainer, 2007). In this form, it sets aside a crucial part of the climate problem as if demand and consumption did not interfere on it and sustainable production were a guarantee of sustainable consumption. It is worrisome that most of the mitigation strategies exclude opportunities related to behavior changes in the consumption systems since the strategies from the conventional approach could be insufficient to mitigate CO_2 emissions due to the rising demand for goods and services promoted by economic growth (even when such growth is small) and prevailing consumption patterns.

In this context, this paper pretends to highlight the importance of consumption patterns on CO_2 emissions; therefore, it is organized as follows. Section 2 examines some alternative approaches that analyze the relationship between climate change and consumption patterns by income level from economic science. Section 3 introduces a simple expenditure-CO_2 emissions elasticity model as a way to study the Mexican case from these alternative approaches, details its methodology and data, and presents and discusses its scope and main results. Finally, section 5 argues the necessity to continue this line of research given the relevance of the results and their little discussion on Mexican climate change studies and hence on public policy.

2. Alternative approaches.

Highlighting the importance of consumption patterns and the diversity of consumption forms, some alternative approaches have already analyzed the dynamic of the demand as a driver of climate change, and at least two ideas are useful for this research: 1) CO_2 emissions responsibility could be allocated to the consumer using consumption-based emission inventories, which consider emissions embodied in goods and services of consumption, whether locally produced or imported; 2) consumption-based CO_2 emissions within a country are heterogeneous among households (or individuals) and such differences could be linked with income levels and prevailing consumption patterns.

Consumption-based CO_2 emission inventories.

An alternative approach to studying climate change from the demand perspective appears with the "consumption-based emission inventories", which seek to weight the impact of consumption activities on CO_2 emissions. Their methodology is a combination of input-output (I-O) techniques and Ecological Footprint analysis (Turner, Lenzen, Wiedmann, & Barrett, 2007). The approach of consumption-based emission inventories derived from concerns about the carbon leakage[7] and equity associated with the structure of trade relations between developing and developed countries, and constitutes a way to account emissions allocating the responsibility to the consumer (Munksgaard, Minx, Christoffersen, & Pade, 2009).

The most commonly used inventories –in fact, used in the UNFCCC– are the "territorial emission inventories", which consider CO_2 emissions produced by domestic and foreign production sectors inland, usually a country, as well as a part of emissions related to consumption, which are derived from the direct energy consumption of household and transport by national and foreigners into the country. In contrast, the "consumption-based emission inventories" consider emissions embodied in products of consumption, whether locally produced or imported, and emissions from energy consumption of household and transport; thereby these inventories exclude emissions from domestic production exported and include emissions from imported production[8].

The I-O analysis applied to environmental effects stems from Walter (1973, quoted in Wiedmann, Lenzen, Turner, & Barrett, 2007), who estimated pollution embodied in traded American products[9]. After two decades, similar studies emerged, many of those focused on carbon emissions embodied in international trade; and in recent years, this interest has risen[10]. Most of the initial studies used I-O models of only one region, where it is assumed that goods and services imported are produced through the same technology as domestic technology in the same sector, which diminish the quality of the results. An alternative to face this problem is to use Multi-Region Input-Output (MRIO) models, which distinguish regions and countries, and where international trade flows are internalized within the intermediate demand. The interdependence among external sectors with different technology, resource intensity, and emissions intensity can be quantified and the results can be improved.

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[7] The carbon leakage is commonly conceived by a "strong" definition as the increase in non-Annex B emissions divided by the reduction in Annex B emissions (Kyoto Protocol classification). Under this definition, the analysis seeks to determine the production that shifts from an Annex B to a non-Annex B country in response to a mitigation policy in an Annex B country. But it ignores the fact that production may increase in non-Annex B countries for reasons disconnected to climate mitigation in Annex B countries –"weak" carbon leakage, that is emissions embodied in trade (Peters & Hertwich, 2008).

[8] To check more detailed discussion about the categories of emissions, see Aall & Hille (2010).

[9] Before I-O applied environmental analysis, Leontief (1970) was the first who exposed the possibility to incorporate pollution, a sub-product of economic activity, into the I-O frame.

[10] Hoekstra (2010, quoted in Tukker & Dietzenbacher, 2013) refers more than 300 papers of environmental I-O analysis published between 1995 and 2010, and he points that since 2005, there has been a proliferation of studies focused on pollution embodied in traded products. A wide revision of studies previous to 2007 that evaluate environmental impacts of consumption activities can be consulted in Wiedmann, *et al.* (2007). Another revision of this kind of studies, but between 2007 and 2009, is available in Wiedmann (2009), specifically studies of consumption-based emission accounting; only in this couple of years, the author refers more than 50 papers, without a completely exhaustive revision. From 2009 to nowadays, the proliferation of this kind of research continues.

The time-space dimensions of the studies of consumption-based emission accounting have been multiple, but most of them have analyzed a specific point in time and a few countries or regions; meanwhile, a few other research articles have studied large periods of time for a wider territorial space. However, given the progress in information availability, this situation is changing and every time there are more studies that encompass even global scales for many years. Nowadays, there are already datasets that report energy and emissions by country based on MRIO models, and they are used in several studies to redistribute emission responsibility from production to consumption; for example, EORA (Lenzen, Moran, Kanemoto, & Geschke, 2013), EXIOBASE (Wood, *et al.*, 2015), GTAP (Aguiar, Narayanan, & McDougall, 2016), WIOD (Genty, Arto, & Neuwahl, 2012), among others. Currently, there is already a dataset available that contains territorial and consumption-based CO_2 emission inventories at an international level from 1990 as part of the Global Carbon Project of the Carbon Dioxide Information Analysis Center, CDIAC (Le Quéré, *et al.*, 2016).

With diverse estimates, given the variety of methodologies, assumptions, and sources of data, the fundamental conclusions of these studies suggest that developed countries import emissions from developing countries by importing products; that is, an important part of production of developing countries meets the consumption necessities of developed countries, whose emissions are considered, so far, the responsibility of the producing country. Sometimes, the contrast between the territorial and the consumption-based accounting can be really drastic. Table 1 shows some examples, where a negative difference points to an exporter CO_2 emissions country, and a positive difference points to an importer of CO_2 emissions country.

Table 1. Differences between the "consumption-based CO_2 emission inventories" and the "territorial CO_2 emission inventories".

Country	Year	Difference (%)	Reference
Africa	2013	-21	Chancel & Piketty (2015)
China	2004	-23	Davis & Caldeira (2010)
China	2013	-25	Chancel & Piketty (2015)
Denmark	2001	20	WWF, 2008, quoted in Aall & Hille (2010)
France	2005	34	Lenglart *et al.* (2010)
Latin America	2013	-15	Chancel & Piketty (2015)
Japan	2004	18	Davis & Caldeira (2010)
Mexico	2004	5	Davis & Caldeira (2010)
Mexico	2014	10	Le Quéré, *et al.* (2016)
Sweden	2003	33	Naturvardsverket, 2008, quoted in Aall & Hille (2010)
United Kingdom	2012	72	Helm et al., 2007, quoted in Aall & Hille (2010)
United States	2004	11	Davis & Caldeira (2010)
United States	2013	13	Chancel & Piketty (2015)
Western Europe	2004	20-50	Davis & Caldeira (2010)
Western Europe	2013	41	Chancel & Piketty (2015)

Own elaboration based on literature review.

In sum, consumption-based emission accounting emphasizes the weight of consumption activities on CO_2 emissions, as well as the inequity of the emission responsibility among countries according to their consumption patterns and the role of international trade. Even when such studies do provide a good indicator of emissions embodied in trade, they remain vastly at the international /regional unit of analysis.

However, climate policy is usually implemented at the national level of analysis, within which there is still substantial work to be done in terms of accounting for inequalities and patterns of embedded emissions. For that, there are other approaches that incorporate economic inequality within countries to analyze this emission responsibility. The next section deepens this literature.

Economic inequality and consumption within countries.

For studying economic inequality and consumption patterns within countries and their relation to CO_2 emissions from a macroeconomic perspective, it is possible to differentiate two approaches: bottom-up and top-down.

Roughly, the bottom-up approach combines information about the household expenditure of different kinds of consumption, energy and emission statistics, and I-O analysis to convert expenditure in physical units of consumed energy or produced emissions by individuals (Chakravarty, *et al.*, 2009). From this, several studies have been developed, mainly at the national level, which seek to estimate the effect of consumption activities on energy use and/or CO_2 emissions and, depending on the level of aggregation, they can estimate such effect by economic strata, household size, region, etc. It is important to highlight that this kind of studies includes both, direct use of energy or the emissions related to this (henceforth direct energy consumption or direct emissions), and the energy embodied in goods and services of consumption or the emissions related to this (henceforth indirect energy consumption or indirect emissions).

Many of these studies do not only analyze the relationship between income levels of households and total energy consumption[11] or total CO_2 emissions[12] but they also distinguish how much each kind of energy or CO_2 emissions is related to each economic strata. The first studies of this type date back to the 1970's by Herendeen, and they recently have proliferated more. Although their estimates and methodologies are diverse, their results have brought out the income or consumption level is closely correlated to indirect individual energy consumption or indirect individual CO_2 emissions; meanwhile, the direct individual energy consumption or the direct individual CO_2 emissions are less correlated[13]. Table 2 presents some results of this kind of studies in order to argue the last asseveration.

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[11] Total energy consumption = Direct energy consumption + Indirect energy consumption.

[12] Total CO_2 emissions = Direct CO_2 emissions + Indirect CO_2 emissions.

[13] The cases of Brazil and rural India are different. The high share of indirect emissions in the Indian rural households could be explained by the fact that many people in India consume a lot of biomass as direct

Table 2. The relationship between income levels of households vs. indirect energy consumption and/or indirect CO_2 emissions.

Country	Year	Economic strata	Indirect energy consumption (%)	Indirect CO_2 emissions (%)	Reference
Brazil [a]	1995-96	Higher income	66		Cohen, Lenzen, & Schaeffer (2005)
		Lower income	62		
China [b]	2005	1st decile	52	61	Golley & Meng (2012)
		2nd decile	61	69	
		3rd decile	65	73	
		4th decile	69	77	
		5th decile	71	79	
		6th decile	73	81	
		7th decile	75	82	
		8th decile	78	84	
		9th decile	79	86	
		10th decile	84	89	
U.S.	1960-61	Poor households	35		Herendeen & Tanaka (1976)
		Rich households	65		
U.S. [c]	2008-12	1st quintile		59	Ummel (2014)
		Top 2%		75	
France [d]	2005	1st quintile	61 / 40		Lenglart, Lesieur, & Pasquier (2010)
		2nd quintile	67 / 43		
		3rd quintile	70 / 43		
		4th quintile	72 / 46		
		5th quintile	73 / 50		
India [e]	2003-04	1st decile		77 / 94	Parikh, Panda, Ganesh-Kumar, & Singh (2009)
		2nd, 3rd deciles		77 / 95	
		4th, 5th, 6th, 7th deciles		82 / 95	
		8th 9th deciles		86 / 94	
		10th decile		83 / 91	

[a] It considers only 11 capital states.
[b] It studies urban households. It assumes that energy and carbon intensity of import products are equal to energy and carbon intensity of domestic products.
[c] It refers to GHG emissions. It completes bottom-up approach with consumption-based inventories (top-down approach).
[d] It excludes emissions related to direct energy consumption in households / It excludes emissions related to direct energy consumption in households and transport.
[e] It does not include CO2 emissions embodied in imported products of consumption. Urban households / Rural households.

Own elaboration based on literature review.

Some bottom-up studies have also estimated the elasticity of expenditure or income level vs. energy or CO_2 emissions. Generally, they have found a high direct correlation between such variables. Though the energy elasticity is not exactly equal to the emissions elasticity, in many countries both elasticities are in a range from 0.7 to 1.0

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energy –mainly rural and poor households– and this share is difficult to measure and to include as part of the total energy consumption. So, direct emissions from biomass consumption are not included as part of total emissions; consequently, the share of indirect emissions rises.

(Chakravarty, *et al.*, 2009). Table 3 lists some articles that have calculated such elasticities.

Table 3. Elasticity of household expenditure vs. per capita energy consumption and emissions.

Country	Year	Elasticity of energy	Elasticity of CO_2 emissions	Reference
Australia	1993-94	0.74 0.59 [a]	0.70 0.55 [a]	Lenzen (1998)
Australia	1998-99	0.78		Lenzen, *et al.* (2006)*
Brazil [b]	1995-96	1.01		Cohen, Lenzen, & Schaeffer (2005)
Brazil [b]	1995-96	1		Lenzen, *et al.* (2006)*
Denmark	1995	0.9	0.9	Wier, *et al.* (2001)*
Denmark	1995	0.86		Lenzen, *et al.* (2006)*
India	1997-98	0.86		Lenzen, *et al.* (2006)*
Japan	1999	0.64		Lenzen, *et al.* (2006)*
Netherlands	1990	0.83 0.63 [a]		Vringer & Blok (1995)
New Zealand	1980	0.4[c]		Peet, *et al.* (1985)*
Norway	1973	0.72		Herendeen (1978)*
Norway	1999-2001		0.88	Peters, *et al.* (2006)*
Republic of Korea	1980-1990 1990-2000	1.38 0.87		Park & Heo (2007)
Spain	2000		0.91-0.99 [d]	Roca & Serrano (2007)*
U.S.	1960-61	0.85		Herendeen & Tanaka (1976)*
U.S.	1972-73	0.78		Herendeen, *et al.* (1981)*
U.S.	2004		0.6-0.8 [e] 0.4-0.6 [a,e]	Weber & Matthews (2008)

* Studies quoted in Chakravarty, *et al.* (2009).
[a] Elasticity with respect to income.
[b] It considers only 11 capital states.
[c] Low value due to high use of hydroelectric electricity in poor households.
[d] Range depends on assumptions used to convert from household emissions to per capita emissions.
[e] Range depends on the specific model used to fit data.

Updated from Chakravarty, et al. (2009).

On the other hand, in recent years, a few top-down studies have been developed to allocate CO_2 emissions among individuals, but these have been done at an international level. The first study of this kind (to the extent of our knowledge) was written by Chakravarty, *et al.* (2009), who designed a scheme for allocating a global carbon reduction target among nations, based on the concept of "common but differentiated responsibilities" among individuals (instead of among nations used by the UNFCCC). For assigning CO_2 emissions among individuals, they used national information about income distribution as well as the carbon intensity of each economy and converted these income distributions into individual CO_2 emission distributions, assuming unitary elasticity. Then, the authors specified a global mitigation target to estimate a universal carbon emission threshold for each individual and derivate national CO_2 emission limits. Based on these limits, they established mitigation responsibilities among individuals of each country.

Although Chakravarty *et al.* (2009)´s research has received some criticism;[14] this work represents an innovative way to study the importance of income distribution within countries. Actually, some subsequent analyses have resumed similar methodological strategies and overcome some issues of this first study. The Climate Equity Reference Project, CERP (EcoEquity; Stockholm Environment Institute, 2015), Chancel & Piketty (2015), and OXFAM (2015) are examples of this kind of studies. They have accomplished top-down analysis at the international level to allocate CO_2 emissions among individuals, and have considered the emissions embodied in trade, with which they managed to capture in a better way the role of consumption. The results of the four studies coincide in pointing out a big carbon inequality between rich and poor people, and a high direct relationship between income level and CO_2 emissions derived from consumption patterns. Also, since there are rich people in the entire world, they notice there are high emitters in both developed and developing countries, so it does not make sense to treat individuals as homogenous blocks about their mitigation responsibilities.

Even though these top-down studies have only been used to allocate emissions among individuals at an international level, we consider this approach to be also useful at a national level, especially when it is difficult to get enough information to performance a bottom-up study, as in the case of Mexico. In this direction, given that Mexico does have relevant data on its consumption-based CO_2 emission inventory, on income distribution, and on household expenditure, we apply a top-down study to establish a connection between CO_2 emissions and the final demand by income level in Mexico from 1965 to 2015, which is explained below.

3. The case of Mexico: an importer of CO_2 emissions with a big internal carbon inequality.

According to the difference between territorial CO_2 emission inventories and consumption-based CO_2 emission inventories, since some years ago Mexico is an importer of CO_2 emissions (Chancel & Piketty, 2015; Davis & Caldeira, 2010; Le Quéré, *et al.*, 2016), a fact that emphasizes the importance of consumption activities in the country. But the influence of consumption patterns and internal economic inequality on CO_2 emissions has only been studied through the relation between income (or expenditure) and direct energy (or direct CO_2 emissions). See, for example, Cruz Islas (2012; 2016), Navarro (2014), Rosas (2011), Rosas, Sheimbaum, & Morillon (2010), and Sánchez Peña (2012a; 2012b), who point to a direct relationship. For the purpose of this research, we did not find any study that relates income (or expenditure) and total

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[14] See, for example, Gluber & Pachauri (2009).

energy (or total CO_2 emissions) in Mexico. For such reason, this paper proposes the following quantitative analysis.

Methodology and data.

This analysis is a top-down estimation that follows the methodology developed by Chancel and Piketty (2015). A simple expenditure-CO_2 emissions elasticity model is used to allocate responsibilities of consumption-based CO_2 emissions among income groups according to their expenditure through the next formula:

$$CO2_i = f_i \left(\frac{CO2_{tot}}{\sum_{i=1}^{N} f_i * y_i^e} \right) y_i^e$$

where,
f_i = the total population share of income group *i* in total population.
y_i = mean expenditure in group *i*.
$CO2_{tot}$ = total consumption-based CO_2 emissions in Mexico.
N = number of income groups.
e = the expediture-CO_2 elasticity.

The datasets used are: 1) consumption-based CO_2 emission inventory from the CDIAC (updated from Peters, Minx, Weber, & Edenhofer, 2011), which estimates CO_2 emissions in Mexico annually from 1990 to 2014; 2) territorial CO_2 emission inventory from the CDIAC (Boden, Marland, & Andres, 2016), which estimates CO_2 emissions in Mexico annually from 1891 to 2015[15]; 3) the Household Income and Expenditure Survey (*Encuesta Nacional de Ingresos y Gastos de los Hogares, ENIGH*) from INEGI (several years), which reports income data from Mexican households, expenditure and general features of households for 1984, 1989 and biennially from 1992 to 2014[16]; 4) similar surveys to the *ENIGH* for 1968,1975, and 1977 from INEGI (2014)[17].

Finally, it should be noted that given that there is no consensus about expenditure-CO_2 emissions elasticity and there is no elasticity estimation for Mexico, we work with elasticities from 0.7 to 1.0, the range generally located in the bottom-up estimates for other countries (see Table 3).

Scope and results.

The main merit of this methodology is that it represents an alternative relatively straightforward to assess the responsibility for CO_2 emissions among individuals of different economic strata and to consider the influence of consumption activities on climate change, which could affect designing and implementation of mitigation strategies and policies. Nevertheless there are at least two limitations: 1) since there are no consumption-based CO_2 emission inventories previous to 1990, we assume that in

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[15] Both 1) and 2) include CO_2 emissions from fossil fuel combustion and oxidation and cement production and exclude emissions from bunker fuels.

[16] Stata Software is used in order to work at microdata level on the *ENIGH*.

[17] Familiar Income and Expenditure Survey of 1968 and 1975; and Household Income and Expenditure Survey 1977, which is the most immediate antecedent of the *ENIGH*.

Mexico during 1965-1989 territorial CO_2 emissions were equal to consumption-based CO_2 emissions; 2) the fact that the ENIGH only reports the expenditure of households, while the CDIAC inventory considers CO_2 emissions embodied in consumption expenditure of households, government, and investment is out of the question.

Given the information availability, this study does not cover all the period 1965-2015 annually; notwithstanding, it covers a significant part: 1968, 1975, 1977, 1984, and biennially 1990-2014. On the other hand, considering the organization of this information, three types of estimates were done: 1) estimates that connect current expenditure[18] by income level with territorial CO_2 emissions in 1968, 1975, and 1977; 2) estimates that connect total expenditure[19] by income level with territorial CO_2 emissions in 1984; and 3) estimates that connect total expenditure by income level with consumption-based CO_2 emissions from 1990-2014 biennially[20]. All of them are calculated with elasticities of 0.7, 0.8, 0.9, and 1.0 (see Annex), but for the discussion in this section, a 0.9 elasticity is used as average.

From estimation 1), as a result of applying the elasticity model in Mexico in 1968, 1975, and 1977, Figure 1 shows three Lorenz curves for CO_2 emissions that describe the proportion of CO_2 emissions produced by a given proportion of families sorted from lowest to highest income according to their current expenditure[21]. In 1968, 5% of the richest families produced 22% of CO_2 emissions in Mexico, while the poorest 5% emitted 1% of CO_2. In 1975, 15% of families with the highest income emitted 36% of CO_2, while the poorest 15% produced 6% of CO_2 emissions. In 1977, 10% of the wealthiest families produced 31% of CO_2 emissions; and just 2% of CO_2 emissions were produced by 10% of the poorest families.

Estimations 2) and 3) are grouped in Figure 2, which exposes the share of eleven household income groups (the bottom nine deciles, a group of the 90-99 percentiles, and the percentile 100) on CO_2 emissions in Mexico according to their total expenditure in 1984 and biennially from 1990 to 2014[22]. Like Figure 1, Figure 2 shows the high participation of rich households on CO_2 emissions. The top 1% emitted 7.4% of total CO_2 in average during the entire period, a share even higher than the share of poorest 20%, which emitted 6.6% of total CO_2 in average in the same period. The red line shows the difference between CO_2 emissions from the richest decile and CO_2 emissions from the poorest decile. In the last 30 years, such difference has not diminished; actually, it has increased a little, a fact that suggests CO_2 emission growth could be attributed mainly to the high consumption levels of the richest people, and not to a greater energetic access or better life conditions of the poorest.

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[18] Total current expenditure is the sum of monetary current expenditure (direct expenditures of households to buy goods and services) and non-monetary current expenditure (remuneration in kind, self-consumption, transfers in kind and the estimate of housing rent).

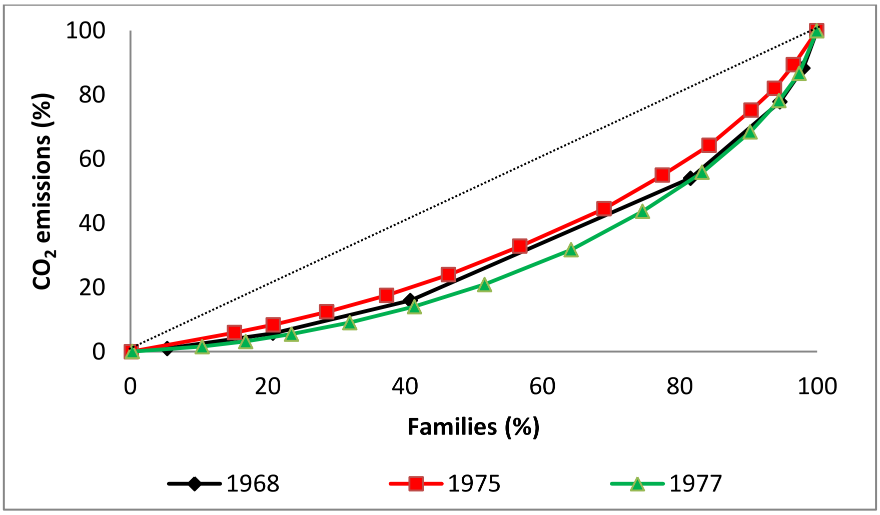
[19] Total expenditure is the sum of total current expenditure and financial and capital erogations.

[20] In this estimates, the *ENIGH* 1989 was used to 1990 analysis.

[21] Figure 1 uses a 0.9 elasticity. For detailed estimates about this and other elasticities, see Tables 4 and 5.

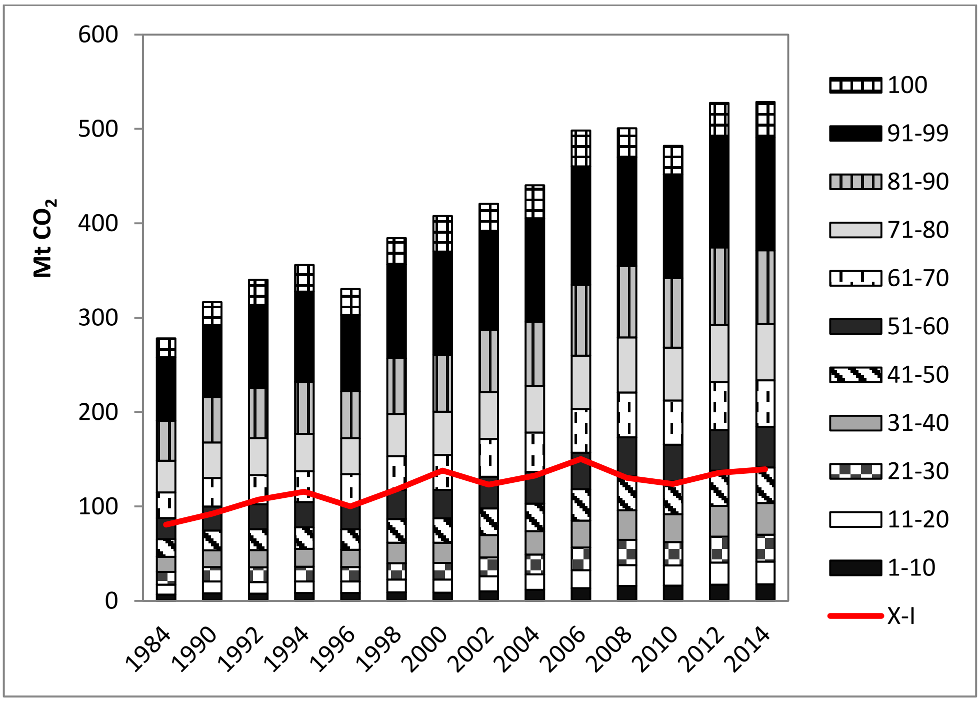
[22] Figure 2 uses a 0.9 elasticity. For detailed estimates about this and other elasticities, see Tables 6 and 7.

Fig. 1. Lorenz curves for CO_2 emissions in Mexico 1968, 1975, and 1977 (e=0.9).



Based on author's calculations.

Fig. 2. CO_2 emissions by income group in Mexico 1984-2014 (e=0.9)



Based on author's calculations.

Finally, CO_2 emissions per capita of each income group from 1984 to 2014 are estimated and presented in Figure 3, which draws attention to an extreme carbon inequality[23]. In 2014, CO_2 emissions per capita of the affluent top 1% were almost 16 times CO_2 emissions per capita of the poorest 10%.

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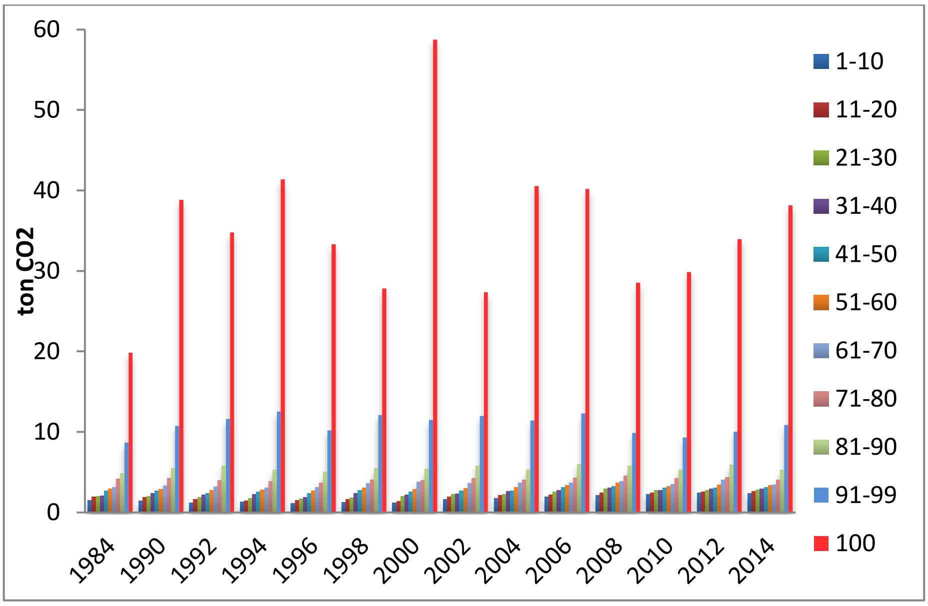
[23] Figure 3 uses a 0.9 elasticity. For detailed estimates about this and other elasticities, see Tables 8.

Fig. 3. Per capita CO_2 emissions by income group in Mexico 1984-2014 (tCO_2).



Based on author's calculations.

4. Final reflections.

In the light of poor results of current climate change mitigation strategies guided by the conventional approach, in this paper, we have presented an alternative approach to study CO_2 emission responsibility in Mexico from the demand side. Nowadays, Mexico is an importer country of CO_2 emissions, which underlines the importance of consumption activities in Mexico on CO_2 emissions; and based on our estimates, there has been a big carbon inequality among income groups in the country during the 1965-2015 period. This carbon inequality is a direct consequence of the prevailing consumption patterns since there are CO_2 emissions embodied in almost all goods and services of consumption and people with high income tend to consume a lot of goods and services, while poorest people do not even satisfy basic necessities.

For climate change mitigation, the previous conclusions have got three implications: 1) it is absolutely necessary to study the dynamic of demand as a significant part of the complex climate problem; 2) all consumption activities –not only direct energy consumption– are drivers of CO_2 emissions and must be analyzed in detail in order to complement the current climate change mitigation strategies; 3) starting from consumption, mitigation strategies must regard different carbon responsibilities among individuals, and focus on the groups and activities with the greatest potential to reduce CO_2 emissions.

So far, there are only a few elements to develop mitigation strategies that include consumption in their analysis, for example, some soft policy instruments for changing consumption patterns, as carbon labeling and other means of providing information to facilitate climate-friendly consumption; however, hard policy instruments that seek to share equally the burdens of reducing CO2 emissions among people, such as taxation and regulation to set per capita emission quotas, are very much debatable (Aall & Hille, 2010). Although in a developing country as Mexico this kind of options are even less considered due to many unsatisfied necessities, the big carbon inequality among individuals of different income levels showed above should change such perspective and promote the development of strategies focused on the consumption patterns. Applying adequately mitigation strategies focused on consumption would not affect the possibility to access to decent living standards for the poorest people, but it would reduce the conspicuous consumption of the richest.

Although this research opens a way for studying and discussing consumption and equity in Mexico related to climate change, still much research is needed for designing and implementing operative mitigation strategies focused on them, for which the role of social sciences could be really relevant.

Annex.

Table 4. Share by income group on CO$_2$ emissions in Mexico 1968, 1975, 1977 (MtCO$_2$).

1968					1975					1977				
Families (%)	Elasticity				Families (%)	Elasticity				Families (%)	Elasticity			
	0.7	0.8	0.9	1.0		0.7	0.8	0.9	1.0		0.7	0.8	0.9	1.0
5	1	1	1	1	0	0	0	0	0	0	0	0	0	0
15	6	5	4	4	15	12	11	10	9	10	5	4	3	2
20	12	11	10	9	6	5	5	4	4	6	4	4	3	3
41	38	37	36	34	8	8	7	7	6	7	6	5	4	4
13	21	22	22	23	9	10	9	8	8	9	9	8	7	6
3	8	9	10	11	9	12	11	11	10	9	12	11	10	9
2	8	9	11	13	10	16	15	15	14	10	15	14	13	12
-	-	-	-	-	12	20	20	19	19	13	23	22	21	20
					8	17	17	17	17	10	24	24	23	23
					7	15	15	15	15	9	23	23	23	23
					6	16	17	18	19	7	23	24	24	25
					3	10	10	11	12	4	17	18	19	20
					3	10	11	12	13	3	14	15	16	18
					3	14	16	18	19	3	19	22	26	30
100	94	94	94	94	100	164	164	164	164	100	193	193	193	193

Families sorted by income level (from lowest to highest).
Author's calculations.

Table 5. Share by income group on CO$_2$ emissions in Mexico 1968, 1975, 1977 (%).

1968					1975					1977				
Families (%)	Elasticity				Families (%)	Elasticity				Families (%)	Elasticity			
	0.7	0.8	0.9	1.0		0.7	0.8	0.9	1.0		0.7	0.8	0.9	1.0
5	2	1	1	1	0	0	0	0	0	0	0	0	0	0
15	6	6	5	4	15	8	7	6	5	10	3	2	2	1
20	13	11	10	9	6	3	3	2	2	6	2	2	2	1
41	41	39	38	36	8	5	4	4	4	7	3	3	2	2
13	22	23	24	25	9	6	6	5	5	9	5	4	4	3
3	9	10	10	11	9	7	7	6	6	9	6	6	5	4
2	8	10	12	14	10	9	9	9	9	10	8	7	7	6
-	-	-	-	-	12	12	12	12	11	13	12	11	11	10
					8	10	10	10	10	10	12	12	12	12
					7	9	9	9	9	9	12	12	12	12
					6	10	11	11	12	7	12	12	13	13
					3	6	6	7	7	4	9	9	10	10
					3	6	7	7	8	3	7	8	8	9
					3	9	10	11	12	3	10	11	13	15
100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Families sorted by income level (from lowest to highest).
Author's calculations.

Table 6. Share by income group on CO_2 emissions in Mexico 1984-2014 ($MtCO_2$).

e	Percentile / Year	1984	1990	1992	1994	1996	1998	2000	2002	2004	2006	2008	2010	2012	2014
0.7	1-10	9	12	11	12	12	13	13	15	17	19	21	22	23	23
	11-20	14	16	16	16	16	18	19	21	21	25	27	26	29	30
	21-30	17	19	20	20	19	22	23	25	26	30	32	30	33	34
	31-40	19	21	22	23	22	26	26	28	30	34	36	34	38	39
	41-50	22	24	26	26	25	29	30	33	34	38	40	39	42	42
	51-60	25	28	30	30	29	34	34	37	38	43	45	43	47	47
	61-70	29	32	33	35	34	39	40	43	44	49	50	49	53	52
	71-80	34	38	40	41	39	45	47	50	51	58	59	56	61	61
	81-90	41	46	51	53	48	57	59	63	65	72	72	70	78	74
	91-99	57	64	74	80	68	83	91	88	92	105	97	93	100	102
	100	13	16	18	19	18	19	24	20	23	25	21	21	24	25
	Total	278	316	340	356	330	384	408	421	440	498	501	482	528	528
0.8	1-10	8	10	9	10	10	11	11	12	14	16	18	19	20	20
	11-20	12	14	14	14	14	16	16	18	19	22	25	24	26	27
	21-30	15	17	17	18	17	20	20	22	23	27	29	27	30	31
	31-40	17	20	20	21	20	24	24	26	27	31	34	32	35	36
	41-50	20	23	24	25	24	27	28	31	31	36	38	37	39	40
	51-60	24	27	28	29	27	32	32	35	36	41	43	41	45	45
	61-70	28	31	32	34	34	37	39	41	43	48	49	48	52	51
	71-80	34	38	40	41	38	45	47	50	51	58	59	56	61	60
	81-90	42	47	52	54	49	58	60	65	67	74	74	72	80	76
	91-99	62	70	81	88	75	91	100	96	101	115	106	101	109	111
	100	16	20	22	23	22	23	30	24	29	31	26	25	29	31
	Total	278	316	340	356	330	384	408	421	440	498	501	482	528	528
0.9	1-10	7	8	8	8	8	9	9	10	12	13	16	16	17	18
	11-20	11	12	12	12	12	14	14	16	16	19	22	21	23	24
	21-30	14	15	15	16	15	17	18	20	21	24	27	25	28	29
	31-40	16	18	19	19	18	22	21	24	25	29	31	30	33	33
	41-50	19	21	22	23	22	25	26	28	29	33	36	35	37	38
	51-60	23	25	26	27	26	30	30	33	34	39	42	39	43	43
	61-70	27	30	31	32	33	36	37	40	42	46	48	47	51	49
	71-80	34	38	39	40	38	45	46	50	50	57	58	56	61	60
	81-90	42	48	53	55	50	59	61	66	68	75	76	74	82	78
	91-99	67	76	88	96	81	99	109	105	109	125	115	110	118	120
	100	20	24	26	28	27	28	38	28	35	38	31	30	35	37
	Total	278	316	340	356	330	384	408	421	440	498	501	482	528	528
1.0	1-10	5	7	6	7	7	7	7	8	10	11	14	14	15	15
	11-20	9	11	11	10	11	12	12	14	14	17	19	19	21	21
	21-30	12	14	14	14	13	15	15	18	19	21	24	23	25	26
	31-40	14	16	17	17	17	19	19	22	22	26	29	27	30	31
	41-50	17	19	20	21	20	23	23	26	27	31	34	32	35	35
	51-60	21	24	25	25	24	28	28	31	31	36	40	37	41	41
	61-70	26	29	29	31	31	34	35	38	40	44	46	45	49	47
	71-80	33	37	38	39	37	44	44	49	49	55	58	55	60	59
	81-90	43	49	54	55	50	60	60	67	69	76	77	75	84	79
	91-99	72	82	96	104	87	107	118	113	118	135	124	118	127	129
	100	24	29	32	34	33	34	46	34	43	46	36	36	42	45
	Total	278	316	340	356	330	384	408	421	440	498	501	482	528	528

Author's calculations.

Table 7. Share by income group on CO_2 emissions in Mexico 1984-2014 (%).

e	Percentile / Year	1984	1990	1992	1994	1996	1998	2000	2002	2004	2006	2008	2010	2012	2014
0.7	1-10	3	4	3	3	4	3	3	3	4	4	4	4	4	4
	11-20	5	5	5	5	5	5	5	5	5	5	5	5	6	6
	21-30	6	6	6	6	6	6	6	6	6	6	6	6	6	6
	31-40	7	7	7	6	7	7	6	7	7	7	7	7	7	7
	41-50	8	8	8	7	8	8	7	8	8	8	8	8	8	8
	51-60	9	9	9	9	9	9	8	9	9	9	9	9	9	9
	61-70	10	10	10	10	10	10	10	10	10	10	10	10	10	10
	71-80	12	12	12	12	12	12	12	12	12	12	12	12	12	11
	81-90	15	15	15	15	15	15	14	15	15	14	14	14	15	14
	91-99	20	20	22	22	21	22	22	21	21	21	19	19	19	19
	100	5	5	5	5	5	5	6	5	5	5	4	4	5	5
	Total	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.8	1-10	3	3	3	3	3	3	3	3	3	3	4	4	4	4
	11-20	4	4	4	4	4	4	4	4	4	4	5	5	5	5
	21-30	6	5	5	5	5	5	5	5	5	5	6	6	6	6
	31-40	6	6	6	6	6	6	6	6	6	6	7	7	7	7
	41-50	7	7	7	7	7	7	7	7	7	7	8	8	7	8
	51-60	9	8	8	8	8	8	8	8	8	8	9	8	9	9
	61-70	10	10	9	9	10	10	10	10	10	10	10	10	10	10
	71-80	12	12	12	11	12	12	11	12	11	12	12	12	12	11
	81-90	15	15	15	15	15	15	15	15	15	15	15	15	15	14
	91-99	22	22	24	25	23	24	25	23	23	23	21	21	21	21
	100	6	6	6	6	7	6	7	6	7	6	5	5	5	6
	Total	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.9	1-10	2	3	2	2	3	2	2	2	3	3	3	3	3	3
	11-20	4	4	4	3	4	4	3	4	4	4	4	4	4	5
	21-30	5	5	5	4	5	5	4	5	5	5	5	5	5	5
	31-40	6	6	5	5	6	6	5	6	6	6	6	6	6	6
	41-50	7	7	6	6	7	7	6	7	7	7	7	7	7	7
	51-60	8	8	8	8	8	8	7	8	8	8	8	8	8	8
	61-70	10	10	9	9	10	9	9	10	9	9	10	10	10	9
	71-80	12	12	11	11	11	12	11	12	11	11	12	12	12	11
	81-90	15	15	16	15	15	15	15	16	15	15	15	15	16	15
	91-99	24	24	26	27	24	26	27	25	25	25	23	23	22	23
	100	7	8	8	8	8	7	9	7	8	8	6	6	7	7
	Total	100	100	100	100	100	100	100	100	100	100	100	100	100	100
1.0	1-10	2	2	2	2	2	2	2	2	2	2	3	3	3	3
	11-20	3	3	3	3	3	3	3	3	3	3	4	4	4	4
	21-30	4	4	4	4	4	4	4	4	4	4	5	5	5	5
	31-40	5	5	5	5	5	5	5	5	5	5	6	6	6	6
	41-50	6	6	6	6	6	6	6	6	6	6	7	7	7	7
	51-60	8	8	7	7	7	7	7	7	7	7	8	8	8	8
	61-70	9	9	9	9	9	9	9	9	9	9	9	9	9	9
	71-80	12	12	11	11	11	11	11	12	11	11	11	11	11	11
	81-90	15	15	16	16	15	16	15	16	16	15	15	16	16	15
	91-99	26	26	28	29	26	28	29	27	27	27	25	25	24	24
	100	9	9	9	10	10	9	11	8	10	9	7	7	8	8
	Total	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Author's calculations.

Table 8. Per capita CO_2 emissions by income group in Mexico 1984-2014 (tCO_2).

e	Percentile / Year	1984	1990	1992	1994	1996	1998	2000	2002	2004	2006	2008	2010	2012	2014
0.7	**1-10**	2.0	2.0	1.7	1.8	1.6	1.8	1.8	2.2	2.3	2.6	2.7	2.8	3.1	3.0
	11-20	2.4	2.4	2.1	2.0	1.9	2.2	1.9	2.4	2.7	2.8	3.0	2.9	3.1	3.1
	21-30	2.4	2.5	2.4	2.3	2.1	2.3	2.6	2.7	2.8	3.1	3.4	3.2	3.2	3.3
	31-40	2.4	2.8	2.6	2.7	2.3	2.8	2.7	2.7	3.1	3.2	3.5	3.2	3.4	3.3
	41-50	3.0	3.1	2.8	3.0	2.7	3.1	3.0	3.1	3.1	3.5	3.6	3.4	3.4	3.5
	51-60	3.2	3.2	3.1	3.2	3.0	3.4	3.3	3.3	3.5	3.7	4.0	3.5	3.7	3.7
	61-70	3.3	3.6	3.5	3.4	3.3	3.9	4.2	3.9	3.9	4.0	4.1	3.7	4.3	3.7
	71-80	4.2	4.3	4.2	4.1	3.8	4.2	4.2	4.3	4.2	4.4	4.6	4.3	4.4	4.2
	81-90	4.7	5.3	5.6	5.2	4.9	5.3	5.4	5.5	5.2	5.8	5.5	5.1	5.6	5.1
	91-99	7.3	9.1	9.7	10.4	8.6	10.0	9.7	10.0	9.6	10.3	8.4	7.9	8.6	9.2
	100	13.6	25.3	22.9	26.9	21.7	18.9	36.5	18.8	26.3	26.4	19.6	20.2	22.7	25.1
	Average	3.7	4.0	3.9	4.0	3.6	4.0	4.1	4.2	4.3	4.6	4.5	4.2	4.5	4.4
0.8	**1-10**	1.7	1.7	1.4	1.6	1.4	1.5	1.5	1.9	2.0	2.3	2.4	2.5	2.7	2.7
	11-20	2.2	2.2	1.9	1.7	1.7	1.9	1.6	2.2	2.4	2.5	2.7	2.7	2.8	2.9
	21-30	2.2	2.2	2.1	2.0	1.9	2.0	2.3	2.5	2.5	2.8	3.2	3.0	3.0	3.1
	31-40	2.2	2.6	2.4	2.5	2.1	2.6	2.5	2.5	2.9	3.0	3.3	3.0	3.2	3.1
	41-50	2.8	2.9	2.6	2.8	2.6	2.9	2.8	2.9	2.9	3.3	3.5	3.3	3.3	3.3
	51-60	3.0	3.1	3.0	3.0	2.8	3.3	3.1	3.2	3.3	3.6	3.8	3.4	3.6	3.5
	61-70	3.2	3.5	3.3	3.2	3.2	3.8	4.0	3.8	3.8	3.8	4.0	3.6	4.2	3.6
	71-80	4.2	4.3	4.1	4.0	3.8	4.1	4.2	4.3	4.2	4.4	4.6	4.3	4.4	4.1
	81-90	4.8	5.4	5.7	5.3	5.0	5.4	5.4	5.7	5.3	5.9	5.6	5.2	5.8	5.2
	91-99	8.0	9.9	10.6	11.5	9.4	11.1	10.6	11.0	10.5	11.3	9.1	8.6	9.3	10.0
	100	16.4	31.5	28.4	33.5	27.0	23.0	46.5	22.7	32.8	32.7	23.7	24.6	27.8	31.0
	Average	3.7	4.0	3.9	4.0	3.6	4.0	4.1	4.2	4.3	4.6	4.5	4.2	4.5	4.4
0.9	**1-10**	1.5	1.4	1.2	1.3	1.1	1.2	1.2	1.6	1.7	2.0	2.2	2.3	2.4	2.4
	11-20	2.0	1.9	1.6	1.5	1.5	1.7	1.4	1.9	2.2	2.2	2.5	2.4	2.6	2.6
	21-30	2.0	2.0	1.9	1.8	1.7	1.8	2.0	2.2	2.3	2.6	2.9	2.8	2.7	2.8
	31-40	2.1	2.4	2.2	2.3	1.9	2.4	2.2	2.3	2.6	2.7	3.1	2.8	2.9	2.9
	41-50	2.7	2.7	2.4	2.5	2.4	2.7	2.5	2.7	2.7	3.1	3.3	3.1	3.1	3.1
	51-60	2.9	2.9	2.8	2.8	2.7	3.1	2.9	3.0	3.1	3.4	3.7	3.2	3.4	3.4
	61-70	3.1	3.3	3.2	3.1	3.1	3.6	3.8	3.6	3.7	3.7	3.9	3.5	4.1	3.4
	71-80	4.2	4.2	4.0	3.9	3.7	4.0	4.0	4.2	4.1	4.3	4.6	4.2	4.3	4.1
	81-90	4.9	5.5	5.8	5.3	5.0	5.5	5.4	5.8	5.3	6.0	5.8	5.3	5.9	5.3
	91-99	8.7	10.8	11.6	12.6	10.2	12.1	11.5	12.0	11.4	12.3	9.9	9.3	10.0	10.9
	100	19.8	38.8	34.8	41.4	33.3	27.8	58.7	27.4	40.5	40.2	28.5	29.9	34.0	38.2
	Average	3.7	4.0	3.9	4.0	3.6	4.0	4.1	4.2	4.3	4.6	4.5	4.2	4.5	4.4
1.0	**1-10**	1.3	1.2	1.0	1.1	1.0	1.0	1.0	1.4	1.5	1.7	1.9	2.0	2.2	2.1
	11-20	1.7	1.7	1.4	1.3	1.3	1.4	1.2	1.7	1.9	2.0	2.2	2.2	2.3	2.4
	21-30	1.8	1.8	1.7	1.5	1.5	1.6	1.8	2.0	2.0	2.3	2.7	2.5	2.5	2.6
	31-40	1.9	2.2	2.0	2.0	1.7	2.2	2.0	2.1	2.4	2.5	2.8	2.6	2.7	2.7
	41-50	2.5	2.5	2.2	2.3	2.2	2.5	2.3	2.5	2.5	2.9	3.1	2.9	2.9	2.9
	51-60	2.8	2.7	2.6	2.6	2.5	2.9	2.6	2.8	2.9	3.1	3.5	3.1	3.2	3.2
	61-70	3.0	3.2	3.0	2.9	3.0	3.5	3.6	3.5	3.5	3.5	3.8	3.4	3.9	3.3
	71-80	4.2	4.1	3.9	3.7	3.6	3.9	3.8	4.1	4.0	4.2	4.5	4.2	4.3	4.0
	81-90	5.0	5.5	5.9	5.3	5.0	5.5	5.4	5.9	5.3	6.0	5.8	5.3	6.0	5.3
	91-99	9.4	11.6	12.6	13.6	11.0	13.1	12.3	13.0	12.3	13.3	10.6	10.0	10.8	11.7
	100	23.8	47.5	42.3	50.5	40.8	33.3	73.2	32.7	49.7	49.0	34.2	36.0	41.2	46.6
	Average	3.7	4.0	3.9	4.0	3.6	4.0	4.1	4.2	4.3	4.6	4.5	4.2	4.5	4.4

Author's calculations.

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