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Population and trends in the global mean temperature

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RESUMEN

El índice ideal de Fisher, que se desarrolló para medir la inflación en los precios, se utiliza para definir una tendencia de temperatura ponderada demográficamente. Este método tiene la ventaja de que la tendencia es representativa de la distribución poblacional a lo largo de toda la muestra pero sin mezclar la tendencia poblacional con la tendencia en la temperatura. Demuestro que la tendencia en la media global de temperatura del aire ponderada por área es diferente en detalles clave a la tendencia ponderada demográficamente. Amplío el índice para incluir los efectos de la urbanización y la isla de calor, lo que modifica nuevamente la tendencia de manera sustancial. Y amplío aún más el índice para incluir la migración internacional, pero esto tiene un impacto mínimo sobre la tendencia.

ABSTRACT

The Fisher ideal index, developed to measure price inflation, is applied to define a population-weighted temperature trend. This method has the advantages that the trend is representative for the population distribution throughout the sample but without conflating the trend in the population distribution and the trend in the temperature. I show that the trend in the global area-weighted average surface air temperature is different in key details from the population-weighted trend. I extend the index to include urbanization and the urban heat island effect. This substantially changes the trend again. I further extend the index to include international migration, but this has a minor impact on the trend.

Keywords: Population-weighted temperature trend, Fisher index, JEL Classification: Q54.

1. Introduction

The global annual mean surface air temperature is typically defined as an area-weighted average of local temperatures. This definition makes sense from a meteorological perspective, but the distribution of the human population over the surface of the planet is rather uneven. Hardly any humans live at sea, and desert, tundra and rainforest show low population densities. Climate change in such areas is much less relevant to the human condition than warming in cities. In this paper, I therefore discuss temperature trends as experienced by humans. I do so in three steps, accounting for changes in population density, for urbanization, and for migration.

Unlike area, population changes over time. Population-weights therefore require more careful thought than area-weights. The second contribution of this paper is an exposition of the methods to deal with changing weights, developed in the discipline of economics. Specifically, I introduce the indices of Laspeyres (1871), Paasche (1877) and Fisher (1892).

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I am not the first to depart from area-weighted trends in climate variables. For instance, Lobell et al. (2011) and Auffhammer et al. (2013) compute cropping-area and growing-season trends in temperature and precipitation. However, they assume that cropping-area and growing season do not change. This implies that the estimated trend is representative only for part of the sample, and discrepancies grow with the distance to the base year. Dell et al. (2014) nonetheless recommend this method.

Studies of energy demand commonly use population-weighted temperatures, or rather population-weighted heating and cooling degree days. Quayle and Diaz (1980), Taylor (1981), Guttman (1983) and NOAA (http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/cdus/degree_days/) compute population-weighted degree-days, but with constant population-weights. These studies suffer the same problem as the Lobell et al. paper cited above. On the other hand, Downton et al. (1988), EIA (2012) and Shi et al. (2016) compute population- weighted degree-days, with current population-weights. The resulting trend does not suffer from lack of representativeness but—as made rigorous below—it does conflate the trend in temperature with the trend in the spatial distribution of the population. Michaels and Knappenberger (2014) fall into the same trap when computing the ''experiential temperature'' trend for the USA.

This paper presents a compromise between unrepresentative and conflated trends. The methods used are taken from price inflation. Price inflation measures the increase in average prices, say of consumer goods. This is a weighted average, as items more commonly bought should be more important. The common basket of goods changes over time and so the weights should be adjusted. Etienne Laspeyres and Hermann Paasche proposed methods to measure price inflation, later refined by Irving Fisher. These methods have in common that the weights used ensure that the weighted average remains representative, and ensure that no spurious trend is introduced.

Obviously, the measurement of price inflation has moved on since the late 19th century (Diewert, 1998; Nordhaus, 1998; Hausman, 2003; Schultze, 2003; Broda and Weinstein, 2006; Handbury and Weinstein, 2015). Most of the later refinements are in response to the peculiarities of consumer prices and expenditures, rather than about the general principles of trends in weighted averages. There are two issues particular to population-weighted temperature averages, viz. urbanization and migration. As a third contribution, I propose and apply methods to correct the temperature record for the urban heat island effect, and for international movement of people.

The paper proceeds as follows. Section 2 presents the data and their sources. Section 3 discusses the methods for computing the population-weighted temperature trend in the presence of changes in population patterns (3.1), urbanization (3.2), and international migration (3.3). Section 4 shows the results. Section 5 concludes.

2. Data

Population data are taken from Klein-Goldewijk et al. (2010). Data are population counts on a 0.5' × 0.5' grid. The Matlab code to convert the data to a 0.5º × 0.5º grid is given in the appendix. I use the data from 1900 to 2000, in 10-yr time steps. Unfortunately, the gridded population for 2010 has yet to be released. The data serve to illustrate the methods outlined below.

Temperature data are from CRU TS v3.24 (Harris et al., 2014). Data are monthly temperature average on a 0.5º × 0.5º grid. I use the data from 1900 to 2010, and compute the 21-yr average centered on 1910, 1920,..., 2000. The code is given in the Appendix.

Data on urbanization are from the World Urbanization Prospects project of the UN Population Division.[1] Specifically, the data are population counts, per pentade, from 1950 to 2015, for the 1692 urban agglomerations that had 300 000 inhabitants or more in 2014. Reba et al. (2016) have data that go back further in time, but coverage is not comprehensive.

The urban heat island effect is not consistently observed over space and time. Instead, I impute the warming due to urbanization by

$$U_{c,t} = \alpha P_{c,t}^{\beta} \tag{1}$$

where $U_{c,t}$ is the warming due to the urban heat island effect in city c at time t; $P_{c,t}$ is the number

[1]https://esa.un.org/unpd/wup/cd-rom/

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