



Macro-economic cycles related to climate change in dynastic China



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ABSTRACT

Investigations of the relationships between climate and human history often place more emphasis on the science of climate change than on understanding human socio-economic processes, and therefore suffer from superficial results and an unbalanced perspective. This is partly due to the lack of high-resolution data concerning long-term socio-economic processes. Here, we base our study of climate and society on a series of 2130-yr-long economic proxy data from China with decadal resolution. The economy was associated significantly with temperature and precipitation at the two predominant bands of 100 and 320 yr. The phase transition of economic states was influenced positively by long-term temperature change combined with triggering effects of short-term changes in precipitation. However, climatic impact on economy should not be recognized as simple causality but some driving–response relation coupled with mediation by human agency at multiple scales. A model of ‘adaptive cycles’ implies, in relative to the developing phases, climate–economy relationship during the declining phases was more easily moderated by slower processes like rigidity and faster processes like unrest. From a more-macro perspective, climatic driving for the macro-economic cycles was moderated by larger and slower processes like social memory, spatial shifting of key economic areas, and social–technical advance.

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Introduction

After extensive travels in Turkmenistan, Central Asia at the turn of the 20th century, Ellsworth Huntington proposed the idea that major cultural changes were strongly influenced by climatic change in his book *The Pulse of Asia* (Huntington, 1907; Wright, 1993). More recently, the idea of climatic determinism is being revived, fueled to some extent by the recent development of high-resolution paleo-climatic reconstructions in many parts of the world. Numerous studies have tried to link climate change with various social aspects ranging from water supply and agricultural productivity (Lucero, 2002; Buckley et al., 2010), human health (McMichael, 2012), population migration (Zhang et al., 2011; Zielhofer et al., 2012; Han et al., 2014), social conflict (Zhang et al., 2007; Tol and Wagner, 2010), and particularly political or civilization collapse (Binford et al., 1997; deMenocal, 2001; Weiss and Bradley, 2001; Haug et al., 2003; Büntgen et al., 2011; Kennett et al., 2012; Walsh et al., 2014). Many studies convey the concept that climate change or extreme droughts constitute the main driver for a large number of cases of abrupt social/civilization collapse.

However, the role of climate and environmental change in the rise or fall of societies is still a matter of intense debate. Many other scholars

strongly object to these dogmatic statements as a simplistic, mono-causal approach to the study of climatic impacts on the fortunes of historical societies (Rosen, 2007; Butzer and Endfield, 2012). A typical example is the Classic Maya collapse. Persistent drought has been highlighted as the main reason for the abrupt collapse of Maya society (Hodell et al., 1995; deMenocal, 2001; Weiss and Bradley, 2001). However, some critics note that Maya civilization did not collapse as quickly as supposed by some of these studies and the process of multisite and regional abandonment in the Terminal Classic played out over at least 125 yr (Turner, 2010; Dunning et al., 2012). These disagreements partly stem from differing views of the nature of collapse (McAnany and Yoffee, 2009; Butzer, 2012; Butzer and Endfield, 2012).

Another similar example concerns climate-forcing leading to the origins of agriculture in the Near East. Many studies based their environmental determinism on the major restructuring of vegetation resulting from climatic fluctuation, and proposed that the shift to wild-cereal cultivation was a response of hunter-gatherers to the Terminal Pleistocene Younger Dryas (YD) climatic deterioration (Wright, 1993; Bar-Yosef and Belfer-Cohen, 2002; Rosen and Rivera-Collazo, 2012). Some works even refer to this as a collapse of Natufian foraging systems (Weiss and Bradley, 2001; Burroughs, 2005). Rosen and Rivera-Collazo (2012) proposed that the hunter-gatherer subsistence systems in the Near East were highly adaptable, and a shift in resource focus did not necessarily result in a major change in social and economic organization. The long-term social memory of past experience helped them

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initiate a series of subsistence procurement responses that allowed them to avoid an eventual shift from foraging systems, which simultaneously delayed the transition from foraging and low-level cereal cultivation to a major commitment to agricultural village farming in the southern Levant (Rosen and Rivera-Collazo, 2012).

A common feature of these studies is simply that they base their conclusions on the temporal correlation between climatic reconstruction and major social/cultural events. The climatic reconstructions can provide detailed background information of environment and ecology, but cannot give more information on the development of human society which often occurs at temporal resolutions different from the climatic events (IHOPE, 2010). Admittedly, many studies mistake the seeming-temporal coincidence between climate change and social fluctuation as a causal link. They fail to incorporate many other important factors that interact with climatic components on different temporal-spatial tiers, as well as the different role played by variable factors in specific spatial and temporal scales (Catto and Catto, 2004; Butzer, 2012). In particular, many socio-economic phenomena operated at different temporal scales from climate change. It is also dangerous to impose a presumed pattern from one geographic region upon another without considering the background environmental and historical contexts. An example of this is the explanation for the collapse of the Tang Dynasty for which a simple correlation was made between climate change and the breakdown of a social system (Yancheva et al., 2007; Zhang and Lu, 2007; Zhang et al., 2008, 2010a,b). Thus it is important to understand the role of climate change in a resilient and complex interlocking system of environment and society.

China can provide a good case study for relationships between climate and society, due to its unique historical rhythms (or “dynastic cycle”) (Elvin, 1973; Fu, 1981; Skinner, 1985) and long-term historical records. Many recent studies have quantitatively demonstrated the statistical relationship between climate change and social phenomena, such as agricultural harvests (Su et al., 2014; Yin et al., 2014), population fluctuation (Lee et al., 2008), and frequency of social unrest and warfare (Zhang et al., 2006). However, most of these studies are still limited by the dearth of long-term socio-economic data and cannot give more quantitative support to the causal mechanisms. The present paper cannot deal with all the problems mentioned above, but we try to provide an important and unique perspective by using historical data, based on a well-understood socio-economic system. These types of data are essential in order to test the relationships between historical rhythms and climatic oscillations, by combining knowledge both from paleoclimatology and history (PAGES, 2009). Besides this, we also propose that the complex relationships between climate change and cyclical patterns can be best illustrated and predicted by a concept of ‘adaptive cycles’ (Gunderson and Holling, 2001).

In this paper we aim to reveal long cycles of macro-economic processes in ancient China, and examine their associations with temperature and precipitation. The wave-like fluctuations of economic development during the Chinese imperial era (221 BC–AD 1911) have been described and recorded in abundant Chinese historical documents. These have been further compiled and studied by contemporary historians in the form of academic books. The books on economic history (see Supplementary Appendix) provide a unique opportunity to reconstruct economic sequences conveying the phase transition of economic states over the past two millennia. In this paper, we first present a 2130-yr long macro-economic series using the method of ‘semantic analysis’ (Osgood, 1957). Then, in order to analyze economic relationships with climate change, we use an existing reconstruction of precipitation, and multi-proxy temperature data at different geographic scales ranging from the region of eastern China at the finest scale to the coarser scale of a range of latitudes in the northern hemisphere. Multi-statistical analyses, including wavelet, correlation, cross-wavelet correlation and regression, are used for the investigation of associations between economic level and climatic indices. Additionally, a ‘Resilience Theory’ model (Gunderson and Holling, 2001) is introduced to explore the role of climate change as one of the factors driving the secular macro-economic cycles in dynastic China.

Materials and methodology

Economic series

The decadal time series of a 2130-yr-long economic state index is constructed on the basis of 1091 records extracted from 25 books. All of these books deal with the history or economic history of China, and most of them are written by leading Chinese scholars and published in the last thirty years (such as the “The Feudal Social and Economic History of China” written by Fu, Zhufu during 1981–1989, see list of books in Supplementary Appendix). We chose the Imperial Era from the unified Qin to the end of the Qing Dynasty (221 BC–AD 1911), as the reconstructed period of study. This was a period with frequent alternation between state establishment and breakdown, but shared similar basic forms of economic organization and symbols and beliefs that justified the distribution of power, status, and wealth for most periods (Goldstone, 1991). The relatively homogeneous agrarian-economic system experienced cycle-like ups and downs of economic development, from a macro-historic perspective.

We analyzed the general performance of the economic system by taking the empire as the unit of analysis, as suggested by Skinner (1985). This was because the materials used primarily addressed the empire-wide or empire-scale economic performance. Spatially, the dynastic economy was built on the development of key economic areas beginning in earlier periods in the region of the middle and lower Yellow River, then expanding to the middle and lower Yangtze River in later periods (Elvin, 1973; Fu, 1981).

Semantic analysis is a concept most widely used in Linguistics and Psychology. The Semantic Differential (SD) technique was first developed by Osgood (1957) in order to identify emotional meaning of words, and has been proven to be a useful and effective tool in indexing qualitative word description such as attitude measurement. It is usually operated in terms of ratings on bipolar scales defined with contrasting adjectives at each end (Osgood, 1957). Three basic dimensions, which have been labeled Evaluation (like good and bad), Potency (like large and small), and Activity (like fast and slow), have been identified in a number of early studies to account for most of the co-variation in ratings (Snider and Osgood, 1969). Semantic analysis has been used successfully to reconstruct long time series’ of dryness/wetness (or precipitation) indices (CMA, 1981; Zheng et al., 2006), grain harvests (Su et al., 2014; Yin et al., 2014), and fiscal balance (Wei et al., 2014), and has been proven to be a suitable approach for converting qualitative descriptions found in literary sources into quantitative data.

In this study we assigned each record a grade ranked 5–1 (according to the word’s semantics) to express the economic performance changing from economic climax (5) to economic collapse (1). These grades represent the relative phase transitions of economic performance which can be measured as the general level of dynastic economic soundness. Here, we tend to define economic collapse as a dysfunction of an empire-level economic system (mainly characterized by major loss of population, large-scale land abandonment, and serious fiscal crisis, usually accompanied by the imperial breakdown). In our analysis we divided the qualitative descriptions into three-level groups according to semantic characteristics and their reliability in reflecting the fluctuation of the macro-economy as a whole. Firstly we used the group with a relatively higher reliability for economic level determination. There are two other reasons for this treatment. First, records from different books, representing opinions of single or a certain number of authors, demonstrate multi-time resolution; second, the economic records of short-term time intervals are not as numerous as those of long-term intervals and therefore they do not yield a continuous high-resolution series. Additionally, to integrate those descriptions from the historical records, we first formulated a sequence of economic trends using records with relatively lower resolution, and then refined it to be a decadal series using records with higher resolution.

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