Lost in luxury: Climate change and silk consumption in mid-Qing China (1735–1840 CE)

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Data sharing is not applicable to this article as no new data were created or analyzed in this study. The sources researched are publicly available literatures and books.

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A quantitative approach has been promoted to understand the history of climate and society. However, statistical research on luxurious expenses under climate change in past societies remains insufficient. Hence, this study statistically examined the association between climate change and the imperial court's luxury expenses on silk products in mid-Qing China (1735–1840 CE) by including major ecological–social–economic stresses. Results indicated that the Qing imperial court's silk consumption increased under favorable climatic conditions and a flourished agrarian economy, and vice versa. However, natural disasters and social crises could hardly affect the Qing imperial court's silk consumption, suggesting its limited support and inactive attitude toward ecological–social–economic stresses. Such an institutional weakness may have increased social vulnerability, which could have led to Qing China's decline since the 18th century. The study serves as the first attempt to reveal a long-term historical climate–luxury linkage and further provides a supplementary explanation of the economic decline from the perspective of the history of climate and society. Based on past lessons, this study raises the emphasis on institutional activeness to tackle upcoming climate change challenges.

Keywords: silk consumption; climate change; ecological–social–economic stress; institutional attitude; mid-Qing China

Introduction

Numerous studies on how natural climate change has profoundly influenced human history have been conducted, and the number is still growing rapidly (Parker 2013; Carleton and Hsiang 2016), thereby providing historical reference to human societies at present (Adamson, Hannaford, and Rohland 2018). Scholarly debates have concentrated on primary sectors of living necessities, such as food security (Schmidhuber and Tubiello 2007) and agricultural harvest (Douglas et al. 2015), which were essential to human survival in the past (Turchin 2005). However, research examining the expenses of luxury under climate change remains insufficient. In particular, luxury consumption by the central government, which shows the privilege and power beyond basic needs (Cabigiosu 2020), could further provide evidence of institutional attitude—political rationale and moral standards (Berg 2004) in the face of climate change and other ecological–social–economic stresses.

Recent research has investigated a long historical time series to reinterpret pre–1900 CE societies holistically to advance the critical evidence of social dynamics under climatic impacts in the past (Hsiang, Burke, and Miguel 2013). China holds rich historical records and thus always receives academic focus on long-term empirical investigation. Among the different dynasties of China, the Qing imperial court consumed a large amount of luxury goods (Peng 1990) and was widely criticized for its corrupt institutions (Dykstra 2020; Park 1997). Particularly, since Emperor *Qianlong*[1], he managed to secure more fiscal revenues than the Qing period under the rule of his father Emperor *Yongzheng* (Kaske 2018) and spent much on luxury goods.

The Qing imperial court annually consumed silk (Lee 2005), a time-consuming and labor-intensive handicraft, involving multiple complicated manufacturing processes (Zhang 1989; Zhu 1992). First produced in China around the fourth or fifth millennium BCE, silk has fulfilled a wide range of social, economic, and political roles in China for many thousands of

years (Lee 2005; Rossabi 1998). As a luxurious clothing material, silk is synonymous with power and wealth and was historically pursued by imperial families in China to make official suits, decorations, sacrificial ceremonies, and trading (Vainker 2004; Chai 2019). The governments of most dynasties in Chinese history had set up official weaving to manage the production of silk and obtain high-quality silk products (Zhang 1989). The official weaving in the Qing Dynasty was large in scale and dominated by three major weaving bureaus in the south of the Yangtze River (Zhang 1989). Their silk products were extremely exquisite and luxurious, and were exclusively provided to the royal family (Zhao 2005). Consequently, the Qing imperial court's expenses on silk products were usually large (Peng 1963) and, in certain years, even exceeded the necessary fiscal expenditure on social welfare and development, such as education (Peng 1990; Ren 2018).

The government usually played a fundamental role in conducting resilience and adaption strategies to deal with climate change and the natural disasters in the global past when the technology for individuals to relieve these natural impacts was not well developed (Haldon et al. 2021). The Qing Dynasty was no exception, and the Qing imperial court's silk consumption was by no means a heavy burden. Moreover, the Qing Dynasty had the most centralized power among all dynasties in Chinese imperial history (Guo 2021). Under a rigid political system, financial resources were dominated by the imperial court (Hao, Xiong, and Zheng 2021; Ni and Uebele 2019). The imperial court's support was essential to social relief and held the most profound impact on social resilience to natural stresses, including climate change and natural disasters (Xiao et al. 2014), and socioeconomic crises (Shen 2004). In this regard, the huge financial spending on silk by the Qing imperial court, a nonessential luxury, may have eclipsed the financial relief of natural stresses and reduced the capacity of climatic resilience.

Our study period is set as 1735–1840 CE from the year when Emperor *Qianlong* took the throne. The study period belongs to mid-Qing China (Hung 2009), which is a prosperous period until the First Opium War in 1840 CE (Zhu et al. 2019). The expenses on luxury goods under climate change are examined through the association between climate change and the Qing imperial court's silk consumption. Recent studies have suggested the need to consider relevant ecological, social, and economic backgrounds systematically to understand the history of climate and society carefully (Degroot et al. 2021). Natural disasters, social crises, and economic well-being fluctuations have been regarded as major ecological–social–economic stresses in historical China (Zheng et al. 2014; Pei 2017). Furthermore, demographic pressure is adopted as the basic social context on a long-term scale (O'Sullivan 2020). Therefore, these factors are considered to understand the climate–luxury association in historical China in a relatively long term.

The study holds academic value in filling the current knowledge gap in the association of climate change and luxury consumption beyond basic needs. Furthermore, this study reflects Qing's imperial attitude toward climate change and other ecological–social–economic stresses at the institutional level. Existing works worldwide at the institutional level usually focused on specific policies or approaches to relieve ecological–social–economic stresses, such as exemption or reduction of taxes in historical China (Hao, Xiong, and Zheng 2021), territory expansion by Ottoman rulers for additional resources (Haldon et al. 2020), and alike. In contrast to these existing academic works, our study particularly indicates Qing's institutional attitude toward ecological–social–economic stresses by examining the changes in the Qing imperial court's silk consumption when these ecological–social–economic stresses occurred.

For clarification, the study adopts a quantitative framework and implements the discussion based on statistical analysis and results. We aim to provide supplementary knowledge to understand past climate–luxury linkage at a long-term scale, as well as Qing's

institutional attitude. Therefore, the study follows the paradigm of effect-of-cause school (White et al. 2023) to understand the past history of climate and society at a macro scale. We do not deny other debates at a different scale of time or space. Furthermore, the study has certain limitations of quantitative analysis. Nevertheless, the statistical results intuitively demonstrate the climate–luxury association at a macro scale and provide a basis for an in-depth discussion of historical responses to ecological–social–economic stresses.

Data and Methods

Data sources

The used datasets are obtained from previously published works to ensure data reliability. Figure 1 shows all the data series used for quantitative analysis.

Climate change indicators: Temperature and precipitation

Temperature and precipitation are regarded as two essential factors determining bioproductivity (Dell, Jones, and Olken 2014) and have been widely employed to investigate past agrarian societies under climate change (Thomsen 2009). Paleoclimatologists and historical climatologists have usually applied proxy records from nature and the index approach based on historical documents to reconstruct the past temperature and precipitation (Nash et al. 2021; Degroot et al. 2022). The study adopted the reconstructed climate data by these two methods based on natural proxies and historical documents. Among different climate change patterns, cooling and drought are most disastrous to historical societies (Parker 2013).

Temperature data (Figure 1A) are derived from Yang et al. (2002) and Shi et al. (2012), which have been used in existing studies (Pei et al. 2016). Temperature data by Yang et al. (2002) are reconstructed from multiproxy, such as ice core and lake sediment, which have been already adopted as a reliable indicator to investigate the relationship between climate change and social response in historical China (Zhang et al. 2005). Temperature data by Shi et al. (2012)

are reconstructed at an annual resolution from instrumental data and published proxy data, which have been considered consistent with other reconstructions (Shi, Li, and Wilson 2014). Therefore, temperature data by Yang et al. (2002) and Shi et al. (2012) are used to obtain a temperature anomaly resolution higher than the current temperature reconstruction, for example, Ge et al. (2013). The annual temperature data used in the study are the average values after the standardization of two adopted temperature series.

Pei and Zhang (2014) constructed the precipitation data (Figure 1B) from documentary-based hydroclimate reconstructions with annual resolutions. This reconstruction has a special merit to show the pure signal of precipitation change in historical China on a long-term scale because other natural proxies, such as tree rings and cave speleothem, may contain mixed temperature signals (Büntgen et al. 2011).

Notably, indicators of temperature and precipitation are anomalies but not instrumental records. In the field of paleoclimatology and historical climatology, climate conditions have been reconstructed by different proxies, including historical documents, tree rings, lake sediment, and ice cores (Mann et al. 2008). Climate reconstruction is used only to reflect temperature or precipitation fluctuations although reconstructed climate anomalies are robust scientific indicators of paleoclimatic conditions (PAGES-2k-Consortium 2013). Therefore, climate reconstruction is not the direct climatic record as measured by currently used instruments.

Silk consumption by the Qing imperial court

Silk consumption by the Qing imperial court has been carefully recorded in historical documents. The dataset is obtained from *The General History of Chinese Silk* by Zhao (2005), which includes the annual outputs of the three official weaving bureaus located in Jiangning (today Nanjing), Suzhou, and Hangzhou, responsible for supplying all kinds of silk products to the imperial court (Fan and Jin 1993; Wei 1992).

We can further categorize total silk consumption by the Qing imperial court into three types: *Shangyong* (silk for the emperor, Figure 1D), *Guanyong* (silk for royalties and officials, Figure 1E), and *Bupai* (silk as rewards, Figure 1F) (Zhao 2005). *Shangyong* was only for the emperor with the highest standards of craftsmanship; *Guanyong* was for imperial families and officials to make costumes; and *Bupai* was rewarded by the Qing imperial court to officials and their families and dependent tribes and states to show the wealth, graciousness, and power of the empire (Zhao 2005). The historical background and the features of these three kinds of silk consumption (Table S1) were summarized with more details in the Supplementary Material. Any missing data were linearly interpolated to achieve an annual time series of silk consumption. The statistical results are interpreted on the basis of the historical background and the features of these three kinds of silk consumption.

Natural disaster

In historical China, coldness, flood, and drought frequently occurred and disrupted agricultural production (Pei 2017). Coldness reflects the abnormal change in temperature. Furthermore, frequent flooding and drought not only damage natural ecosystems but also lead to serious agricultural loss and even societal chaos (Yan et al. 2021). Records on coldness, flood, and drought are obtained from the *History of Natural Disasters in China* compiled by Gao (1997), which comprehensively records various natural disasters in history (Liu, Zhang, and Gao 2001). The datasets by Gao (1997) have been widely used to study the past natural disasters and related impacts on historical China (Lee and Zhang, 2010, 2013). The original data were counted every 10 years. Thus, we converted 10-year data into annual data by linear interpolation. Coldness, flood, and drought have been arithmetically summed to indicate the general conditions of natural disasters (Figure 1G).

Social crisis

Wars, famines, and epidemics are considered to indicate social crises (Figure 1H), which have also been traditionally regarded as Malthusian Checks (Malthus 1798) and exerted major social stresses on preindustrial societies (Tol and Wagner 2010). War data are counted at annual resolutions gathered from *Chinese Military History*, compiled by the Nanjing Academy of Military Sciences (2003) with high systematicity and authority. The dataset on epidemics is derived from the chronological table of pestilence in China (Sun 2004); it provides a complete summary of epidemics every year in the whole historical period of China (Pei et al. 2015). Famine data are derived from the *History of Natural Disasters and Agriculture in Each Dynasty of China*, compiled by the Chinese Academy of Social Sciences (1988). The dataset is valuable for its consistency and has provided strong support for research on the social impacts of natural disasters (Teng, Su, and Fang 2014). The original data of famine were not the number of occurrences, but the index of occurrence or not for each year. To obtain data in the same form as war and epidemic, we first calculated the cumulative occurrence probability of each decade and then converted the 10-year data into annual data using linear insertion method. We count the number of wars, epidemics, and famines between 1735 CE and 1840 CE and sum them up as the index for the social crisis. Given that the famine dataset has a different temporal scale from datasets of wars and epidemics, we conduct additional tests to verify that the processing of famine data does not affect the conclusion, as shown in Section 3, Supplementary Material.

Economic well-being

In this study, real gross domestic product (GDP) per capita and rice price index are adopted to indicate the economic well-being in Qing China. GDP per capita is an important and useful indicator of the economic development level (Wang et al. 2015), and the real economic data can eliminate the effects of inflation rates over a long investigation period (Pindyck and Rubinfeld 1995). Real GDP per capita data (Figure 1I) are derived from Liu (2009). These data

provide economic data in ancient China and have been used to investigate the political economy of early modern China (Deng 2012).

The rice price index is another important indicator of economic condition in Qing China (Pei et al. 2016), and it has been used to examine the economic impacts of climate change (Ge 2011). Data on the rice price index (Figure 1J) are obtained from the studies of Peng (1957) and Wang (1992). The quality of these two datasets has been recognized by previous research worldwide (Allen et al. 2011; Cheung 2012). The price series of Peng (1957), which shows the rice market fluctuations in China, covers 961–1910 CE, whereas that of Wang (1992), which reflects the rice price in the Yangtze Delta, the center of rice production in China, covers 1638–1935 CE. These two datasets are initially standardized and then arithmetically averaged to obtain the rice price index series.

Population

Population data (Figure 1K) are retrieved from the *History of Chinese Population* (Zhao and Xie 1988). Compared with other population data, for example, Jiang (1993) and Cao (2000–2002), Zhao and Xie's (1998) population series has a higher resolution. Furthermore, Zhao and Xie's (1998) population data have been evaluated and found to be reliable (Turchin 2006). The natural logarithm of existing data points is first obtained, then linearly interpolated, and finally antilogged to replace missing data and create an annual time series. This method prevents any distortions in the population growth rate resulting from data interpolation.

Statistical methods

Datasets on silk consumption, real GDP per capita, and population size are naturally logged before the quantitative analysis to remove the exponential trend and stabilize data variances for statistical analysis (Pemberton and Rau 2011). Silk consumption by the Qing imperial court includes the total silk consumption and three categories of silk consumption (i.e., *Shangyong*, *Guanyong*, and *Bupai*) as the targeted dependent variables. We have checked multicollinearity

when conducting multivariate regression analysis. According to Table S2 in the Supplementary Material, the correlation values among real GDP per capita, rice price, and population are quite high. A multicollinearity issue is found between real GDP per capita and population, as shown in Table S3 in the Supplementary Material. Therefore, real GDP per capita, rice price, and population are separately included in the regression analysis, as shown in Table 2 (Models 1–3).

Granger causality analysis (GCA) is applied to investigate the statistical closeness between dependent and independent variables in Tables 3 and 5. Notably, the GCA does not suggest causality but statistically indicates the quantitative closeness of the relationships among variables (Zhang et al. 2011). Prior to GCA, the augmented Dickey–Fuller (ADF) test is employed to check the stationarity of the time series (Agung 2011), as shown in Table S4 in the Supplementary Material. The unstationary series is transformed into stationary ones by the differencing method. The time lag for ADF and GCA is set on the basis of Akaike's information criterion (Akaike 1974). The significance level for statistical analysis is set to 0.05 (95%).

Results and Analysis

In Figure 1, the total silk consumption declined from the peak in 1736 CE, then fluctuated, and generally maintained a downward trend. The consumptions of *Shangyong*, *Guanyong*, and *Bupai* differ in quantity, but they all present a decreasing trend during the whole study period. Further statistical analysis has been conducted on silk consumption under climate change and other selected ecological–social–economic stresses.

Total silk consumption

Correlation analysis shows that suitable climatic conditions and a booming agrarian economy were accompanied by an increase in total silk consumption. As shown in Table 1, the total silk consumption is significantly correlated with temperature, precipitation, real GDP per capita,

rice price index, and population. The positive coefficients of temperature and precipitation mean that higher temperature or more precipitation is statistically correlated with more silk consumption. The positive coefficient of real GDP per capita and the negative coefficient of the rice price index suggest that higher real GDP per capita or lower rice price is statistically correlated with more silk consumption. High real GDP per capita and low rice prices indicate economic prosperity (Pei et al. 2016) to support the Qing imperial court's expenses. A negative correlation value exists between silk consumption and population because demographic pressure hindered economic development in historical China and exhausted the resources in agrarian China (Huang 1990).

Similar to the correlation results, temperature, precipitation, real GDP per capita, rice price index, and population are significant in multivariate regression, as shown in Table 2. Although temperature is insignificant in Model 2, two adopted climatic indicators in the study generally have significance to the total silk consumption. The coefficients of real GDP per capita, rice price index, and population are also significant. This finding further justifies that economic well-being and demographic conditions have significant effects on total silk consumption.

Despite the results of correlation and regression, the statistical closeness of each linkage is not strong enough according to the GCA results in Table 3, even though they are significant in Tables 1 and 2. Therefore, the ecological–social–economic stresses could affect the Qing imperial court's total expense on luxury silk products, but in a limited way.

Consumption of Shangyong, Guanyong, and Bupai

In Table 1, the consumption of *Shangyong* and *Guanyong* share similar results with the total silk consumption. Another significant linkage further exists between social crisis and the consumption of *Shangyong* only in correlation analysis rather than regression analysis. The

negative correlation coefficient indicates that the consumption of *Shangyong* would decrease if more social crises occurred.

However, the consumption of *Bupai* shows a different pattern from *Shangyong* and *Guanyong* because it is insignificantly correlated with any variables. As mentioned, the consumption of *Bupai* is the reward given by the Qing imperial court (Fan 1988), highlighting Chinese superiority and suzerainty (Zhang 2009). The consumption of *Bupai* is therefore maintained as a routine practice to show the influence and wealth of the Qing imperial power, which usually ignores domestic conditions.

The consumption of *Shangyong*, *Guanyong*, and *Bupai* is further examined through multivariate regression analysis, as shown in Table 4. Again, the results are similar in the consumption of *Shangyong* and *Guanyong*, whereas *Bupai* shows a different pattern.

The GCA results in Table 5 identify the significant linkages of "precipitation–*Shangyong*," "real GDP per capita–*Shangyong*," "real GDP per capita–*Guanyong*," and "rice price index–*Guanyong*." However, in contrast to the other two categories, the consumption of *Bupai* has no significant variables in all GCA results. In terms of three specific categories, the Qing imperial court mainly considered economic well-being, the source of fiscal income for their expenses, but not other ecological or social factors according to the statistical results.

Discussion

Climate change and silk consumption by the Qing imperial court

According to the statistical results, climate change has a significant effect on silk consumption by the Qing imperial court, which has indicated the role of climate change in two aspects. First, climate change directly affects silk production because the production of raw silk involves mulberry planting and silkworm breeding (Zhu 1992). Mulberry prefers warm and moist conditions, and silkworms are active under warm climates (Zhang and Yu 1985). In this regard, cooling or drought conditions of climate dampen silk production[2], which also affect the silk

consumption even by the Qing imperial court. Furthermore, climate change holds a similar importance to luxury goods of certain types, the production of which closely depends on agricultural activities, such as tea (Nowogrodzki 2019) and coffee (Jaramillo et al. 2011) within the past agrarian context.

Second, climate change can indirectly affect silk consumption because the agrarian economy is heavily dependent on climate conditions (Carleton and Hsiang 2016). Our statistical results show that economic well-being has a closer linkage with silk consumption by the Qing imperial court than climate change according to Tables 1–4, particularly for consumption of *Shangyong* and *Guanyong*. Given that the consumption of luxury goods is positively related with income increase, silk consumption by the Qing imperial court highly depends on the agrarian economy (Ghosh and Varshney 2013).

More factors should exist to affect the Qing imperial court's consumption. However, our results statistically support the above mechanisms, which show the uncovered role of climate change to affect the expenses on luxury products by the Qing imperial court significantly. In recent years, the role of climatic change has been expanded to understand historical dynamics. Such inclusion is essentially important to the unification between natural sciences and humanities in the light of the current and coming Anthropocene (Carter 2020). Although our study statistically reveals that silk, an important luxury product in imperial China, was affected by climate change, we still admit that the importance of climate change should not be overstated.

Ecological–social–economic stresses and silk consumption: Lost in luxury

Among those selected ecological–social–economic stresses, natural disasters and social crises have no sway over the Qing imperial court's total silk consumption based on our results. In general, natural disasters and social crises negatively affect silk production and government revenue[3]. At this moment, the expense of unnecessary consumption of luxury silk products

adds extra burdens to societies. However, the Qing imperial court did not fully consider the public miseries (natural disasters and social crises) when consuming those luxury silk products, as reflected from the insignificant results of total silk consumption.

In terms of three different categories of silk consumption, climate change, economic well-being, and demographic pressure still hold significance to the consumption of *Shangyong* and *Guanyong*. In addition, social crisis only significantly affects the consumption of *Shangyong*, as shown in Table 1. However, as a fatal external shock, natural disaster was more or less ignored by the Qing imperial court given its luxury consumption in any categories. As a more shocking result, the consumption of *Bupai* is particularly different from the other two categories, based on those statistical analyses. As the "face" of the Qing Dynasty, the consumption of *Bupai* is guaranteed regardless of ecological, social, and economic sufferings. For example, during the sixth year of *Qianlong*'s reign (1741 CE), despite severe floods, the emperor gave officials almost 70,000 rolls of silk cloth in a royal celebration[4]. In the eye of the Qing imperial court, political legitimacy seemed to be prioritized over the miseries suffered by civil communities.

These statistical results imply that the Qing imperial court did not hold an active institutional attitude to address the ecological–social–economic stresses. We cannot deny that the Qing government dealt with ecological–social–economic stresses through temporary tax exemption and tax postponement, stored grain distribution (*Changping Cang* and *Yi Cang*), and barn construction (Hao et al. 2020)—all were implemented to forestall or partially curtail the impact of food crisis (He 2021). However, the Qing imperial court did so only half-heartedly. The court preferred to expand the fiscal revenue source rather than reduce extravagant spending (Shen 2004), using one historical record[5] as a proof: private donations were collected to support the extravagant spending of the Qing imperial court. Therefore, the meager and weak institutional willingness to enhance social resilience might have eventually

impaired the social capacity to cope with the ecological–social–economic stresses in Qing China.

In a centralized society, institutional response decides the result of addressing potential or ongoing ecological–social–economic stresses. Institutional neglect and incompetence discourage the public from managing climate and related ecological risks (Lo et al. 2021). Both also discourage the public from recognizing the importance of a government having the right attitude toward social resilience through legislation, public supervision, and other means to reduce social vulnerability (Holcombe 2018). The lack of support from the central government consequently hindered the development of historical China, which has been recognized in some historical records[6].

Qing's institutional attitude toward ecological–social–economic stresses

The quantitative examination of climate change and luxury expenses on silk products could further reflect Qing's attitude toward ecological–social–economic stresses at the institutional level. In recent years, many scholars have considered institutional mechanisms together with past climate change to explain the economic decline in the early 19th century (Li 2007). Climate change greatly affected historical China owing to the high social vulnerability in historical China (Pei et al. 2016). As one of the disastrous stresses to human societies, climate change in the past could fundamentally trigger natural disasters and social crises (Büntgen et al. 2011; Yan et al. 2021). Despite the results in correlation and regression analyses, no significant linkages exist in the GCA analysis among climate change, natural disaster, social crisis, population size, and silk consumption (in total and three categories, except "precipitation–*Shangyong*" in Table 3). In terms of three specific categories, natural disaster and social crisis have been more or less ignored owing to insignificant statistical results in correlation and regression analyses, except for social crisis and *Shangyong* in Table 1. The

Qing imperial court thus held a limitedly active institutional attitude toward climate change and other ecological–social–economic stresses.

Notably, the study of economic history found that China began to experience economic depression since the mid-Qing Dynasty (Wu 2001; Pei 2021). Long-term economic growth has declined since the 18th century, which is known as *Jiadao Zhongshuai* (the decline in the *Jiaqing* and *Daoguang* period, 1796–1850 CE). One key explanation of this decline focuses on institution (Little 2008), which was also explained by the climate vulnerability of the Qing Dynasty during the 18th–19th century (Pei et al. 2016; Li 2007). This study thus reinterprets the economic depression based on Qing's institutional attitude toward ecological–social–economic stresses.

The economic depression emerged among various social factors (e.g., technology, colonization, and corruption) (Little 2008). In agreement with current understandings, this study emphasizes that the inactive institutional attitude toward ecological–social–economic challenges in Qing China was a further contributing factor. As claimed by Brandt, Ma, and Rawski (2014), even if China had the technology or equipment, the country still lacked the vision of economic development. Therefore, unsurprisingly, the Qing imperial court's public spending was limited to address external security needs (Gupta, Ma, and Roy 2016). Local governments copied the imperial court's inaction and corruption, so much so that nearly half of the provincial treasury and grains were embezzled by local officials in the mid-to-late Qing[7]. Consequently, Qing China's inactive institutional attitude toward ecological–social–economic stresses made Qing China vulnerable and may have further facilitated the decline in the early 19th century.

Conclusion

This study analyzes the association between climate change and silk consumption by the Qing imperial court to expand the understanding of the impact of historical climate change beyond

living necessities. The study followed the framework of history of climate and society and paradigm of effect-of-cause school to understand the abovementioned association only from a macro scale. Our findings indicate the Qing imperial court's inactive institutional attitude may have increased social vulnerability and contributed to Qing China's decline and even fall behind preindustrial Europe. Our work, as the first attempt, provides a supplementary explanation of the economic depression since the mid-Qing, in addition to the current debates from the institutional perspective.

However, the study recognizes its limitations of quantitative analysis, which deserves further examination in the future. More quantitative studies should be conducted in the future if more datasets will be available. For instance, the famine dataset should be improved, although additional tests have been conducted to validate the findings and discussion as shown in Supplementary Materials. As another example, the Qing's institutional attitude must be examined again if datasets on fiscal revenues and expenditures of a long-term scale become available. The limitations of this study may imply that the quantitative analysis is useful to understand ecological–social–economic nexus at a macro scale. In the meantime, each data point and historical record on certain phenomena of micro scale highly affect the data availability and quality. Therefore, archives (records), methods (quantitative/qualitative), and scale (macro/micro) should be emphasized simultaneously with equal importance in the field of history of climate and society.

Based on historical lessons of Qing China, this study further reminds our present societies to review and encourage institutional action to tackle ecological–social–economic challenges. Social resilience is not only about coping with crises after they happen, but it also emphasizes the capacity of adaptability and transformability in response to global change (Keck and Sakdapolrak 2013). The state holds immense power, which can shape the definition of and the determinants of resilience in current social systems (Pike, Dawley, and Tomaney

2010). Whether the government has a positive attitude to make changes in the face of challenges, such as adjusting unnecessary expenditure, will affect the direction of social transformation and is crucial to social resilience.

End notes

1 Emperor *Qianlong* took the throne in 1735 CE, which is selected as the starting year of study period. The first year of the Qianlong reign period is 1736 CE.

2 The relationship between climate change and silk production found in this study is a trend on a long-term scale, and directly using historical records on a micro scale as evidence is difficult. We have identified some examples indicating that the short-term meteorological disasters killed mulberries and/or silkworms. One example is that in the ninth year of Jiaqing's reign (1804 CE), the summer was dry, planting beans was impossible, and buckwheat was harvested, but silkworm cocoon was not. The original sentence is（嘉慶九年）夏旱，不能種豆，蕎麥有收，蠶繭不成。《方城縣誌》卷五 (Records of Fangcheng County, Chapter 5). Another example is that in the 13th year of Tongzhi's reign (1874 CE), the mulberry trees were damaged by the frost last winter, the price of mulberry leaves rose to 60 coins, and some people even buried their silkworms. The original sentence is（同治十三年）桑被客冬凍損，鬻葉一斤價至六十文，甚有埋其蠶者。《陽城縣誌》卷十八 (Records of Yangcheng County, Chapter 18).

3 For example, in the spring and summer of the 34th year of Qianlong's reign (1769 CE), heavy rains fell in Huzhou (in Zhejiang Province) for several consecutive months, and silkworms and wheat were damaged. The heavy rain flooded the farmland, and the harvest failed in the autumn. The original sentence is（乾隆三十四年）春夏，湖州霪雨連旬，損蠶麥，大水，田禾淹沒。秋無收。《長興縣誌》卷九 (Records of Changxing County, Chapter 9). Another example is that in the 10th year of Jiaqing's reign (1805 CE), the harvest of wheat and beans was suddenly reduced, and the harvest of silk became even worse owing to heavy rains in March and April in the Hang, Jia, and Hu prefectures in the western Zhejiang Province. As a result, prices increased, and people's lives became difficult; hence, they needed to be properly compensated. The original sentence is 浙西杭、嘉、湖三府屬因本年（嘉慶十年）三四月間陰雨較多，麥豆收成頓減，蠶絲更為歉薄，價漸長，民食維艱，極須妥為撫恤。《嘉興府誌》卷二十 (Records of Jiaxing County, Chapter 20).

4 During the sixth year of the Qianlong's reign (1741 CE), 16 counties, including Fengyang (in Anhui Province), were hit by floods; crops were also damaged. On November 25 of the same year, the emperor rewarded officials almost 108,750 teals of silver and 69,738 rolls of silk cloth to celebrate

the 50th birthday of the emperor's mother. The original sentences are 乾隆六年……今年上江鳳陽等十六州縣夏秋被水。有傷禾稼。《大清高宗純皇帝實錄》卷一百五十三 (Records of Emperor Gaozong Chun (Qianlong) of the Qing Dynasty, Chapter 153)；本年十一月二十五日、恭遇皇太後五十萬壽。……共應賞銀十萬八千七百五十兩。布六萬九千七百三十八匹。《大清高宗純皇帝實錄》卷一百五十四 (Records of Emperor Gaozong Chun (Qianlong) of the Qing Dynasty, Chapter 154).

5 The original sentence is 既無開銷正項之體。則必取之商捐。《大清高宗純皇帝實錄》卷三百四十 (Records of Emperor Gaozong Chun (Qianlong) of the Qing Dynasty, Chapter 340).

6 During the 55th year of Qianlong's reign (1790 CE), an investigation found that officials in various provinces were not doing their jobs properly and had bad reputations among the people. The original sentence is 各督撫聲名狼藉。吏治廢弛。經過各省地方。體察官吏賢否。商民半皆蹙額興嘆。各省風氣。大抵皆然。《大清高宗純皇帝實錄》卷一千三百六十七 (Records of Emperor Gaozong Chun (Qianlong) of the Qing Dynasty, Chapter 1367).

7 The original sentence is 各省節年積欠錢糧。半由吏蝕官侵。《清實錄道光朝實錄》卷四十二 (Records of Emperor Daoguang of the Qing Dynasty, Chapter 42).

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Figure caption

Figure 1. Data series in the study. A. Temperature anomaly (unit: ℃); B. Precipitation anomaly (unit: mm); C. Total silk (unit: 1,000 rolls); D. *Shangyong* (silk for the emperor) (unit: 1,000 rolls); E. *Guanyong* (silk for royalties and officials) (unit: 1,000 rolls); F. *Bupai* (silk as rewards) (unit: 1,000 rolls); G. Natural disaster (unit: number of events); H. Social crisis (unit: number of events); I. Real GDP per capita (unit: grams of silver); J. Rice price index; K. Population (unit: 10 million).