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Cost of resilience to climate change: migration, conflicts, and epidemics in imperial China

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Abstract

A growing scholarship is focusing on the cost of social resilience to climate change in the past. Among different resilience strategies, migration could be effective for nomadic societies despite the potential consequences of conflicts and epidemics. Thus, this study utilizes historical records to statistically investigate the linkages among nomadic migrations, nomad–farmer conflicts, and epidemics under climate change and population pressure in imperial China (200 BCE–1840 CE) on the national and provincial scales. The current study will first attempt to empirically identify and analyze the cost of resilience to climate change mainly in the direction from nomadic societies to agrarian societies in historical China. In particular, we show the cost of nomadic migration passed in a chain mechanism as 'climate change → nomadic migration → nomad–farmer conflicts → epidemics.' Nomad–farmer conflicts were one direct effect of nomadic migration, while epidemics were an indirect one. Spatially, more provinces were affected under the direct effect than under the indirect effect. Furthermore, the first level of chain 'nomadic migration → nomad–farmer conflicts' covers more provinces than the second level 'nomad–farmer conflicts → epidemics'. These empirical results remind us to identify and avoid the cost of resilience as early as possible before the cost may transmit further in a chain manner. However, the provinces outside the concentrated nomad–farmer conflicts did not demonstrate significant linkages between conflicts and epidemics, which highlights the importance of peaceful cross-civilizational and inter-societal interactions against common challenges of climate change. This study with a cross-scale perspective in geography provides a theoretical implication to improve the current understanding on climate justice and have a practical value to avoid or minimize the cost of resilience.

1. Introduction

Past lessons have been empirically studied to seek successful resilient approaches and strategies to address current climate challenges. In recent years, the cost of resilience in history has received increasing academic attention (Brook 2010, Degroot *et al* 2021). Among the different resilient approaches, migration has been regarded as an effective one, particularly in nomadic societies, despite its potential impact, of which conflicts and epidemics are two major consequences (Barros Damgaard *et al* 2018, Pei *et al* 2020). However, current studies have mainly understand past resilience on a case basis (White *et al* 2023). To advance critical evidence and findings from case studies, recent research has endeavored to investigate long historical time series to holistically re-interpret pre-1900 CE social dynamics under climate change (Hsiang *et al* 2013). China holds rich records on nomadic migration, nomad–farmer conflicts, and epidemics, providing a sound basis for statistical investigation into the long time series of historical records.

In Chinese history, nomads and farmers comprise two major players (Turchin 2009). Note that nomad is a broad term in this study, indicating tribes in China's northern marginal areas that launched periodic large-scale migration into the country's agricultural zone. Nomads are ready to migrate to relieve climatic impact, whereas farmers prefer to stay on their land (Pei *et al* 2018). Therefore, nomadic migration presents a resilient strategy to climate change (deMenocal and Stringer 2016). However, this strategy comes with costs, leading to various chaos (Feng *et al* 2019). In this regard, the current study will focus on the aforementioned cost of nomadic migration by two major effects: nomad–farmer conflicts and epidemics.

Despite the increasing attention to the cost of nomads' resilient migration, there are still some major points unanswered. First, nomadic migration did not always result in actual and close contact between farmers and nomads (Pei *et al* 2020). If nomad–farmer contact occurred, it usually led to conflicts (Zhang *et al* 2015). The mechanism connecting nomadic migration, nomad–farmer conflicts, and epidemics has not been clearly described with empirical support. Second, there is still a lack of sufficient studies to reveal the cost of resilience to climate change on a long-term scale, which has been highlighted to investigate the relevant past (Baldwin 2017). Meanwhile, there are numerous cases on nomadic migration and the related consequences of epidemics and conflicts, of which five cases have been chosen as examples listed in the appendix. However, conducting a long-term quantitative analysis on many of these records is worth of the further effort. Third, although cross-scale analysis in space is important to resilience research (Cash *et al* 2006), previous studies have lacked sufficient attempts to understand the cost of migration across different spatial scales (Xu *et al* 2011). To date, conflicts or epidemics resulting from the nomadic migration under climate change have been mainly studied at the national scale (Bai and Kung 2011, Tian *et al* 2017). Such a nation-scale practice has relatively failed to consider regional climatic–demographic diversity across China's vast territory.

To address the current research gaps, this study sets the temporal scale over the period from 200 BCE to 1840 CE. The analysis across spatial scales (national, and provincial) will advance current understanding on the cost of nomadic migration as a resilient strategy to climate change (Turner 2014). Disastrous climate change in China's past usually included cooling or drought (Parker 2013). We hypothesized that nomadic migration to relieve climatic impact would induce cost in historical China by resulting in more nomad–farmer conflicts and epidemics. Moreover, nomad–farmer conflicts, which result from actual contact, should be a more important factor of epidemic occurrence than nomadic migration. This study aims to substantially understand two starkly different civilizations (Hermes *et al* 2018), namely, nomadic and agrarian societies, as a key to understand imperial China and global past.

This study will provide a first attempt to empirically identify and analyze the cost of social resilience to climate change mainly in the direction from nomadic to agrarian societies in historical China. However, it does not mean that no cost of resilience existed from agrarian to nomadic societies. Furthermore, the application of a cross-scale perspective provides a theoretical implication on cost of social resilience and also has practical value to realize the fairness of social resilience to climate change in the realm of climate justice. Our findings on cost of social resilience in a non-Western and historical setting may be valuable for preparing current societies to address potential climatic challenges in the future.

2. Data sources

China has accumulated numerous historical records, such as the Twenty-Four Histories and local chronicles. The records adopted in this study are from books compiled based on these valuable records. This study adopts a quantitative framework, which requires consistent statistical standards for the data. However, during the years 200 BCE–1840 CE examined in the study, the boundaries of the country and provinces in imperial China changed many times in history. In order to make the quantitative analysis more accurate, this study quantitatively examines the territory within China's current political borders as the national scale covering almost all dynasties and geopolitical changes (Zhang *et al* 2015). To perform the quantitative analysis at the provincial scale, the study understands that there are many debates on the province boundary. Therefore, we follow the common practice to use the current provincial division of China with a few slight changes as 'provincial scale' (see section 1.2 in the appendix), because historical records were usually compiled accordingly (Zhao and Xie 1988, Ge *et al* 1997, ECCMH 2003, Zhang 2007, Ben-Ari *et al* 2012). Provincial datasets of nomadic migration, nomad–farmer conflicts, epidemics, and population size are all available. Although this approach is not a perfect one, it could realize the consistency between the datasets from the compiled books and spatial scale set in the study. Please refer to section 1, appendix for additional information on records and datasets for analysis.

2.1. Reconstructed climate: precipitation and temperature

This study adopts precipitation (figure S1, appendix) and temperature (figure S2, appendix) reconstructed from historical documents, ice cores, tree rings, and other proxies. The detailed process is explained in section 1.2 of the appendix. The regional data of temperature and precipitation reconstruction are used to represent the changing patterns of climate in each province (Pei *et al* 2020). Thus, climatic conditions for province-scale analysis are based on regional climate and landscape history in China (see table S1 in the appendix): Northeast China, Northwest China, the Qinghai–Tibet Plateau, North China, and Central–South China (Zhao 1986, Zhang *et al* 2015). Since the study adopts the province boundary at present based on the spatial scale used in the compiled books on data, the boundaries of these five regions also are set according to the province boundary in the study. Such a practice is used to keep the consistency of spatial scale to analyze the linkages in the study at the provincial level. The sources of climate reconstructions on the provincial/regional scale are listed as table S2 in the appendix. In imperial China, Northeast China, Northwest China, and the Qinghai–Tibet Plateau were mainly nomad-occupied regions featuring less rainfall and lower temperature (Pei and Zhang 2014). North China in the past was a major agrarian region, and the main zone of interaction between nomads and farmers.

2.2. Nomadic migration records

We obtained the records of nomadic migration from the chronological table in *The Chinese Migration History* (Ge *et al* 1997), which includes detailed records from 890 BCE to 1949 CE. We adapted them for the provincial scale analysis, with a total of 1745 historical records on nomadic migration, as shown in figure S3, appendix.

2.3. Nomad–farmer conflict records

The nomad–farmer conflicts, as presented in figure S4, appendix, include military conflicts and violent battles that occurred between nomads and farmers' polities. The locations of nomad–famer conflicts are clearly indicated in the historical records. We used the location information to assemble the data series of nomad–famer conflicts that occurred in each province. In this study, the records on nomad–famer conflicts in each province are obtained from previous publications (ECCMH 2003), covering records from 790 BCE to 1911 CE. Moreover, there are 2263 records of nomad–farmer conflicts with precise location information.

2.4. Epidemic records

Epidemics used in this study are from Zhang's book (2007) titled *The Table of Epidemics in Historical China*, covering 674 BCE to 1840 CE, which has been well recognized and cited in current studies, such as Qiu (2011) and Su (2012). This compiled book by Zhang's book (2007) provides the records which could be made into data series consistent with other data sources in the study at both national and provincial scale. Therefore, the compiled book by Zhang's book (2007) has been adopted, rather than other existing epidemic datasets, such as Gong (2019), which is one of most influential work in the field of historical medical geography. The complete provincial scale data series includes 1399 epidemic events with clear information on occurrence year and location. Zhang's book (2007) kept the original format of epidemic records in historical documents. To maximize the coverage on epidemic events, the different synonyms of epidemics are all collected in Zhang's book (2007). For more information on epidemics in the study, please refer to section 1.5 in the appendix.

Notably, China's medical system was historically different from that of Western societies. Traditional Chinese medicine and modern biomedicine differ substantially in theory, diagnostics, and treatments (Liu 2007). Ancient Chinese records only used the generic 'plague' or 'epidemics' (both are written as 疫 in Chinese) without providing a specific name for the infectious diseases or even rudimentary descriptions of their symptoms (with a few exceptions). Traditional Chinese medicine believes that functional information (e.g. symptoms, signs and behaviours) of patients should be holistically interpreted with the natural environment and societal background (Zhou *et al* 2010). Although medical records in Chinese historical documents are thus valuable to understand human ecology changes in imperial China, we may be unable to interpret traditional Chinese medicine according to modern biomedicine.

2.5. Population data

We retrieved data on population size from *The History of Chinese Population* by Zhao and Xie (1988), as shown in figure S6, appendix. The book provides estimates for the population size of the entire country and of each province by current administrative division in China from 684 BCE to 1949 CE. Notably, there are also many important works to calculate the population in historical China, for example, Cao (2000–2002). In the study, Zhao and Xie (1988) population series are used because it provides the population change at the provincial scale with a high resolution. Furthermore, the population data by Zhao and Xie (1988) have been evaluated and found to be reliable (Turchin 2006), and have also been well recognized in climate history research (Lee and Zhang 2013).

3. Analysis and results

This study first chooses and analyzes five historical cases in section 1.1, appendix to narratively support the hypothesis. Thereafter, quantitative analysis of the datasets from the aforementioned sources will be performed on the national and provincial scales. The data series of migration, conflicts, and epidemic are made in the format of count data based on the event numbers. Thus, we adopt Poisson regression for data analysis at the national and regional scales because Poisson regression is the benchmark model for count data (Cameron and Trivedi 1998). Before the analysis, we took the natural logarithm of population data (i.e. ln *population* or $\log_e$ *population*, e is a mathematical constant approximately equal to 2.71828) to remove the exponential trend and stabilize the data variances in the population dataset.

Table 1 presents the results of the nation-scale Poisson analysis, which will establish the chain mechanism of the cost of resilience. Furthermore, panel data model based on province-scale data by feasible generalized least squares (FGLS) was used for robustness verification. The reason is that panel data consisting of time series and cross-sectional data contain large sample size, which can improve the accuracy of estimation and deal with endogeneity problems caused by unobservable individual heterogeneity (Arellano and Honoré 2001). Moreover, the FGLS method has the capability to solve the problems of autocorrelation, cross-sectional correlation, and heteroskedasticity (Bai *et al* 2021). The FGLS results confirmed the chain mechanism identified at the national scale, as shown in table S7, appendix. Table 2 summarizes the results of province-scale Poisson analysis from tables S3–S6, appendix. The FGLS method was also applied as robustness verification (see table S8, appendix).

To further understand the established chain mechanism on the provincial scale, we adopted the difference-in-differences (DID) approach based on province-scale data, which is capable of analyzing the different treatment effects across regions besides timespans (Delgado and Florax 2015). The DID approach will follow the current practice (Cao and Chen 2022) to examine whether the periods and regions with more nomadic migration would have more conflicts and epidemics. Additional discussion on the DID approach is provided in section 2.2, appendix.

3.1. Established chain mechanism on the national scale

The results of the Poisson analysis on the national scale are presented in table 1. According to significant coefficients, climate change, particularly precipitation, induced nomadic migration, which led thereafter to numerous nomad–farmer conflicts. Although nomadic migration did not have a significant effect on epidemics, nomad–farmer conflicts was significantly and directly linked with epidemic occurrence. Demographic pressure plays a significantly positive role, because the considerably large population pressure in historical China generally increases the possibility of disease outbreaks (Morabia 2009).

According to the statistical results on the national scale, we have built up a chain mechanism as ‘climate change → nomadic migration → nomad–farmer conflicts → epidemics’ to understand transmission of the cost of resilience. The linkage ‘climate change → nomadic migration’ is the resilient approach of nomads to climate change. The rest of the linkages in the chain mechanism could be regarded as the cost of nomads’ resilient migration (Barros Damgaard *et al* 2018, Pei *et al* 2020). Our results on epidemics are consistent with existing findings on the climate–epidemics linkage of the entire imperial China (Xu *et al* 2011, Tian *et al* 2017). The results from the Poisson analysis on the national scale can be further supported by the FGLS analysis (see table S7, appendix).

3.2. Established chain mechanism on the provincial scale

The chain mechanism indicates a markedly diverse pattern according to the statistical results on the provincial scale. As summarized in table 2, nomadic migration is significantly correlated with nomad–farmer conflicts in 15 out of 28 provinces, but in only 6 out of 28 provinces with epidemics. By contrast, nomad–farmer conflicts were a considerably significant factor of epidemic occurrence in 9 out of 28 provinces. If we place nomadic migration and nomad–farmer conflicts together to check their impact on epidemics, then more provinces will be affected by nomad–farmer conflicts (9 out of 28 provinces) than nomadic migration (4 out of 28 provinces). The strength in the two directly linked factors are stronger in the aforementioned chain mechanism than the indirectly linked factors.

Each direct link in the chain mechanism presents a spatial pattern according to the climatic zone. Nomadic migration mainly leads to numerous nomad–farmer conflicts in Northwest China, North China, and Central–South China. In historical China, Northwest China was mainly occupied by nomads

Table 1. Poisson regression results at the national scale in imperial China.

IV \ DV	Model (1) Migration	Model (2) Conflicts	Model (3) Conflicts	Model (4) Epidemics	Model (5) Epidemics	Model (6) Epidemics	Model (7) Epidemics
Migration			0.047^{**} (0.000)		0.007 (0.230)		0.003 (0.622)
Conflicts						0.006^{**} (0.000)	0.006^{**} (0.000)
Precipitation	-0.045^{**} (0.000)	-0.053^{**} (0.000)	-0.041^{**} (0.000)	-0.044^{**} (0.000)	-0.043^{**} (0.000)	-0.041^{**} (0.000)	-0.041^{**} (0.000)
Temperature	-0.723^{**} (0.000)	-1.038^{**} (0.000)	-0.825^{**} (0.000)	-1.144^{**} (0.000)	-1.114^{**} (0.000)	-1.028^{**} (0.000)	-1.017^{**} (0.000)
ln(Population)	-0.505^{**} (0.000)	-0.008 (0.845)	0.130^{**} (0.004)	0.243^{**} (0.000)	0.263^{**} (0.000)	0.267^{**} (0.000)	0.275^{**} (0.000)
Constant	6.089^{**} (0.000)	1.190^{**} (0.004)	-0.293 (0.500)	-2.218^{**} (0.000)	-2.426^{**} (0.000)	-2.431^{**} (0.000)	-2.515^{**} (0.000)

Notes: DV means dependent variables; IV means independent variables. * $p < 0.05$; ** $p < 0.01$. *P*-values in parentheses.

Table 2. Summary of positively significant results at the regional scale.

Migration → Conflict	Migration → Epidemic	Conflict → Epidemic	Migration + Conflict → Epidemic	
			Migration	Conflict
Gansu	Gansu	Hebei	Gansu	Hebei
Inner Mongolia	Inner Mongolia	Henan	Inner Mongolia	Henan
Xinjiang	Hebei	Ningxia	Ningxia	Ningxia
Qinghai	Ningxia	Shaanxi	Shanxi	Shaanxi
Hebei	Shandong	Shandong		Shandong
Henan	Shanxi	Anhui		Anhui
Shaanxi		Hubei		Hubei
Shandong		Jiangsu		Jiangsu
Shanxi		Jiangxi		Jiangxi
Anhui				
Hubei				
Jiangsu				
Jiangxi				
Sichuan				
Zhejiang				

Notes: Results were obtained using Poisson regression. Significant at the 0.05 and 0.01 levels. Temperature, precipitation, and population are controlled. Please see appendix: tables S3–S6 for complete results.

despite containing many farmlands with frequent nomad–farmer interactions (d'Alpoim Guedes 2015). Climatic condition in Northwest China is relatively dry and cold. If climate became drier or colder in the past, then nomads would migrate southward to North China for more water and heat, which would be occupied, in turn, by nomads and farmers (Zhang *et al* 2015) as major buffering zone for nomads. However, we find that the nomadic migration from Northwest China under climate change had more external impact on agrarian China (i.e. nomad–farmer conflicts and epidemics), which is consistent with current findings on nomads and imperial China (Pei *et al* 2020). If climate deteriorates further, Central–South China will be affected by the nomadic migration. The linkage between nomad migration and nomad–farmer conflicts presents a north–south direction in space.

The significant linkage between nomad–farmer conflicts and epidemics is mainly located in North China, including Hebei, Henan, Ningxia, Shaanxi, Shandong, and Anhui. If climate became harsher, then more nomads from Northeast and Northwest China would migrate to North China. Therefore, provinces with significant linkages between nomad–farmer conflicts and epidemics correspond to the grey zone in figure 1 of intensive conflicting region. Although nomad–farmer conflicts were scattered across China, provinces with more intensive nomad–farmer conflicts experienced more epidemics in North China. This situation indicates the importance of actual and close contact (i.e. nomad–farmer conflict) in the spread of diseases. Furthermore, the spatial patterns of chain mechanism should be examined more on the provincial scale.

The DID approach was applied in two steps, as shown in tables 3 and 4, to further quantitatively examine the constructed chain mechanism according to current practice (Cao and Chen 2022).

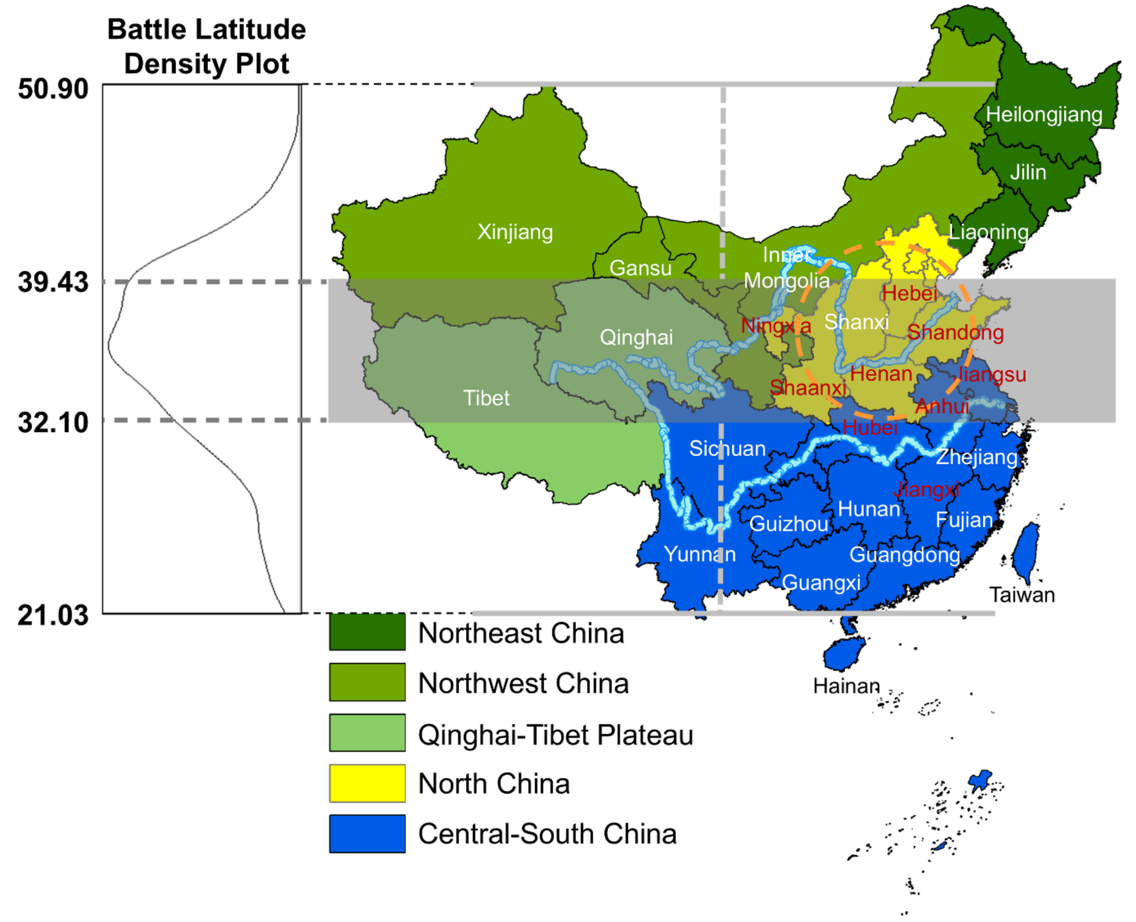

Figure 1. Spatial patterns of nomad–farmer conflicts and epidemics. Province names in red present the significantly positive coefficients of nomad–farmer conflicts on epidemics in the statistical analysis (based on table 2). The nomadic regions of China were mainly distributed in Northeast China, Northwest China, and Qinghai–Tibet Plateau. The agrarian regions of China were mainly distributed in North China and Central–South China. The grey region of the boxplot shows the latitudinal band representing the densest region of conflicts between nomads and farmers. The orange circle indicates central China (heartland of China) in history (Pei *et al* 2019).

Table 3. DID results with period dummy variables.

IV \ DV	Model (1) Conflicts	Model (2) Epidemics	Model (3) Epidemics	Model (4) Conflicts	Model (5) Epidemics	Model (6) Epidemics	Model (7) Epidemics
Migration × *Yin* periods	0.831^{**} (0.000)	0.099 (0.078)		0.810^{**} (0.000)	0.103 (0.089)		0.055 (0.411)
Conflicts × *Yin* periods			0.057^{**} (0.003)			0.053^{**} (0.005)	0.049^{*} (0.014)
Precipitation				0.039 (0.167)	−0.024 (0.073)	−0.025 (0.050)	-0.026^{*} (0.049)
Temperature				0.170^{**} (0.000)	0.028 (0.677)	0.018 (0.783)	0.020 (0.762)
ln(Population)				0.205^{**} (0.001)	0.225^{*} (0.022)	0.218^{*} (0.027)	0.218^{*} (0.027)
Constant	0.654^{*} (0.034)	0.731^{*} (0.022)	0.731^{*} (0.022)	−0.800 (0.104)	−0.799 (0.288)	−0.753 (0.321)	−0.751 (0.321)
Province FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Note: DV means dependent variables; IV means independent variables; FE means fixed effect. * $p < 0.05$, ** $p < 0.01$. *P*-values in parentheses. Robust standard errors are clustered at the province level.

First, we set period dummy variable that equals one when nomadic tribes established empires on the agricultural heartland, and zero when agriculturalists occupied the agricultural heartland. The three periods of large-scale nomadic migration are 304–581 CE, 1127–1368 CE, and 1644–1840CE, which led to vast nomad–farmer conflicts in Chinese history (Zhang *et al* 2015). Accordingly, these periods are

Table 4. DID results with space dummy variables.

DV / IV	Model (1) Conflicts	Model (2) Epidemics	Model (3) Epidemics	Model (4) Conflicts	Model (5) Epidemics	Model (6) Epidemics	Model (7) Epidemics
Migration × *Yin* provinces	0.668** (0.000)	0.001 (0.976)		0.653** (0.000)	0.001 (0.982)		−0.059 (0.281)
Conflicts × *Yin* provinces			0.086** (0.007)			0.085** (0.007)	0.088** (0.010)
Precipitation				0.053 (0.094)	−0.022 (0.100)	−0.023 (0.070)	−0.023 (0.074)
Temperature				0.139** (0.003)	0.025 (0.707)	0.019 (0.769)	0.020 (0.763)
ln(Population)				0.220** (0.001)	0.227* (0.022)	0.222* (0.023)	0.222* (0.023)
Constant	0.602 (0.056)	0.731* (0.022)	0.691* (0.029)	−0.922 (0.069)	−0.810 (0.285)	−0.815 (0.282)	−0.812 (0.284)
Province FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Note: DV means dependent variables; IV means independent variables; FE means fixed effect. * $p < 0.05$, ** $p < 0.01$. *P*-values in parentheses. Robust standard errors are clustered at the province level.

called the *Yin* period in Chinese history (Lee 1933) and were set as one. In the three periods, Central China (heartland of China; see figure 1) was controlled politically and militarily by nomads but not farmers, such as the Qing Dynasty (1644–1840CE) was established by Manchu, which witnessed the large-scale nomadic migration to the south. Such a historical background enables the DID approach, and the results confirm the aforementioned effects in the chain mechanism at the provincial scale. The results in table 3, with the significantly positive coefficients between migration and *Yin* period, indicate that the active nomadic period would bring numerous conflicts, and this effect increased with an increase in the number of migrations. However, in periods of intense nomadic activities, increased migration did not increase the number of epidemics but increased conflict did.

Second, we followed the idea of DID and set space dummy variable that equals one when conflict variable is significant to epidemics in the preceding provincial Poisson regression (9 provinces of Conflict → Epidemic in table 2 named as *Yin* provinces) and zero otherwise. The results (table 4) show that in provinces with a stronger conflict–epidemics relationship (*Yin* provinces) than others, the number of conflicts increased with an increase in the number of migrations, while the number of epidemics increased with an increase in the number of conflicts. In summary, the chain mechanism confirmed that the number of nomad–farmer conflicts increased with an increase in the number of nomadic migrations. The number of epidemics increased with an increase in the number of nomad–farmer conflicts.

4. Discussion

4.1. Direct and indirect costs of the resilient migration of nomads under climate change

This study utilizes empirical evidence to propose the following chain mechanism: 'climate change → nomadic migration → nomad–farmer conflicts → epidemics.' Direct and indirect mechanisms of cost was empirically identified in the nomadic migration as the resilient approach to climate change based on historical cases of imperial China and different quantitative methods. Nomads' resilient migration under climate change will likely lead to nomad–farmer conflicts as a direct effect. To date, numerous studies have uncovered nomadic migration owing to the impact of climate change as a trigger of nomad–farmer conflicts (Hsiang *et al* 2013). Although migration may relieve climatic impact for nomads, it may also lead to suffering in the adjacent agrarian regions.

Epidemics as one of the resilient migration's costs should be interpreted as an indirect effect through the nomadic migration. However, identifying and handling such a cost are occasionally difficult, if epidemics operate through an indirect mechanism (Stewart and Ghani 1991). In imperial China, agrarian and nomadic societies developed their respective medical practices (Janes 1995), but medical services in both sides remained relatively poor by modern standards (Chen and Chen 2014). By contrast, statistical results and five historical cases imply that inter-societal conflicts would directly result in epidemics, particularly when there was a weak public health system in the past. In addition, present-day awareness indicates that war causes the breakdown of public health systems, leading to the emergence and re-emergence of epidemics (Cohen 2000). Therefore, nomads' resilient migration to climate change should receive additional attention to explaining the potential cost of resilience along with our identified chain mechanism.

4.2. Spatial pattern of resilient cost in the chain mechanism

The province-scale analysis in this study empirically reflects the spatial patterns of significant effects along with the chain mechanism. The statistical results indicate that direct linkage affects more provinces than indirect linkages. The linkage 'nomadic migration → nomad–farmer conflicts' significantly affects 15 provinces, while the indirect 'nomadic migration → epidemics' only has 6 provinces with significant results. Furthermore, the cost of nomads' resilient migration decreases along with the level degradation. The first level in the chain mechanism, 'nomadic migration → nomad–farmer conflicts,' significantly affects most of the provinces spatially (15 provinces). Meanwhile, the second level 'nomad–farmer conflicts → epidemics' only covers 9 provinces. However, spatial coverage by the second level 'nomad–farmer conflicts → epidemics' is still relatively wide. Therefore, our study reminds to identify and stop the cost of resilience as early as possible before the cost may transmit along with a chain manner.

On the basis of the spatial pattern results, provinces outside the concentrated nomad–farmer conflicts did not demonstrate significant linkages between nomad–farmer conflicts and epidemics. Therefore, our results may suggest that relatively peaceful and less violent interactions between both groups are less likely to have facilitated the outbreak and spread of epidemics. Certain past studies have explained the spread of epidemics to west Eurasia through nomadic migration, such as in the case of the Mongolian migration and the Black Death (Pederson *et al* 2014, Schmid *et al* 2015). However, these studies did not distinguish between the peaceful interactions and violent conflicts resulting from nomadic migration. In this regard, the findings here suggest another way to reduce and stop the cost of resilience if peaceful cross-civilizational and inter-societal interactions are promised to tackle with climate change.

4.3. Understanding the cost of resilience to climate change from the geographical scale thinking

The study emphasizes the importance of scale in geography to the field of climate justice both theoretically and practically, based on the empirical analysis on China's past. Cost of resilience has been a critical issue and received substantial attention in the field of climate justice (Bikomeye *et al* 2021). However, current studies have disregarded cross-scalar views but only understood the costs of some certain measures within one region or country, such as carbon tax (Bailey 2017) or decarbonization (Cha and Pastor 2022). Therefore, geographical scale thinking provides a new pathway to understand the cost of resilience and eventually realize climate justice.

In our study, geographical scale thinking helps to reveal the chain mechanism to spread the cost of resilience. Meanwhile, the direct or indirect effect, different levels, and regions with different sensitivities will possibly be identified as the application of geographical scale thinking. The current study used nation and province for cross-scale analysis in space owing to the historical records in China. Accordingly, conducting similar research to even more specific regions, such as cities, is possible if there are supportive historical records in China or other regions or countries in the world.

Modern cities worldwide are highly vulnerable to climate change owing to their climate, landscape, and demographic conditions (Wardekker 2021), which are factors that have also been included in the current study. Moreover, the analysis of cities within one large region/country could share the similar cross-scale approaches adopted in this study. Interactions of materials, people, and even information among cities have become even closer than before (Shi *et al* 2022). Therefore, the transmission of the cost of resilience among cities will be easier and faster from now on. Thus, geographical scale thinking provides a practical tool to recognize and block the chain mechanism of cost transmission in real practice, which has been empirically proven by this study on historical China.

5. Conclusion

Interdisciplinary methods and a new spatiotemporal scale thinking enable us to identify the chain mechanism and link the spatial coverage with the direct or indirect effect. Although retro-diagnoses based on existing historical data are difficult and problematic, we believe that a substantially detailed analysis of human societies will become feasible with the help of improved records and datasets. Additional research should be conducted to understand the cost of resilience from agrarian to nomadic societies in the future, apart from our study (i.e. from nomadic to agrarian societies). Note that out study mainly used geographical scale thinking to re-interpret the cost of resilience. We are convinced that there are other potential and important factors to carefully examine the cost of resilience if using a different perspective from ours.

By extending the findings from imperial China to the modern global context, our conclusions are particularly pertinent in contemporary societies characterized by high mobility and diverse cultures, in addition to the unprecedented threat posed by global climate change. Hence, the cost of social resilience must be identified and avoided at the early stage. Furthermore, the cost of social resilience reminds us to consider fairness at various scales in time and space. As globalization increases, the cost of social resilience will be more evident than before. Accordingly, resilient choices for current climate change should now be reviewed. Our study reminds us to identify and stop the cost of resilience as early as possible before other consequences occur. To avoid the cost and further transmission of cost, our findings also suggest that contemporary societies should promise peaceful cross-civilizational and inter-societal interactions as an effective approach and strategy to address current climatic challenges.

Data availability statement

All data that support the findings of this study are included within the article (and any supplementary files).

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Conflict of interest

The authors report there are no competing interests to declare.

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