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<https://doi.org/10.1057/s41599-023-02246-0>

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# Human civilization dynamics: why we have different civilization patterns in history

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After the Axial Age, the West moved toward continuous disunity, but China had successfully maintained a persistent unity pattern. Conventional case (history event) studies are subject to selection bias and theoretical frameworks, which is not objective narrative. We use agent-based modeling (ABM) to reveal the historical dynamics of why civilizations take on distinct patterns (unity versus disunity). In China, the Qin Dynasty (initial unity) opened the Great Unity tradition in 221 BC. Before this, there was a major chaotic period (770 BC to 221 BC) with two periods. The first period, the Spring and Autumn (770 BC to 221 BC), opened this chaotic process and indirectly led to the initial unity. Then, the second period, the Warring States period (475 BC to 221 BC), directly led to this initial unity. This work models the second period and focuses on the question of why human civilizations take on different patterns in history. Finally, we have solved the conditions and boundaries of two patterns. Based on the second period, we have different conclusions. The bellicosity threshold is around 0.2 (for the previous period, this is 0.3), and the alliance propensity threshold is around 0.8 (for the previous period, this is 0.7). Moreover, the higher winner cost (beyond 5%) makes it impossible to achieve Unity. This work has one new contribution, such as solving social knowledge. We use BP neural networks to evaluate the knowledge graph to support history learning. It explains civilization patterns for humankind.

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**Introduction**

**Civilization patterns in human history.** The origin of civilization has commonalities. According to the circumscription theory (Carneiro, 1970) and hydraulic hypothesis (Eberhard, 1958), we can find similar social characteristics from the origins of global civilizations. The hypothesis of the Axial Age (Eisenstadt & Wittrock, 2005) also illustrates the similar historical and cultural features between ancient Chinese and Western civilizations. After the chaos and disunity of the Axial Age, the Qin state first unified ancient China (the Great Unity). After some turmoil and chaos, Chinese civilization still inherits this unity pattern. By contrast, after the brief unity of the Roman Empire, western civilization (Europe) had inevitably moved toward continuous disunity since then. Global civilization falls into two patterns: (a) Unity pattern of civilization can be well represented by China. The unity pattern refers to the continuity of civilization’s development (Blakeley & Chang, 2010). Under the unity pattern, the identity of people has been expressed by civilization instead of a sense of nationhood (Ikenberry, 2009). The cohesive and more homogenous culture, endogenous growth economy, and compactness of geographical vicinity also promote the historical process of unity civilization (Xia, 2014). In the life cycle of civilization, social development has a centripetal force, which stems from the centralized political structure and becomes a common characteristic (Ehsan & Wang, 2018). (b) Europe represents the disunity pattern. The disunity pattern is the opposite, and it refers to the discreteness of civilizations. Under centrifugal force, civilization manifests as a political co-ownership power structure (Chang, 2018), different economic currencies, and cultural separation (Scheidel, 2007). Therefore, civilization is segregated into unity and disunity according to different evolutionary patterns.

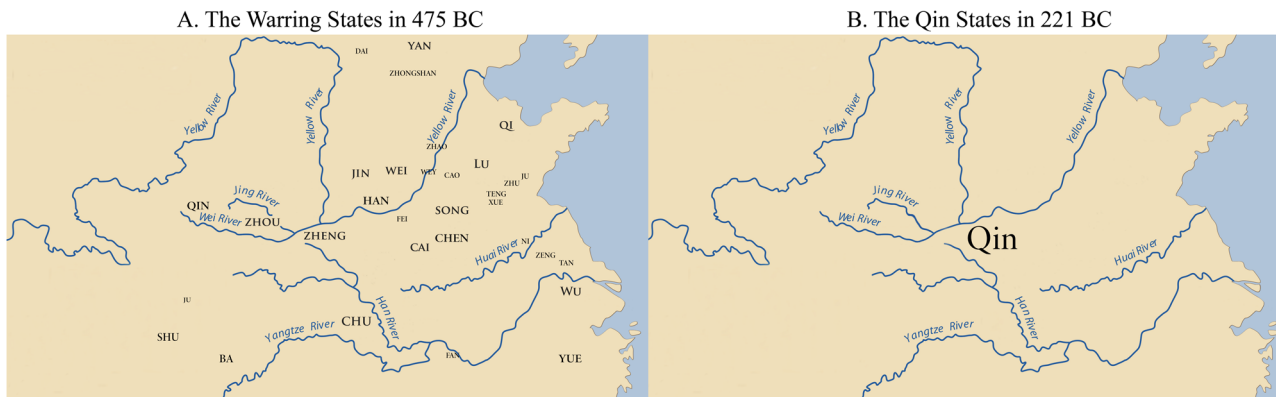
China is a unity civilization with a long history (Loewe & Shaughnessy, 1999). As shown in Table 1, although there were some chaotic periods (1252 years), the unity (about 2293 years) is still mainstream. Meanwhile, Europe has been in a state of diversity, discord, and conflict since the breakup of the Roman

Empire in 395 AD (Ko et al., 2018; Nearing (2004)). As the shifting period, the Warring States period played a critical role in exploring the origin and mechanism of differentiation civilization patterns. China’s politics, economy, and culture then experienced significant changes and developments (Lewis, 1999). The large-scale reforms in politics, the establishment of household farming in the economy, and the hundred schools of social thought jointly laid a solid foundation for the unity of the Qin Dynasty (Li & Zhang, 1985). They shaped this grand unity empire during the Warring States period, crucial for civilizational differentiation. Many factors influenced this process, such as geography, demography, the previous ruling styles, successor regimes, ideological power, and the possibility of unity (Carneiro, 1970; Doyle, 1986; Scheidel, 2008). Most historians generally agree that wars determine the evolutionary process for the states (Downing, 1992; Edgar & April, 2001; Ertman, 1997; Tilly, 2017).

**Related research for this period.** The research on the Warring States period can be summarized in the following aspects: (a) The statistics of wars. Detailed statistics on the war frequency during this period laid the foundations for subsequent research (Chiang, 2005). Through the statistical analysis of the scale of wars, we can further explore the reasons for the changes in the scale of wars in this period (Gunner, 2019). (b) The effects of wars. Researchers generally believe that the wars during the Warring States period shaped the civilizational pattern of China. The war-driven rationalization has constituted the formation of the Confucian-legalist state of China (Zhao, 2015). The war also shaped the Chinese bureaucracy (Zhao, 2004). It favors promoting China’s unity pattern (Hui, 2005). The roles of wars and violence can be summarized as the coercive forces of political order, definers and creators of social groups, signs of meaning, and elements in mythology (Lewis, 1990). (c) The causes of wars. Due to the defensive purpose, states attempt to ensure their security by

**Table 1 Chaotic and unified period in Chinese history.**

Chaotic period			Unified period		
Years	Key Events	Duration	Years	Key Events	Duration
1392 BC	Turbulence of the Ninth Generation	118	1600 BC	Shang exterminated Xia	208
1114 BC	Wen Ding killed Ji Li	69	1274 BC	Wu Ding ascended the throne	160
771 BC	Western Zhou Disunity	515	1045 BC	Zhou Gong’s Eastern Expedition	274
209 BC	The peasant uprising in the late Qin Dynasty	14	256 BC	Qin exterminated Eastern Zhou	47
17 AD	The peasant uprising in the late Xin Dynasty	13	195 BC	White horse Alliance	212
184 AD	Yellow Turbans Uprising	79	30 AD	The Reign of Emperor Guangwu	154
304 AD	Five groups of barbarians invaded Northern China	69	263 AD	Wei destroyed Shu	41
384 AD	Late Five groups of barbarians invaded Northern China	26	373 AD	The Kingdom of Former Qin swallowed the Shu Kingdom	11
526 AD	The Riot of Six Military Towns	51	410 AD	Jin Dynasty destroyed the Kingdom of Southern Yan	116
612 AD	The peasant uprising in the late Sui Dynasty	9	577 AD	Northern Zhou exterminated Northern Qi	35
875 AD	The peasant uprising in the late Tang Dynasty	50	621 AD	Tang Dynasty exterminated the Zheng Kingdom and the Xia Kingdom	254
933 AD	Five dynasties and ten kingdoms	33	925 AD	Kingdom of Later Tang exterminated the Kingdom of Former Shu	8
1127 AD	Incident of Jingkang	107	966 AD	Northern Song Dynasty exterminated the Kingdom of Later Shu	161
1351 AD	Red Turbans Rebellion	17	1234 AD	The Mongol Kingdom exterminated the Jin Dynasty	117
1627 AD	The peasant uprising in the late Ming Dynasty	19	1368 AD	The Ming Dynasty exterminated the Yuan Dynasty	259
1673 AD	Revolt of Three Feudatories	5	1646 AD	Qing Dynasty exterminated the Southern Ming Dynasty	27
1851 AD	Taiping Rebellion	13	1678 AD	The death of Wu Sangui	173
1900 AD	Boxer Movement	45	1864 AD	The death of Hong Xiuquan	36
Total	1252 years		Total	2293 years	



**Fig. 1** The state's annexation in the Warring States period. **A** shows the 32 states in 475 BC. **B** indicates the Qin state (221 BC) at the end.

adopting armaments and wars (Jervis, 1978). The equilibrium of military capabilities will increase the stability of the system. Thus, some states will launch preventive wars to avoid hegemony and maintain the power balance among states (Levy, 1998). In addition, warfare is more likely to break out when states seek control of resources or fall prey to false optimism about the outcomes and advantages (Evera, 2013). (d) The war strategies of states. War strategies describe the best way to wage wars, including operations, tactics, and the battlefield environment (Osinga, 2005). In the early Spring-Autumn period, the Zhou emperors were the source and exercisers of power, and the states were obliged to follow the orders (Yu, 2019). It makes the wars between states aim at honor and not at the destruction of states. However, no great power ever annexes another great power. During the Warring States period, the war became an annexation of land and expanded the territory and army (Yu, 2019). The primary focus is the statistics, effects, causes, and patterns of war in the Warring States period. However, due to the limitations of traditional research methods, their research inevitably has the characteristics of subjectivity, static, locality, and induction (Turchin, 2006, 2018).

**The application of agent-based modeling.** We analyze this process dynamically and non-linearly through agent-based modeling (ABM). It aims to use computing power to build a model that allows the self-organized behaviors of the agents under a set of rules. The ABM method allows researchers to observe how simple behavioral rules can lead to complex outcomes. It helps researchers more accurately discover the key factors that affect the development of complex systems. ABM can reveal war's influence on forming a unity civilization in a historically complex system. Our work is to restore the historical dynamic of the wars during the Warring States period through dynamic complex systems and non-linear interactions. Based on the search for the mechanisms and rules, we combine all parameters with exploring all possibilities of historical results in the parallel system and then explore the boundaries and conditions of the unity of civilizations.

**Methods and materials**

**Key facts of actual history.** The actual history is the foundation for the modeling and validation. In 475 BC, China's history transitioned from the Spring & Autumn period to the Warring States period. During this new period, various autonomous states launched wars due to the decline of the central power (Zhao, 2015). However, the purpose of war is no longer pure hegemony. During the Spring and Autumn period, states fought for supremacy and power, often accompanied by small but frequent wars (Lu, et al., 2022a). However, during the Warring States period,

states launched wars to unify the whole state, characterized by annexation (Lu et al., 2023). The scale, frequency, and duration of wars have also changed dramatically. Essential information has been considered to validate our model: (a) The dynamic number of states. We have 7 strong states (Qi, Chu, Qin, Yan, Zhao, Wei, and Han) and 25 weak states in this period (32 states). These states allied or attacked each other for their benefit. Various measures were adopted to expand the territory, increase the population, and ensure the regime's stability. Ultimately, the Qin State completed the grand unity, creating China's unity civilization pattern for over 2000 years (Loewe & Shaughnessy, 1999). (b) The duration of the Warring States period. The 475 BC period started the Warring States, which most historians acknowledge (Gray, 2004). Then, the Warring States period indisputably ended in 221 BC. This turbulent period lasted a total of 255 years. In our model, the run-ticks should be close to 255. (c) Territorial dynamics of states. Territorial annexation was the primary purpose of the wars during the Warring States period (Rozakis, 1987). With the continuous occurrence of wars, states' territories were also changing dynamically. The territorial maps (as shown in Fig. 1) are imported into our model to describe the territory changes directly. First, we set 32 agents (states) in Fig. 1A based on actual historical records. These agents interact (wage wars and form alliances) according to specific action rules. Thus, we can simulate the territory dynamically. Finally, in Fig. 1B, only one agent remained (the state of Qin), which conquered all the others and gained their territories. (d) The dynamic number of wars. During the Warring States period, historical documents recorded about 360 wars (Chiang, 2005). Considering the statistical error in the actual number of wars caused by the incompleteness of historical records, the actual number of wars would fluctuate slightly around 360. Therefore, the actual situation must be reflected in the model. (e) The total number of alliances. Common political interests determined alliances in the Warring States period. Such alliances often rest on shaky and unstable foundations. Changes in common interests often lead to betrayals. According to historical records, there were 60 alliances in total (Hu, 2015). Hence, the model should match the results in history. Compared to modeling the first period (Lu, et al., 2022a), we have four indicators, such as (a) to (d). For modeling the second period (the Warring States), in this paper, we have added two new indicators, such as the total number of wars and alliances, to validate our agent-based modeling.

**Agent settings.** According to complex system theory, the whole China can be considered a system with multiple agents (the warring states). To explore boundaries and conditions of civilization patterns, we build the multi-agent system (MAS) to examine all possibilities of civilization history. Based on previous

(first) period (Lu et al., 2022a), we define similar properties of agents and key action mechanisms for the states during this second period in this paper. For this second period, different from basic process modeling that merely explores the mechanism of achieving the unity pattern in China, we focus on two civilization patterns for both China and the West, and the core is to accurately solve conditional boundaries between them, based on this second period.

(a) The mechanism of wars. The dominance of military competition over other factors promoted the main pattern of civilizational development. The war mechanic is the primary structural determinant in the Warring States period. The war is caused by many reasons, such as competition for resources, national disputes, the ruler's character, etc. Each cause is indeterminate and has non-linear effects. In this model, we simulate the mechanism of wars and costs. First, states have the power ( $Pwr_i$ ), which is a comprehensive indicator. It includes the state's economy, politics, military, population, and culture (Scheidel, 2014). The power dramatically determines the outcome of the wars. Second, we define the war propensity ( $F_i$ ) to generalize the reason for this complexity. War propensity represents the probability of starting a war, shaped by many aspects of the state apparatus (political, economic, and military construction). Thus, we set the war propensity to  $F_i \in (0, 1)$ . Owing to the huge effect of power on bellicosity, we set the initial value of  $F_i$  to be  $Pwr_i/100$ . However, the bellicosity is not constant, it increases over time. The war propensity of states is driven by other factors. We use a dynamic variable ( $b_i$ ) to describe this process. If the state wins the war, the  $F_i$  increases by the  $b_i$ . If fails, it decreased by the  $b_i$ .

$$Rule_1 : War_{i \rightarrow j}^t = \begin{cases} 1 (War), & \text{if } F_i \geq \gamma_w \text{ and } Pwr_i \geq Pwr_j \\ 0 (Peace), & \text{if } F_i \geq \gamma_w \text{ and } Pwr_i < Pwr_j \\ 0 (Peace), & \text{if } Pwr_i < Pwr_j \end{cases} \quad (1)$$

Under the war propensity  $F_i$ , state  $i$  may launch a war against state  $j$ . At the same time, we also set the threshold of war ( $\gamma_w$ ). As described in Eq. (1), when the war propensity is greater than the war threshold and the power ( $Pwr_i$ ) of state  $i$  is more than the power ( $Pwr_j$ ) of state  $j$ , the war will break out. In reality, the result of a war depends on multiple factors, such as political institutions (Reiter & Stam, 2003), war aims (Sullivan, 2007), public opinion (Eichenberg, 2005), military strategies (Tzu, 2008), and military weapons (Potholm, 2010). Although the changing climate (Zhang et al., 2007), the geospatial information (Dincecco & Wang, 2017), and so on may also influence the war outcome, these factors are hard to qualify in the Warring States period. We defined these additional factors as a random impact ( $\xi$ ) on the war outcome for the state that wages war. Hence, the comprehensive power ( $U_{i+a_1}^t$ ) and random impact ( $\xi$ ) is adopted to simulate war outcomes of who is waging war. The comprehensive power ( $U_{i+a_1}^t$ ) refers to the summation of the power ( $Pwr_i^t$ ) of state  $i$  and the power ( $Pwr_{a_1}^t$ ) of allies. Meanwhile, the opposite side also has comprehensive power ( $U_{i_2+a_2}^t$ ). The result of war also determines the war's cost. We compare the powers to decide Winner ( $U_{i_1+a_1}^t * \xi > U_{i_2+a_2}^t$ ), Balance ( $U_{i_1+a_1}^t * \xi = U_{i_2+a_2}^t$ ), or Defeat ( $U_{i_1+a_1}^t * \xi < U_{i_2+a_2}^t$ ). The war costs of Winner ( $w$ ), Balance ( $b$ ), and Defeat ( $l$ ) is illustrated in Eq. (2). For previous work uses exact numbers, such as 6-10-3 in Ref (Lu, et al., 2022a) and 6 & 10 in Ref (Lu, et al., 2023), we use

parameters ( $w$  and  $l$ ) to check model's flexibility and generality.

$$Rule_2 : Cost_i^t = \begin{cases} w (= Vicotry), & \text{if } U_{i_1+a_1}^t * \xi > U_{i_2+a_2}^t \\ b = \frac{w+l}{2} (Balance), & \text{if } U_{i_1+a_1}^t * \xi = U_{i_2+a_2}^t \\ l (= Failure), & \text{if } U_{i_1+a_1}^t * \xi < U_{i_2+a_2}^t \end{cases} \quad (2)$$

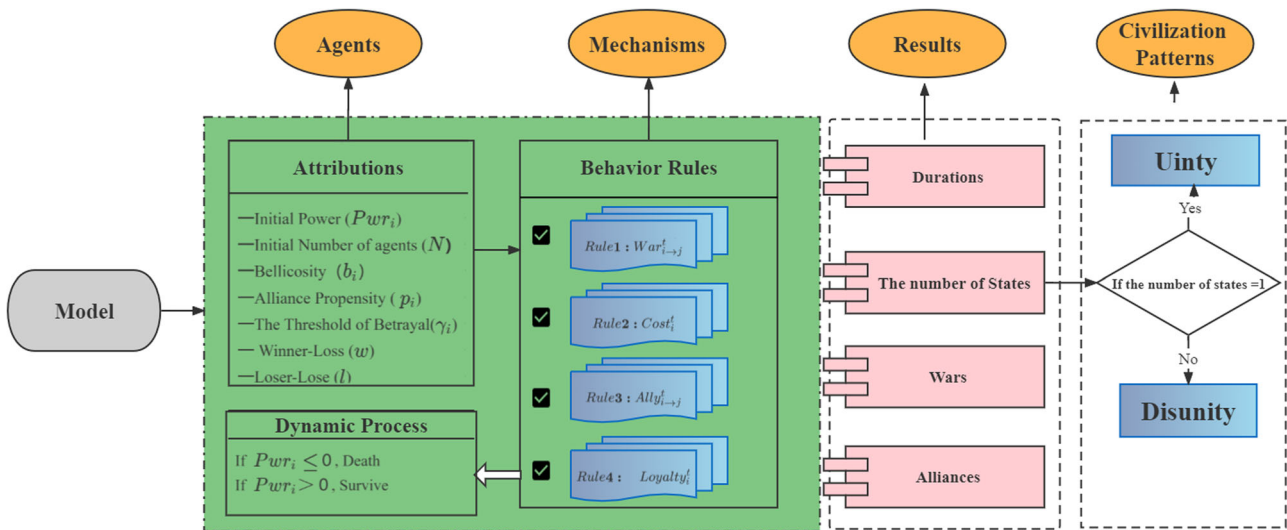
(b) The mechanism of alliances. The purpose of allying is usually to achieve (protect) their own interests for the states. However, the dynamics of state-owned interests and other nonlinear factors make it difficult to quantify and generalize the complexity of alliances. Viewing alliances as random events better explains complex and diverse motivations, including equilibrium, commitment, bandwagon, and hedging (Griffin, 1992). Therefore, we use random alliances modeling, in Eq. (4), to simulate real history. All states have the alliance propensity, which is determined by related factors (the power, ruler, location, and so on). We set the alliance propensity as  $p_i \in [0, 0.5]$  for each agent (state). With the alliance propensity ( $p_i$ ), state  $i$  sends the alliance offer to potential allies ( $j$ ). State ( $j$ ) may or may not accept this offer. Under rational calculations, state  $j$  will select one from the offers (states). The alliance network, formed by ( $i$ ) and ( $j$ ), can be denoted as the  $Ally_{ij}^t = \{a_{i \rightarrow j}^t\}$ . At each tick ( $t$ ), the alliance is decided by dynamic power ( $Pwr_i^t$ ). The outcome is either 1 ( $j$  rejects  $i$ ) or 0 ( $j$  accepts  $i$ ). Any two states have the possibility to be allied, whether the power is weak or strong. We use the maximal power to model the first period, but we use 90% of the maximum to reflect bounded rational actions of them, in Eq. (3).

$$Ally_{ij}^t = \{A_{i \rightarrow j}^t\}, \text{ where} \\ Rule_3 : Ally_{i \rightarrow j}^t = \begin{cases} 1 (Accept), & \text{if } Pwr_i^t \geq 0.9 * Pwr_j^t \\ 0 (Reject), & \text{if } Pwr_i^t < 0.9 * Pwr_j^t \end{cases} \quad (3)$$

(c) The mechanism of betrayal. The dynamics of the power ( $Pwr_i$ ) force each state to adjust strategies and actions, to maximize their own interests. In actual history, the number of alliances is uncertain (hard to calculate) (Gray, 2004). Rational rulers will always make diplomatic decisions based on their national (country) interests, including quitting the alliances (Burnell, 1995; Shackelford & Buss, 1996). For example, in 307 BC, the Chu and Yue states jointly attacked the Qi state, but the Chu did not send troops to support the Yue. Then, the Yue was furious and allied with Qi to attack the Chu. However, the Chu allied with Qi, and wiped out the Yue. We simulate this mechanism in Eq. (4). The threshold ( $\gamma_b$ ) is set as the betrayal threshold. In our model, the initial number of opportunists is 32, which means that all states will betray the alliance under certain situations. A state's interests are the driving force for alliances, so power has become the primary criterion for alliances. Betrayal happens when members of an alliance are too weak. Once the power ( $Pwr_j$ ) of state  $j$  is less than a certain percentage ( $\gamma_b$ ) of the state ( $i$ ), the state ( $i$ ) will betray the alliance and seek another stronger one. Thus, alliances are also subject to changes, and speculation always accompanies the life cycle of states. It is also different from Ref (Lu et al., 2022a).

$$Rule_4 : Loyalty_i^t = \begin{cases} 1 (Alliance), & \text{if } \gamma_b * Pwr_i \leq Pwr_j \\ 0 (Betray), & \text{if } \gamma_b * Pwr_i > Pwr_j \end{cases} \quad (4)$$

(d) Life cycle dynamics of the power (state). We define the initial power ( $Pwr_i^0$ ) for 32 states as normally distributed, from 0 to 100. In Eq. (5), the power of states changes every year (tick). To reflect natural development, the power ( $Pwr_i$ ) increase by 10 units every year (tick). However, the productivity and resources were limited during this Warring States period, and we set the limit as



**Fig. 2 The logic of the modeling.** Figure 2 shows the main logic of our model. The model has seven main attributions for the agents, and the agents' actions follow the behavioral rules. The main indicators to compare the differences between unity and disunity are the number of states, duration, wars, and alliances.

100. For this complex system, the power ( $Pwr_i^t$ ) and the number of states ( $N$ ) changes dynamically. War will reduce the power more or less, depending on the war results. The state will die if the power reaches zero, and the winner gets its territory and resources. We drop the classification of weak and strong states (Lu et al., 2022a), which is too subjective. Alternatively, we use the continuous life cycle value to indicate the instant status of the states.

$$Outcomes : Pwr_i^t = Pwr_i^{t-1} + 10 - Cost_i^t = \begin{cases} Living, & \text{if } Pwr_i^t > 0 \\ Death, & \text{if } Pwr_i^t = 0 \end{cases} \quad (5)$$

$$Par^*(\cdot) = ArgMin(\Delta) = ArgMin[f_{sim}(\cdot) - f_{real}(\cdot)] \\ = ArgMin\left(\sqrt{\frac{\sum(y_1-1)^2}{(500-1)}} + \sqrt{\frac{\sum(y_2-255)^2}{(500-1)}}\right) \\ + \sqrt{\frac{\sum(y_3-320)^2}{(500-1)}} + \sqrt{\frac{\sum(y_4-60)^2}{(500-1)}} \quad (6)$$

**The best-fitted solution.** We adopt four critical indicators to validate the model and use key indicators (final number of states) to recognize possible patterns of the system (civilization). First, comparing actual and simulated data is an effective way to test the validity and robustness of the model (Rubio-Campillo, 2016). Besides critical indicators such as the final number of states ( $y_1$ ) and total duration ( $y_2$ ), we add new indicators such as total number of wars ( $y_3$ ) and total number of alliances ( $y_4$ ). According to real history, the observation value ( $Y_i$ ) is obtained from the target function  $f_{real}(\cdot)$ . Under each (unique) combination of parameter values, we repeat the simulation 500 times, to obtain robust outcomes ( $\hat{Y}_i$ ), and to check the large number distribution. The robust outcomes ( $\hat{Y}_i$ ) forms our simulated function  $f_{sim}(\cdot)$ . The best-fitted combination of parameter values,  $Par^*(\cdot)$ , will be obtained from the minimal difference ( $\Delta$ ) between two functions in Eq. (6). Second, the purpose of the ABM simulations is to explore the boundaries of unity and disunity of civilizations by observing the emergence of microscopic subjects. All parameter ranges are listed in Table 1. The Bellicosity ( $F_i$ ) takes values from 0.1 to 1.0; the alliance propensity ( $p_i$ ) is from 0.1 to 1.0; the  $\gamma_b$  of betrayal grows from 0 to 1; the winner's cost is from 1 to 12, and

the loser's cost takes values from 13 to 24. The final number of states ( $y_1$ ) will be monitored and calculated, which can be used to identify civilization patterns under each combination.

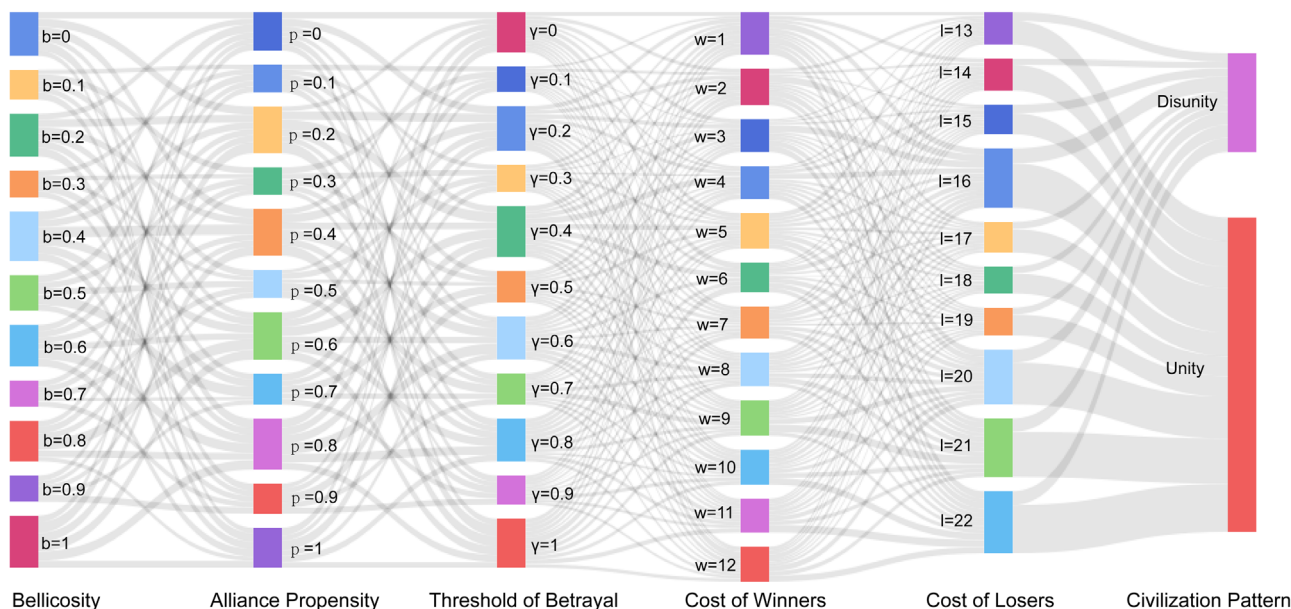
**Emergence of civilization patterns**

**Whole map of unity and disunity patterns.** In this multi-agent system, if the number of states (agents) can decline from 32 to 1 within 600 years (ticks), we consider this as the unity pattern in Fig. 2. Otherwise, we have the disunity pattern. Then, we solve boundaries and conditions for both patterns, which can be seen in Fig. 3A. (a) Unity pattern. The red block indicates the unity pattern. It seems that unity can be achieved in most cases. Under the unity pattern, if a new state wants to consolidate itself, it must integrate into a unity civilization system (Pines, 2000), which means that agents will have to annex others until only one remains. We further find out the parameter combinations (boundaries and conditions) of the unity pattern. For example, whatever the value of the winner-cost ( $w$ ) and the loser-cost ( $l$ ) are, the model will achieve a unity civilization when the threshold of betrayal ( $\gamma_i$ ) is larger than 0.9 ( $b_i = 0.1$  &  $p_i = 0.1$ ). Whatever the winner-cost ( $w$ ) and the loser-cost ( $l$ ) are, the model can also achieve the unity when  $b_i = 0.5$  ( $p_i \geq 0$ ,  $\gamma_i \geq 0$ ). (b) Disunity pattern. The purple block refers to the disunity pattern. In some cases, the system will achieve the disunity civilization pattern. For example, whatever the betrayal threshold ( $\gamma_i$ ), the alliance propensity ( $p_i$ ), the winner cost ( $w$ ), and the loser cost ( $l$ ) are, the model will achieve disunity when bellicosity  $b_i = 0$ . Likewise, whatever the loser cost ( $l$ ) is, when  $b_i = 0.1$ ,  $p_i = 0.1$  &  $w \geq 9$  ( $0.8 \geq \gamma_i \geq 0$ ), the model will achieve the disunity civilization.

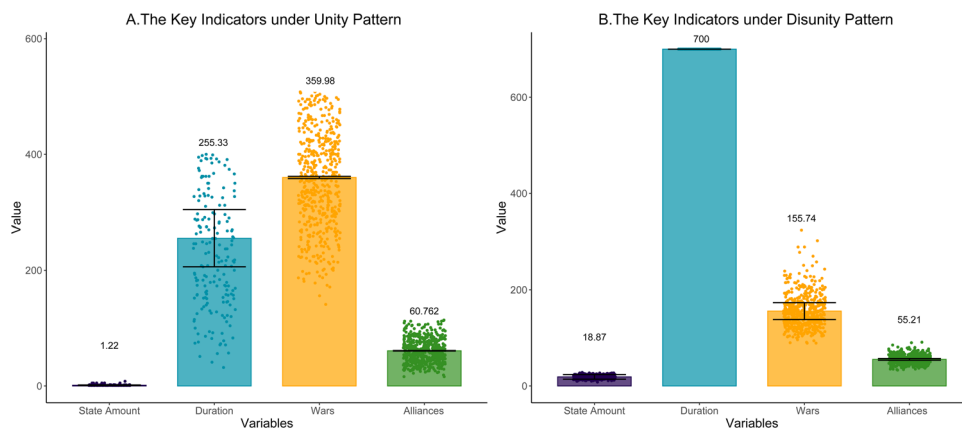
**Two patterns under typical combinations.** Unity and disunity are two typical civilizational patterns. The Chinese unity civilization has lasted for thousands of years, and the mechanism and logic behind it show a great difference in the disunity civilization. To examine the differences between unity and disunity patterns, we selected two typical parameter combinations based on the boundaries of these two patterns, which aim to explore the difference in bellicosity, alliance propensity, alliance reliability, winner cost, and loser cost.

(a) State number. The number of states is a critical indicator in determining the patterns. In the unity civilization, a coalition of city-states would become increasingly integrated. One state will

### A. Boundaries of Civilization Patterns



**Fig. 3 The boundaries of unity and disunity.** A shows the conditions and boundaries of the different patterns of civilization. The parameters from left to right are bellicosity, alliance propensity, alliance reliability, winner cost, and loser cost. The civilization pattern shows the outcomes of unity and disunity.



**Fig. 4 The comparison between unity and disunity.** compares the mean value of key indicators under the unity and disunity patterns, including the state’s number, duration, war’s number & alliance’s number, respectively. A represents the unity pattern, and B represents the disunity pattern.

control a disparate group of regimes, and a practical, non-feudal, non-hereditary state will be formed (Mayhew, 2012). In Fig. 4A, the number of agents shows a significant declining trend. At the initial time, there were 32 agents in the model. As the model runs to completion, we find that the average number of agents has changed to 1.22(≈1). However, under a disunity civilization, more than one regime or government can run a fragmented and unstable country (Craze et al., 2016), which means that many states can be established simultaneously. At the initial time, there are 32 agents in the model, but at the end of the simulations, 18.97 (≈19) states exit.

(b) Duration. From 475 to 221 BC, the Warring States period lasted 255 years. As Fig. 4A shows, the agents change from 32 to 1 in 255.33 ticks under the unity civilization, which is close to the real history of 255 years. In our model, if agents cannot change to 1 within 600 ticks, we set it to represent a disunity civilization. Thus, we set the model to end after 700 ticks to observe the evolution of the agents. In Fig. 4B, agents changed from 32 to 18.77 in 700 ticks, which shows a disunity pattern in Table 2.

(c) The number of alliances and wars. There were about 320 wars and 60 alliances in this period. Under the unity civilization, there are 359.98 (≈360) wars (SD = 87.95), close to actual history. There are 60.792 alliances (SD = 20.55), which is very close to real wars in this period. Under the disunity civilization, there are 155.74 wars (SD = 35.49) and 55.21 alliances (SD = 9.68). The number of wars under a unity civilization is much higher than those under disunity, and the former is more than double the latter. However, the number of alliances is similar, whether it is a unity or disunity civilization. Furthermore, the number of alliances under a unity civilization is only 5, higher than those under a disunity civilization.

#### Effects of wars and alliances on patterns

**Effects of bellicosity.** (a) Effects of bellicosity on unity and disunity. When the alliance propensity ( $p_i$ ) is 0.4, the betrayal threshold ( $\gamma_b$ ) is 0.8, the winner cost ( $w$ ) is 7, the loser cost ( $l$ ) is 14, we iterate the parameter values of bellicosity from 0 to 1. Figure. 5A shows that

when bellicosity ( $b_i$ ) is below 0.1, the number of agents (100%) does not decrease to one within 600 ticks (years), which takes on the disunity civilization. When  $b_i > 0.1$ , most simulations decrease to one state within 600 ticks (years). For example, when  $b_i = 0.2$ , the number of agents changes from 32 to 1 for 91.67% of all simulations. When  $b_i = 0.3$ , the number of agents changes from 32 to 1, for 95.67% of all simulations. When  $b_i$  grows from 0.4 to 1, we have 96%, 92.67%, 99.99%, 97.33%, and 98% of them, taking on the unity pattern. Furthermore, we use the Decision Tree with CART (Classification and Regression Trees) (Timofeev, 2004) to find precise classification of unity and disunity with the influence of the bellicosity ( $b_i$ ). Figure 5B shows the classification outcome. The orange boxes represent the classification of the unity pattern. The green box represents disunity. When  $b_i < 0.15$ , the states will achieve a unity pattern, accounting for 82% of simulations. When  $b_i > 0.15$ , the states will achieve a disunity pattern, accounting for 18% of all. In

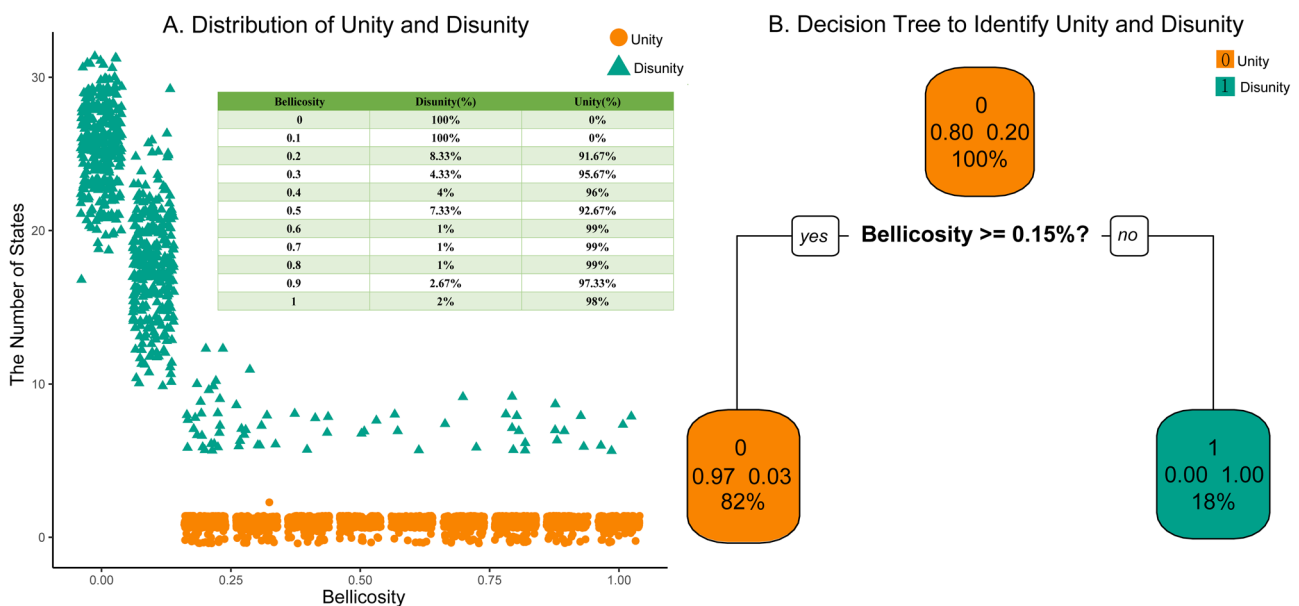
classification results with the unity pattern, 97% of states can achieve the unity pattern, and only 3% achieve the disunity. Similarly, 100% of states achieve the disunity pattern in the classification with the disunity pattern. The Decision Tree with CART shows well fitness.

(b) Trend of duration under the unity. When the alliance propensity ( $p_i$ ) is 0.2, the betrayal threshold ( $\gamma_b$ ) is 0.8, the winner cost ( $w$ ) is 7, and the loser cost ( $l$ ) is 14, the system will achieve the unity pattern only the bellicosity ( $b_i$ ) is higher than 0.2. We further explore the effect of bellicosity on unity time (duration) under a unity civilization. When  $b_i$  increases, the duration will decrease. As Fig. 6A shows, when  $b_i$  increases from 0.2 to 1, the duration has a significant variation tendency. The duration reduced from 328.59 ticks ( $b_i = 0.2$ ) to 178.04 ticks ( $b_i = 1$ ), and the consumption time is nearly two times shorter than the case of  $b_i = 0.2$ . Furthermore, we also find that when  $b_i < 0.5$ , the duration significantly decreases from 325.59 ticks to 169.2 ticks. When  $b_i \geq 0.5$ , the changing trend stabilizes, and the duration is about 160 to 170 ticks.

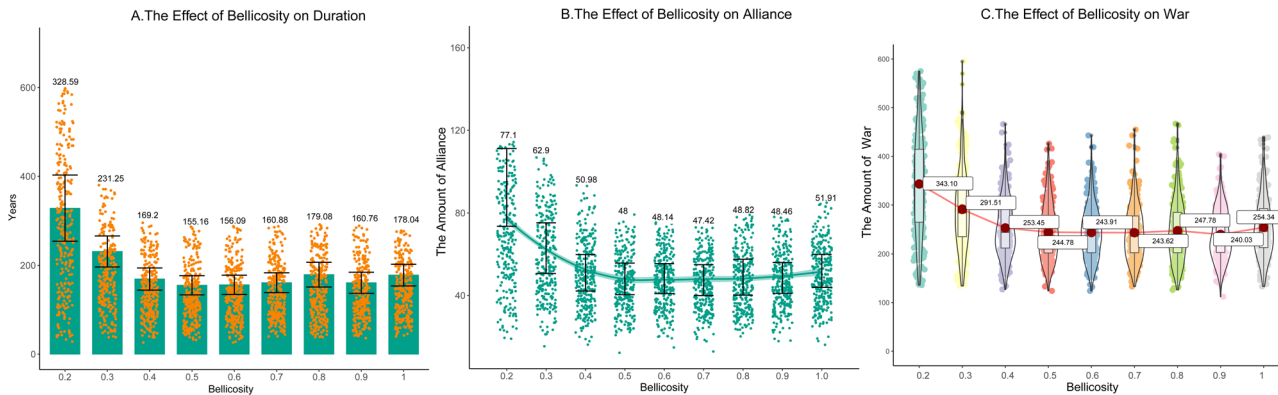
(c) Trends of alliance and war under the unity. The Warring States are rife with interstate conflict between the states, and the states are involved in a series of conquests and annexations, consolidations of power and territory, and shifting alliances (Harper, 1995). So, we also explore the changes of alliances and wars under different bellicosity ( $b_i$ ) values. Figure. 6B, C show the effect of bellicosity ( $b_i$ ) on variations of alliance and war frequency. We find an apparent decreasing trend. When  $b_i$  changes from 0.2 to 1, the number of alliances also changes from 77.1 to 51.91. Similarly, the number of wars changed from 343.10 to 254.34, showing an apparent decreasing trend. However, although the number of alliances and wars decreases during when  $b_i$  increases. If the  $b_i$  is larger than 0.4, the number of alliances and wars will show a slowing decline. There are approximately 50 alliances and 245 to 250 wars, when  $b_i$  is higher than 0.5. Meanwhile, no matter how alliances and wars change, the number of wars is always higher than the number of alliances. More importantly, we find that when  $b_i$  is below 0.2, the unity time is higher than the actual history of 255 years. When  $b_i$  is higher than 0.2, the unity time is less than 255 years, indicating that a stronger bellicosity will accelerate the unification process.

**Table 2 Two typical parameters under different civilization patterns.**

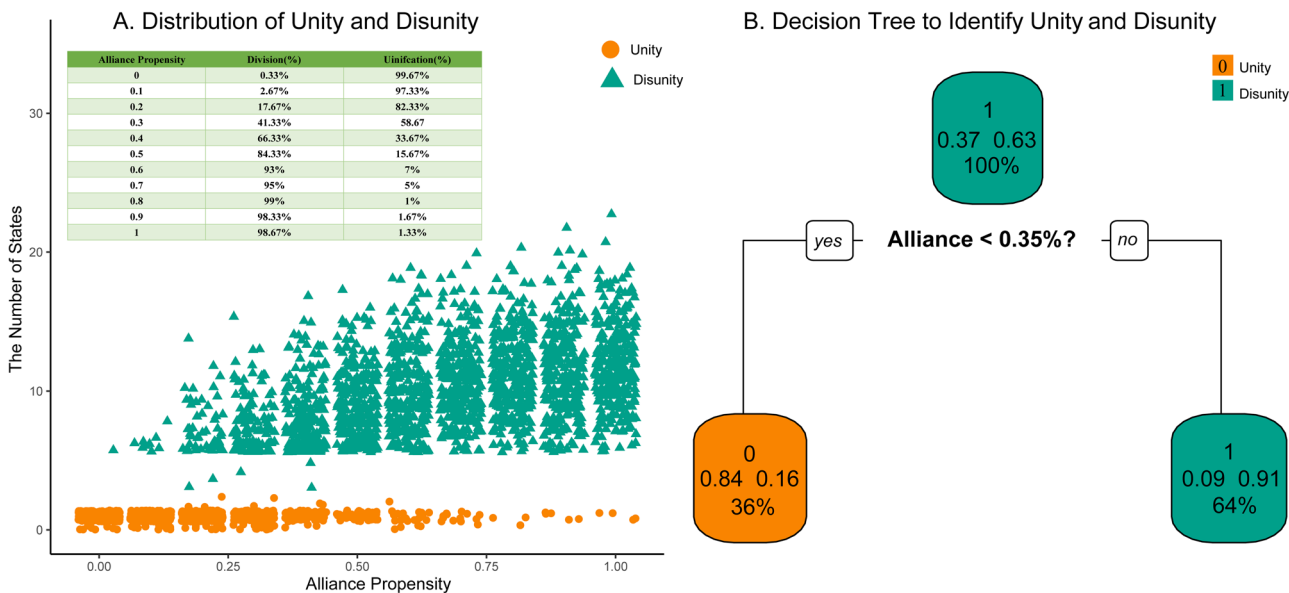
Interpretation	Symbol	Unity	Disunity
The initial number of states	$N$	32	32
Initial state's power	$Pwr_i$	Dynamic ( $Pwr_i \leq 100$ )	Dynamic ( $Pwr_i \leq 100$ )
Initial bellicosity	$F_i$	$Pwr_i/100$	$Pwr_i/100$
A dynamic variable of bellicosity	$b_i$	0.3	0.15
Cost	Winner	$w$	6
	Balance	$b$	9.5
	Loser	$l$	13
Alliance propensity	$P_i$	0.33	0.75
The threshold of betrayal	$\gamma_b$	0.8	0.45
The threshold of war	$\gamma_w$	0.548	0.548



**Fig. 5 Effects of bellicosity on unity and disunity.** A shows the number of states under different levels of bellicosity. The green triangles represent the disunity pattern, and the turmeric dots represent the unity pattern. The table in Panel A shows the proportion of unity and disunity under different levels of bellicosity. B is a Decision Tree with CART. The green box represents the disunity pattern, and the orange boxes represent the unity pattern.



**Fig. 6 Effects of bellicosity on duration, alliances, and wars.** Under the unity civilization pattern, **A** shows the duration under different bellicosity from 0.2 to 1. **B** shows the number of alliances under different bellicosities from 0.2 to 1. **C** shows the number of wars under different bellicosities from 0.2 to 1.



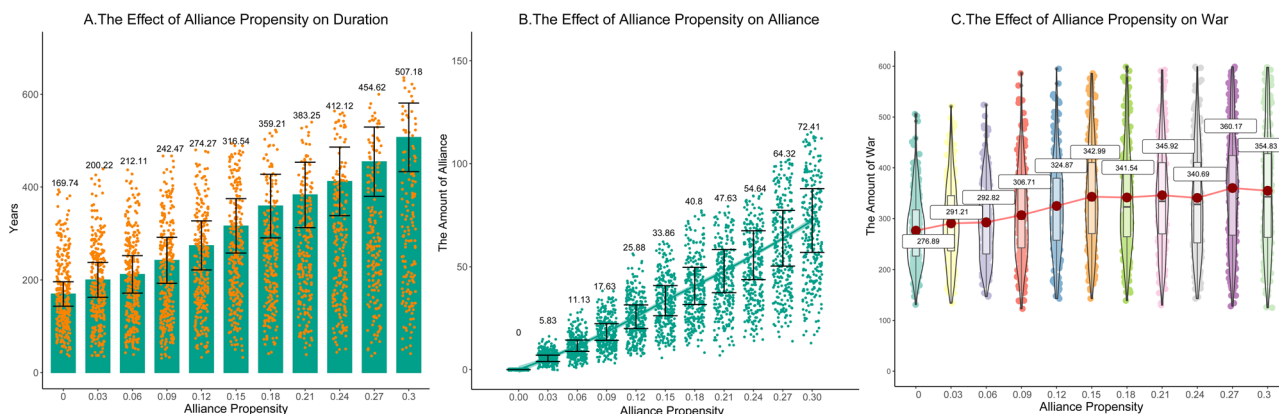
**Fig. 7 The effects of alliance propensity to unity and disunity.** **A** shows the number of states under different alliance propensity. The green triangles represent the disunity pattern, and the turmeric dots represent the unity pattern. The table in **A** shows the proportion of unity and disunity under different alliance propensities. **B** is a Decision Tree with CART to classify unity and disunity under different alliance propensities from 0 to 1.

**Effects of alliance propensity.** (a) Effects of alliance propensity on unity and disunity. We further explore the effect of alliance propensity on civilization patterns. We set  $b_i = 0.2$ ,  $\gamma_b = 0.8$ ,  $w = 7$ , and  $l = 14$ , keeping four attributions unchanged. Then, we also iterate the alliance propensity ( $p_i$ ) from 0 to 1. As Fig. 6A shows, there are two significant patterns under different alliance propensity values. When the alliance propensity ( $p_i$ ) is lower than 0.4, most simulations will achieve the unity. Under  $p_i = 0, 0.1, 0.2, 0.3$ , 99.67%, 97.33%, 82.33%, 85.67% of all simulations decrease the agents from 32 to 1. Consequently, we set the model to achieve unity under  $p_i < 0.4$ . Under  $p_i \geq 0.4$ , there are only 33.67%, 15.67%, 7%, 5%, 1%, 1.67%, and 1.33% of all that have achieved the unity. But 66.33%, 84.33%, 93%, 95%, 99%, 98.33%, and 98.67% achieved the disunity, higher than unity. So, we assume that when  $p_i \geq 0.4$ , the system will achieve disunity. We also use Decision Tree with CART to classify unity and disunity during alliance propensity changes from 0 to 1. The system will achieve a unity pattern when the alliance propensity is more than 0.35. Instead, it will achieve a disunity pattern when the alliance propensity is less than 0.35.

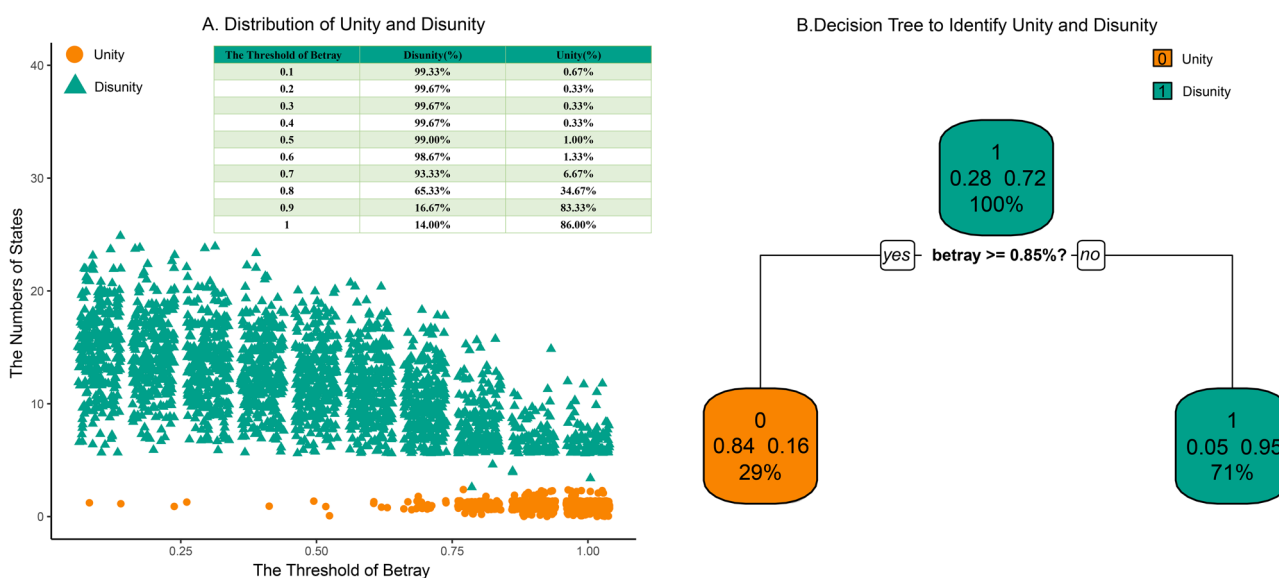
(b) Trend of durations under the unity. Under the unity pattern, we explore the effect of alliance propensity on the

unification process duration (Duration). Overall, when  $p_i$  increases from 0 to 0.3, the duration also increases. Figure 7A shows that the duration has been on an upward trend when  $p_i$  increases to 0.3. When the alliance propensity reaches zero, the number of agents decrease to one only within 169.75 ticks (years). While, under  $p_i = 0.3$ , the system will achieve the unity within 507.18 ticks (years). When the  $p_i$  is lower than 0.09, the unity duration is 200.22, 212.11, and 242.47 years (ticks), respectively, less than the actual history of 255 years. Under  $p_i > 0.09$ , the unity time is higher than 255 ticks.

(c) The trends of alliances and wars under the unity. The effect of alliance propensity on alliances and wars is noticeable. In Fig. 8B, when  $p_i = 0$ , no state would choose to ally, and the number of alliances is zero. However, under the unity, when  $p_i$  changes from 0 to 0.3, and the number of alliances will grow from 0 to 72.41. The number of alliances increases as the alliance propensity ( $p_i$ ) grows. Regardless of whether states form alliances, the number of wars is always greater than zero (the war exists all the time). Under  $p_i = 0$ , there are 276.89 wars. When it from 0 to 0.3, the number of wars will increase from 276.89 to 354.83. Overall, the number of wars is increasing.



**Fig. 8** The effects of alliance propensity on duration, alliances, and wars. Under the unity civilization pattern, **A** shows the duration under different alliance propensities from 0 to 0.3. **B** shows the alliance's number under different alliance propensities. **C** shows the war's number under different alliance propensities.

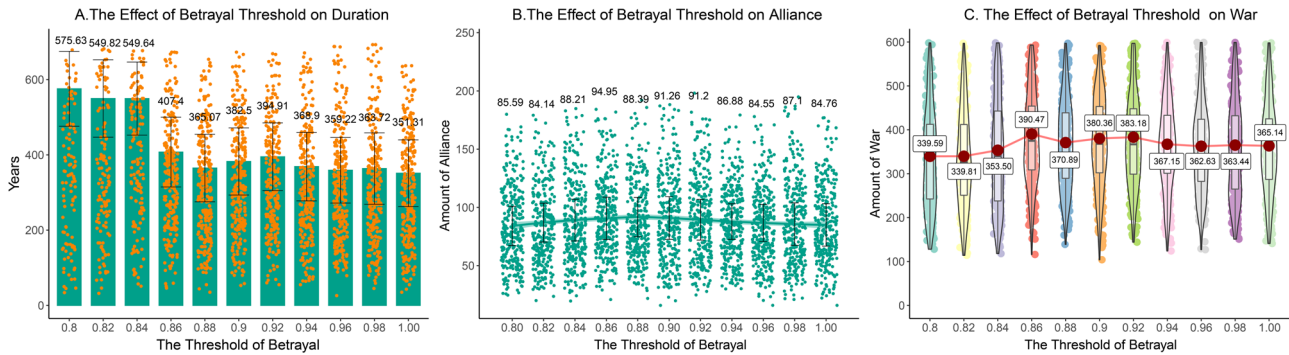


**Fig. 9** Effects of different betrayal thresholds on the unity and disunity. **A** illustrates the number of states under different thresholds of betrayal ( $\gamma_b$ ) values. The green triangles refer to disunity, and the orange dots represent unity. In **A**, the table indicates the proportion of two patterns under different  $\gamma_b$ . **B** is the Decision Tree classification, indicating the validity of our artificial classification. Each note box shows predicted classification (0 or 1), predicted probability of correct classification and misclassification, and the percentage of observations in the node.

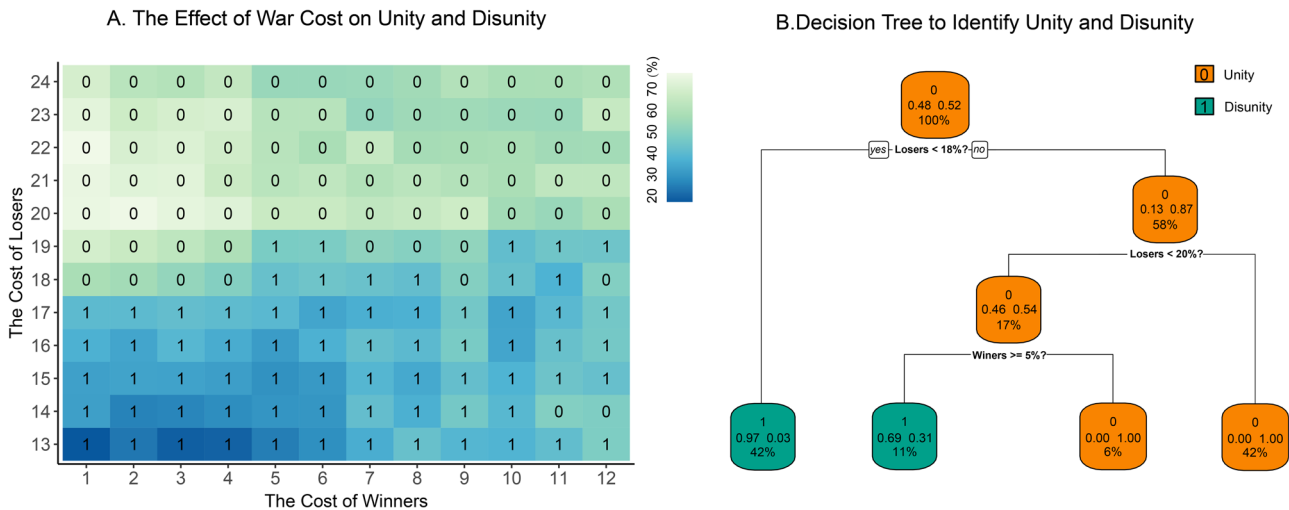
**Effects of the betrayal threshold.** (a) Effects of different betrayal thresholds. First, we further investigate the effect of betrayal ( $\gamma_b$ ) on patterns under typical parameters. The typical parameters refer to  $b_i = 0.2$ ,  $p_i = 0.4$ ,  $w = 7$ , and  $l = 14$ . Figure 9A indicates two civilization patterns under different betrayal threshold ( $\gamma_b$ ). With the increase of betrayal threshold  $\gamma_b$ , the proportion of the unity increases as well. As the table in Figure A shows, under  $\gamma_b \leq 0.8$ , most simulations show a disunity pattern. The simulations demonstrate that a lower  $\gamma_b$  will result in more dividing forces, impeding the process of unity. However, the civilizational pattern creates a large possibility of unity under  $\gamma_b \geq 0.8$ . For example, when the  $\gamma_b$  are 0.9 and 1, the proportion of Unity pattern accounts for 83.33% and 86.01%, respectively. It indicates that a higher  $\gamma_b$  will bring more powerful force, more successful annexation and the unity civilization. Therefore, the boundary between two civilizational patterns can be considered as  $\gamma_b = 0.8$ . Second, we also examine the effectiveness of classifying two patterns using the Decision Tree algorithm. The final number of states ( $\gamma_1$ ) can be regarded as results with dozens of dimensions for the number of states ( $\gamma_1$ ), which may range from 1 to 32. We

adopt to reduce the dimensions of the number of states ( $\gamma_1$ ). If the classifications of dimensional reduction can match the real patterns, then the two civilization classifications are algorithmically plausible. Figure 9B illustrates the classifications based on the Decision Tree. The boundary (threshold) of unity and disunity can be considered as 0.85 of the alliance's betrayal. For the unity results, the correct classification is 84%. In case of disunity, the correct classification is 95%. Besides a few misclassified samples, most are classified correctly, proving the validity of our classification.

(b) Effect of betrayal threshold ( $\gamma_b$ ) under the unity. Under this pattern ( $0.8 \leq \gamma_b \leq 1$ ), different betrayal threshold values may influence the duration, alliances, and wars. Figure 10A visualizes the effect of betrayal threshold ( $\gamma_b$ ) on the duration. When is increases from 0.8 to 1, the duration decreases as well. For example, when  $\gamma_b$  is 0.8, the duration will last for 575.63 years (average). When the  $\gamma_b$  reaches 1, the duration only lasts for 351.31 years (average). However, the  $\gamma_b$  has little effect on the number of alliances and wars. For instance, when it is 0.8, the numbers of alliances and wars presents are 85.59 and 339.59



**Fig. 10** Effects of betrayal threshold on the duration, alliances, and wars. **A** shows the duration dynamics when the betrayal threshold is under unity pattern (0.8 to 1). **B** shows the alliance's number under different betrayal thresholds, and **C** shows the number of wars.

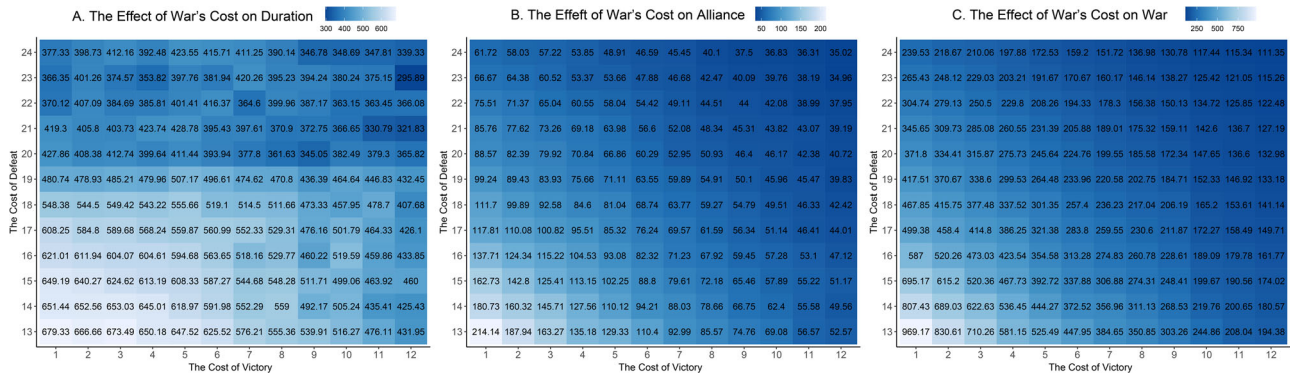


**Fig. 11** Effects of war cost on unity and disunity. **A** shows the unity and disunity in different war costs. The numeric mark 0 represents unity, while the numeric mark 1 is the disunity. The color of the heatmap indicates the proportion of unity in 500 simulations. **B** refers to the result of the Decision Tree, examining the validity of the classification. Each box shows the predicted classification, the predicted probability of correct classification and misclassification, and the percentage of observations.

times, respectively. When it is 1, the number of them is 84.76 and 365.14, respectively. The variation of  $\gamma_b$  will significantly change the comprehensive power ( $U_{i+a_1}^t$ ) of an alliance. Then, the decisions to wage wars or construct an alliance are shaped by the comprehensive power ( $U_{i+a_1}^t$ ), which also changes correspondingly. This is why we have stable scales of alliances and wars.

**Effects of the war cost under two patterns.** (a) Effects of different war costs. First, under typical parameters ( $b_i = 0.2, p_i = 0.4, \gamma_b = 0.8$ ), we explore the impact of war costs on two patterns. For example, when the loser cost is less than 18, most patterns present disunity. When the loser cost equals 18, the ratios between two patterns are roughly equal. When the loser cost ( $l$ ) exceeds 18, most patterns are unity. So, larger loser cost will enhance the chance of unity achieved. For the winner cost, the effect on final patterns is not obvious. Second, we examine artificial classification by adopting the Decision Tree algorithm. The simulated results may present many outcomes and patterns, and the algorithm for dimensionality reduction can better prove the validity of the two civilizations' differentiation. Figure 11B demonstrates the algorithm classification marked by color and the numeric label. The correct classification rates are 97%, 69%, 100%, and 100%. For most cases, war costs are classified correctly, indicating the validity of two civilizational patterns.

(b) Effects of war costs on the duration, alliances, and wars. First, we explore the war cost effects on the duration. Figure 12A indicates the general pattern that as the war cost grows, the duration decreases. The effects of winner and loser costs are slightly different locally. For instance, when winner costs increase from 1 to 12, the duration declines from 679.33 to 431.95. For a growing war cost of 11, the duration is reduced by 247.38. By contrast, when loser cost grows from 13 to 24, the duration declines from 679.33 to 377.33 (a reduction of 302.00 years). Meanwhile, the war costs in different value ranges are also different. The loser cost (higher value) will reduce the duration more effectively (promote the unity faster). Second, we explore the war cost effects on the scale of alliances. The general pattern is clear that higher war costs will decrease the scale of alliances, which does not follow the common sense. When  $w$  grows from 1 to 12, the number of alliances declines from 214.14 to 52.57. Meanwhile, when  $l$  grows from 13 to 24, the number of alliances declines from 214.14 to 61.72. Third, we explore the effects of war costs on the scale of wars. The general pattern is that higher war cost will produce the number of wars, which follows the common sense. For instance, when the winner cost grows from 1 to 12, the number of wars decreases from 969.17 to 194.38. When the loser cost increases from 13 to 24, the number of alliances decreases from 969.17 to 239.53.



**Fig. 12** Effects of war cost on the duration, alliances, and wars. **A** shows the trend of unification duration under different war costs. **B** indicates the dynamics of the scale of alliances under war costs, while **C** shows the dynamics of the number of wars.

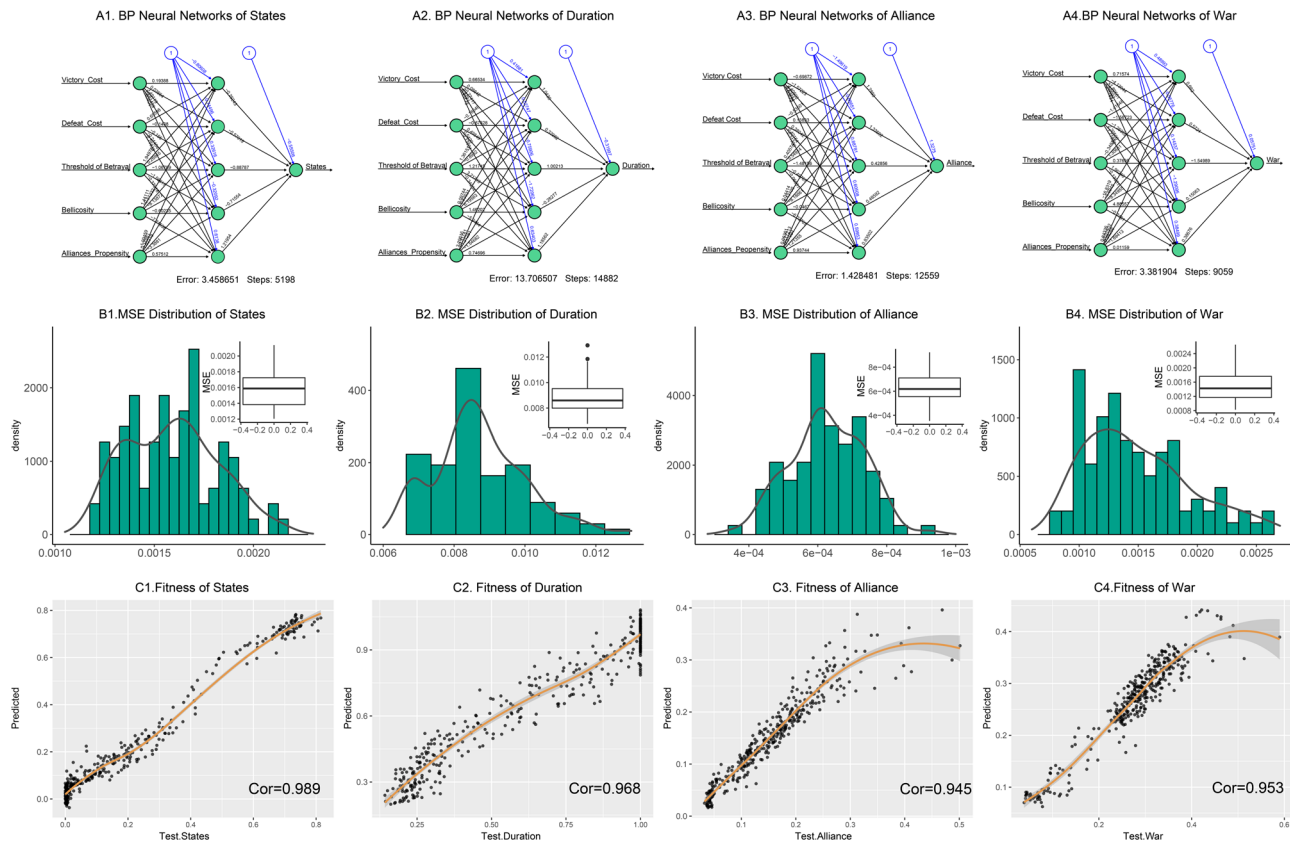
**History knowledge via BP neural network**

We used Agent-Based Modeling to create an ideal complex system, which is the general civilization system, to reveal underlying mechanisms of human civilization dynamics. Compared to basic process modeling for the first period (Lu et al., 2022b) and for this second period (Lu et al., 2023), we have solved social knowledge from the history process, which is new for history learners (divided states) in the following chaotic periods. Social knowledge is a necessary condition for history learning, and it is also the mechanism for later dynasties and empires to learn from previous dynasties for the new round of unification. Compared to previous research that made simple inferences about unity conditions (Lu et al., 2023; Lu et al., 2022b), we constructed the structural knowledge graph using neural networks. It will inspire the exploration of historical learning mechanisms used in different dynasties for the unification of the whole system. To further examine the effects of related factors, the Back Propagation Neural Networks (BPNN) are adopted to predict independent variables (IV), such as the states ( $y_1$ ), duration ( $y_2$ ), number of alliances ( $y_3$ ), number of wars ( $y_4$ ). The dependent variables (Grinyaev et al., (2021)) include the bellicosity ( $x_1$ ), the propensity of alliance ( $x_2$ ), the betrayal threshold ( $x_3$ ), the winner cost ( $x_4$ ) & the loser cost ( $x_5$ ). All related variables ( $x_1, x_2, x_3, x_4, & x_5$ ) are regeared as five input neurons to construct the input layer of BP neural networks. The K-fold cross-validation slices the data into the training set and test set. The data includes 29616 items. We select the case of  $k = 10$ . For each iteration, the data set of 2962 items would be considered the test set. To ensure the interpretability of the model, we introduce five neurons to construct five hidden layers. For the output layers, the independent variables ( $y_1, y_2, y_3, & y_4$ ) is regarded as output results. The results of BP neural networks are visualized in Fig. 13A1, A2, A3, & A4, respectively. Since the BP neural network algorithm results vary for each computation, we run the BP neural network by 100 times to obtain robust results. The mean squared error (MSE) can be seen as an indicator of fitness, and the MSE of each independent variable by 100 times is plotted in Fig. 13B. In Fig. 13B1, the mean of MSE is 0.00159, and the standard deviation (SD) is 0.000227. In Fig. 13B2, the mean MSE is 0.008753, and the SD is 0.001268. In Fig. 13B3, the mean of MSE is 0.000628, and SD is 0.000106. In Fig. 13B4, the mean of MSE is 0.001523, and the SD is 0.000433. Therefore, all the distributions in Fig. 13B1, B2, B3 & B4 are slightly skewed, and all the MSE presents a small value. In Fig. 13C, we visualize the paired scatters of observed (true) and predicted (train)  $y_1, y_2, y_3,$  and  $y_4,$  values to examine the fitness of our model. The correlation coefficient (indicator of model fitness), can be 0.989, 0.968, 0.945, and 0.953, respectively. The neural network predictions are in excellent agreement with real data and

simulated outcomes. The neural network model aims to simulate the actual civilizational conditions and patterns. Outstanding fitness is sufficient to achieve the goal. Accordingly, adopting other models, such as KNN or fuzzy neural networks, is unnecessary to improve the fitness.

**Conclusions and discussions**

Originally, the East (China) and West (Europe) civilizations have similar social characteristics but they, then, evolved into different civilizational patterns (unity and disunity). We employ agent-based modeling (ABM) to simulate civilizational evolution in the critical phase (the Warring States period of China). By introducing real history outcomes such as the number of states ( $y_1$ ), duration ( $y_2$ ), number of alliances ( $y_3$ ), number of wars ( $y_4$ ), we have precisely back-calculated and restore the process of this Warring States period, and solved the thresholds of two civilizational patterns. The counterfactual experiment provides reasonable inferences. It indicates: (a) Effects of bellicosity. Under  $b_i \geq 0.2$ , most model simulations achieve unity (more than 95%). Otherwise, the model is disunity. Furthermore, under the unity pattern, when the bellicosity ( $b_i$ ) increases from 0.2 to 1, the duration, the number of alliances, and the number of wars will decrease. But when it is higher than 0.4, the changes of the duration, the number of alliances, and the number of wars are not obvious. (b) Effects of alliance propensity. We further iterate the alliance propensity ( $p_i$ ) from 0 to 1, while keeping the other parameters the same. When it is below 0.3 ( $p_i < 0.3$ ), most simulations achieve unity. Otherwise ( $p_i \geq 0.3$ ), the system achieves disunity. Under the unity pattern, when it increases, the duration, alliances, and wars increase correspondingly. (c) Effects of betrayal threshold ( $\gamma_b$ ). When the threshold is lower than 0.8 ( $\gamma_b \leq 0.8$ ), it is likely to get the unity. Otherwise ( $\gamma_b > 0.8$ ), the pattern is more likely to be disunity. So, the increase of the betray threshold promotes the probability of unity. Because a strong civilization could ensure steady Winner and annexation in frequent wars. A lower betrayal threshold will lead to more fragile and vulnerable alliance relationships, and more small states will fight independently. Under the unity pattern, the increase of betrayal threshold ( $\gamma_b$ ) will reduce the duration, but has weak effect on the number of wars and alliances. Because the decision to construct an alliance and wage war will be carefully impacted by the change of the comprehensive power ( $U_{i+a_i}^t$ ). (d) Effects of war's cost. The higher loser cost has more effect on the probability of unity, which slightly influences the pattern of civilization. Besides, the winner cost and loser cost have different effects on the duration. While the higher or lower cost also affects the duration. On the one hand, the effect of war costs on the number



**Fig. 13 Neural Networks (BP) for the number of states ( $y_1$ ), duration ( $y_2$ ), number of alliances ( $y_3$ ), number of wars ( $y_4$ ). A1–A4 refer to the BP neural network outcomes of  $y_1$ ,  $y_2$ ,  $y_3$  &  $y_4$ . B1–B4 are the probability density distribution of MSE in 100 iterations. C1–C4 plot the paired scatters.**

of alliances & wars differs from their effects on duration. Increased war costs, within a lower range, are prone to reduce alliances and wars. On the other hand, increased war costs, within a higher range, have relatively weak effects. (e) Limitation and future research. We construct idealized agent-based model (multi-agent system) to restore the stable causal emergence by adopting important variables (the war & alliance) in the Warring States period. The non-significant factors, such as geographical vicinity and spatial relationships, are censored. Further research should include more real-world variables and complex behaviors to explore internal causality. Furthermore, the phased history of the Spring-Autumn period and the Warring States have been researched. However, the two-phased history of the Eastern Zhou period took place as a whole. Integral Eastern Zhou history and following learners in the history should be explored in the future.

### Data availability

The data of our paper will be opened to the public online (<https://github.com/zhuoyue2018/-humanities-and-social-sciences-communications>).

Received: 23 November 2021; Accepted: 16 October 2023;

Published online: 10 November 2023

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## Acknowledgements

This work was supported by the National Social Science Foundation of China (Grant No. 21ASH003 & 18VXK005), Wuhan East Lake High-Tech Development Zone (also known as the Optics Valley of China, or OVC) National Comprehensive Experimental Base for Governance of Intelligent Society Project, and the Fundamental Research Funds for the Central Universities of Central South University (Grant No. 2022ZZTS0300 & CX20230127).

## Author contributions

PL: conceptualization, methodology, software, writing-original draft; ZZ: data cleaning, visualization, simulation; CHO: revise, review, simulation; ML: software, validation, writing, review & editing.

## Competing interests

The authors declare no competing interests.

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