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Beyond climate and conflict relationships: new evidence from copulas analysis

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Abstract

This paper contributes to the new climate-society literature (Carleton and Hsiang, 2016) by analysing the role of climate in conflicts over the historical period from 1500 to 1800, in the vein of the recent literature initiated by Tol and Wagner (2010) and Burke and Hsiang (2014). As far as we know, this study is the first to apply copulas and time-varying copula analysis to climate-economics literature and to the analysis of climate and conflicts in a historical time series context. Effects of temperatures, precipitation and ENSO/NAO teleconnection on conflicts were investigated. Copula analysis enabled us to identify a positive dependence between temperatures and conflicts, and negative or positive dependences between anomalous precipitation and conflicts, by explicitly focusing on the joint marginal distribution of our variables. Using a time-varying approach, we were also able to precisely identify the periods/regimes during which the link between climate and conflict was genuinely active and then check the robustness of previous literature, such as Zhang et al. (2006, 2007, 2011).

JEL Classification: C33, O40, Q54.

Keywords: Climate change, Conflicts, Social Disturbances, Global Crisis, Copulas.

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1. Introduction

A new multi-disciplinary literature referred to as climate-society literature has emerged recently to investigate how climate is likely to affect society (Carleton and Hsiang, 2016). This literature constitutes a multidisciplinary renaissance of quantitative empirical research highlighting important linkages in the coupled climate-human system [1].

In this work, we focus on the association between climate and conflicts, which is a controversial topic. Although Hsiang et al. (2013), among others, identified an empirical connection between violence and climate change across 12,000 years of human history, Adams et al. (2018) considered that the connections between climate change and conflicts were overstated by sample biases, since the countries that were mentioned most were also the most violent recently [2]. More precisely, this paper is in the vein of a specific literature that has been clearly identified by Tol and Wagner (2010) and Burke and Hsiang (2014), and which adopts a long-term historical perspective to understand the links between climate, social disturbances and war. The seminal literature by Zhang et al. (2006, 2007 and, to a lesser extent, 2011) suggested that the link between climate and conflicts is not recent and already existed in pre-industrial societies.

In this paper, for the first time, we used copulas and, more precisely, time-varying copulas to reinvestigate the empirical association between climate and conflicts. Here, conflicts were defined very generally as encompassing both social disturbances or riots, and wars. Since the papers in the literature have generally been more interested in wars, we expected to find positive correlations between social disturbances and wars, and therefore investigated them simultaneously. Copula methodology was interesting in that it enabled us to investigate the dependence of the statistical distribution of our two variables, while time-varying analysis enabled us to classify periods with zero, negative or positive dependence and study temporal heterogeneities.

In our context, this provides a way of making a distinction between periods of close association between climate and violence or social disorders and periods without any correlation. Using historical records, we can explain whether the periods identified by our empirical methodology can be explained by any particular events. Finally, this methodology is interesting to identify whether the relationship between climate and conflict is a mean relationship or stems from extreme events, and whether it is stable over time and gradual or, on the contrary, whether particular sub-periods are driving the negative correlation found in the previous literature. Finally, as also stressed by De Juan and Wegenast (2019), temporal variability has received substantially less attention than spatial variability. However, it is particularly important if we want to assess the potential impact of climate change on violence in the future. In addition, it is crucial to understand

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[1] See especially Dell et al. (2014) for a survey of macroeconomy-climate change literature.

[2] See also Burke et al., 2010a and b and Buhang, 2010 about some controversial exchanges in the PNAS journal.

the adaptation potential of populations to climate variations, such as past changes in agricultural practices, innovation or institutional responses.

What is the definition of conflict considered in this paper? In this study, conflict is above all a proxy of intergroup violence and social interactions, as classified by Burke and Hsiang (2016). In this vein, climate variations influence relationships between different groups in society and can lead to social disturbances, for instance civil unrest, including riots or insurrections. In this respect, climate change is likely to increase civil conflicts and social disturbances inside a country. Land invasion in Brazil (Hidalgo et al., 2010) or civil war induced by droughts in Somalia (Maystadt and Ecker, 2014) are examples of such cases.

Cooling periods in feudal Europe are also likely to have been a major cause of economic and human crisis via social disturbances (Zhang et al., 2011 or Parker, 2013). As a consequence, civil war or armed conflicts and social unrest are different types of conflicts that can potentially be affected by climate. Both types will be considered in this paper, since we suggest that they can potentially be linked by the same drivers and reinforce each other. Social disturbances can also lead to intergroup violence outside the country via inter-State conflicts and wars. When the effects of climate on social interactions are strong, this can lead to institutional breakdown and State failure (see Burke and Hsiang, 2016), leading to dynastic changes in China, for example (Zhang et al., 2007).

More generally, climate can generate interpersonal violence (Hsiang et al., 2013 and Burke et al., 2015), from low-level aggression to violent crimes (see Ranson, 2014 for example) through physiological and cognitive mechanisms and even suicides (Burke et al., 2018). Although this definition of conflict is very topical, it is not related to the period studied in our paper.

We focus in this paper on social disturbances and wars over the 1500-1800 period in Europe, using an historical perspective and large-scale aggregate data. In other words, our objective is to identify a long-term link and, more especially, a potentially time-varying link between climate proxies and social disturbances and war over a 300-year period. As previously explained by Zhang et al. (2007, 2011) and Pei et al. (2013), a large geographic scale can help us understand the complex interactions between nature and human society, while focusing on a specific socioeconomic period (pre-industrial Europe in this case) can help us to interpret the relationship between climate and socioeconomic variables. Our study thus brings an interesting contribution to the literature on the long-term impact of climate change. Only a limited number of studies have quantitatively detected the short- and long-term impacts of climate variations on society during the pre-industrial era (Pei et al., 2013) and only two, to the best of our knowledge, in economics [3]

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[3] Waldinger (2015) used European city panel data to assess the economic effects of long-term, gradual climate change over the 1500-1750 period when people have time to adapt. However, she focused on panel data about major European cities with a very low time-series dimension to explore the city dimension of the data. The evidence indicates that decreased temperatures led to shortened growing periods and more frequent harvest failure in this period. Using historical wheat prices, the author

Considering data for 1500-1800 enables us to address marked climate change dynamics and possibly identify close links between climate and society by working on pre-industrial Europe during the Little Ice Age period. The 1500-1800 period falls within the period of lowest temperatures at any time in the past millennium, the so-called Little Ice Age (see for instance Osborn and Briffa, 2006) [4]. From a climatology point of view, taking into account the Little Ice Age enables us to proxy important climate changes and infer some results about actual climate change. From a society point of view, working on pre-industrial Europe is interesting to show how economic or social vulnerability might lead to, or reinforce effects of climate on conflicts. Considering Tol and Wagner (2010), the economies in the 1600's were very similar (in income comparisons) to some vulnerable developing countries today. Since countries are particularly concerned by probable future climate change, a cliometric investigation can help policy makers warn populations and implement suitable climate change mitigation policies. From a methodology point of view, focusing on the 1500-1800 period leads us to compare our results with some benchmark studies and check their robustness (especially Tol and Wagner, 2010 and Zhang et al., 2011) and to use relatively rich data, considering the abundance of detailed records during this particular period. In addition, large-scale data and historical analysis enable us to avoid some potential sampling bias, especially in panel studies, as pointed out by Adams et al. (2018). From a history point of view, the period covers the macroeconomic and general human crisis of the seventeenth century (Fisher, 1996; Parker, 2013) already studied by Zhang et al. (2011) or Pei et al. (2014, 2015).

Unlike previous literature that used correlation and Granger causality in time series with filtered data (Zhang et al., 2007, 2011) or regression analysis (Tol and Wagner, 2010), we applied copula methodology to non-transformed data. As far as we know, this study was the first to use copulas and time-varying copula analysis in the climate-economics literature and therefore in the analysis of climate and conflicts in a time-series historical context. Copula analysis identified a positive dependence between temperatures and conflicts, and negative or positive dependence between precipitation anomalies and conflicts, by focusing explicitly on the joint marginal distribution of our variables. Moreover, using the time-varying approach, we were able to precisely identify the periods/regimes during which the link between climate and conflict was genuinely active. In addition, we tried to link these dependence regimes to historical information to identify a causal pattern between climate and the so-called "general crisis" including macroeconomic crisis, revolts, social and political conflicts. The impact of climate on bioproductivity and cereal yield leading to famines and poor

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showed that temperatures affected economic growth via their effect on agricultural productivity. Iyigun et al. (2017a) were more similar to our contribution and used panel data with a new conflict dataset over 1400-1900, finding that climate change increased conflict.

[4] The Little Ice Age is a controversial topic: see for example White (2014) as opposed to Kelly and O$'$ Gra$'$da.

macroeconomic indicators has been suggested previously in the literature (Zhang et al., 2007, 2011 and Pei et al., 2014). We checked the robustness of this causal pattern and added new mechanisms to investigate the ex-post link between economic crisis, famine and the likelihood of social disturbances and wars linked to a variation in climate. Finally, we tested the potential climate origins (see for example Parker, 2013) of the cooling period induced by the Little Ice Age and its effects on humans by investigating the ENSO and NAO effects on climate variations and therefore on conflicts (ex ante).

The rest of our paper is structured as follows. Section 2 presents the related literature, followed by the hypotheses, methodology and data in section 3. Section 4 discusses the results of the Copula analysis. Concluding remarks are in section 5.

2. Related Literature

There is an abundant literature about the potential causality of climate on conflicts, notably recently in African countries since the 1980's: among others, see Miguel et al. (2004) on the link between rainfall and civil conflict in Sub-Saharan countries, Burke et al. (2009) on adding temperatures to control previous causality between climate and civil wars in Africa, or Couttenier and Soubeyran (2013) employing the Palmer Drought Severity Index focusing on water availability, which all point to an increasing violence effect of climate anomalies. On a more global level and using modern data, Dell et al. (2012), Bergholt and Lujala (2012) and Hsiang et al. (2011) are the most quoted studies. Hsiang et al. (2011) are a little different in the sense that they evaluate the impact of ENSO (El Nino Southern Oscillation) teleconnection, which is to say a global climate change and not a local climate change (temperature, rainfall, storms etc...) on the probability of conflict measured by an ACR (Annual Conflict Risk) proxy.

However, historical studies using quantitative analysis are scarcer. Hsiang and Burke (2013) adopted an interesting point of view by classifying empirical studies based on whether the data began before or after 1900. They argued that this cutoff was relevant to the characteristics of each kind of study: pre-1900 studies examine long historical time series, while the others examine shorter and more recent panel data where spatial heterogeneity is more pronounced. In the context of this study, we focused on the Little Ice Age period between 1500 and 1800 and were therefore in line with pre-1900 studies. In many pre-1900 studies, the value added lies in examining low-frequency climate changes that are absent per se or difficult to analyze in recent 1900 data. Thus, we are looking at historical studies here, especially concerning Europe, the geographical scope of our study.

Basically, as summarized by Scheffran et al. (2012), long-term historical empirical studies consist in investigating a potential coincidence between climate variability and armed conflict in line with some narratives about the evolution of societies and, for instance, the collapse of civilizations. Zhang and other researchers from Hong-Kong are sometimes considered the pioneers of quantitative investigation of this link (Tol and Wagner, 2010). Relying on correlation, linear regression and bivariate Granger causality tests, Zhang et al. (2006, 2007) found evidence that cooler periods were correlated to periods of violence in eastern China. The first empirical analysis of the link between climate and conflicts was not conducted on Europe but on Asia and China (Zhang et al., 2006; Yancheva et al., 2007 or Bai and Kung, 2010). See also Haug et al. (2003), Kennett et al. (2012) among others for the Americas Zhang et al. (2011) also conducted similar investigations in Europe afterwards. More generally, they showed that climatic change was a large-scale human crisis, especially over the 1500-1800 period corresponding to the Little Ice Age period.

Tol and Wagner (2010) also focused on European countries, but over a longer period (the last millennium, 1000-1980), computing Pearson correlations and regressions (with a deterministic trend or autoregressive specifications) on non-filtered and filtered data with Hamming window series. They found evidence of a negative correlation between temperature reconstructions (especially Luterbacher et al., 2004) and the number of wars (source?) and a positive correlation between precipitations (Pauling et al., 2006) and conflicts proxied on the same basis as previously. Using different subsamples, they found that the largest mean negative effect was concentrated in the 1250-1775 period; the effect during the Little Ice Age period (1500-1700) seems to disappear over the 1700-1900 sample. This last period is interpreted as a transition period from a cold/violent to a warmer/peaceful period (Zhang et al., 2011, Hsiang and Burke, 2013). These results also suggest that temporary cooling episodes during moderate or warm periods have little effect on conflict in comparison to considerable cooling from cold baseline conditions. Büntgen et al. (2011), looking over a more extended period, found an association between times of cooling and turmoil in Europe, especially during the 30-Year War in the 1600's, in line with the present study.

Alongside this literature about climate and conflicts defined as civil conflicts or wars, there are some articles focusing on food riots, social unrest and social disturbances more generally. Juan and Wegenast (2019) assessed the impact of temperatures on social unrest over 300 years (1500-1817) in England and confirmed the negative association between temperatures and food riots. However, they found that this association was inconsistent and largely confined to the 18th century, using time-varying correlations with a 20-year window. Moreover, computing 50km*50km gridded data, they found that past exposure of a region to adverse weather conditions dampened the effect of current exposure. Almer et al. (2017) looked at how deviations of the current drought situation from the long-run average affected the level of rioting in a cell via water scarcity. They relied on Tollefsen et al. (2012) for data on the number of distinct ethnic groups in a cell.

3. Methodology

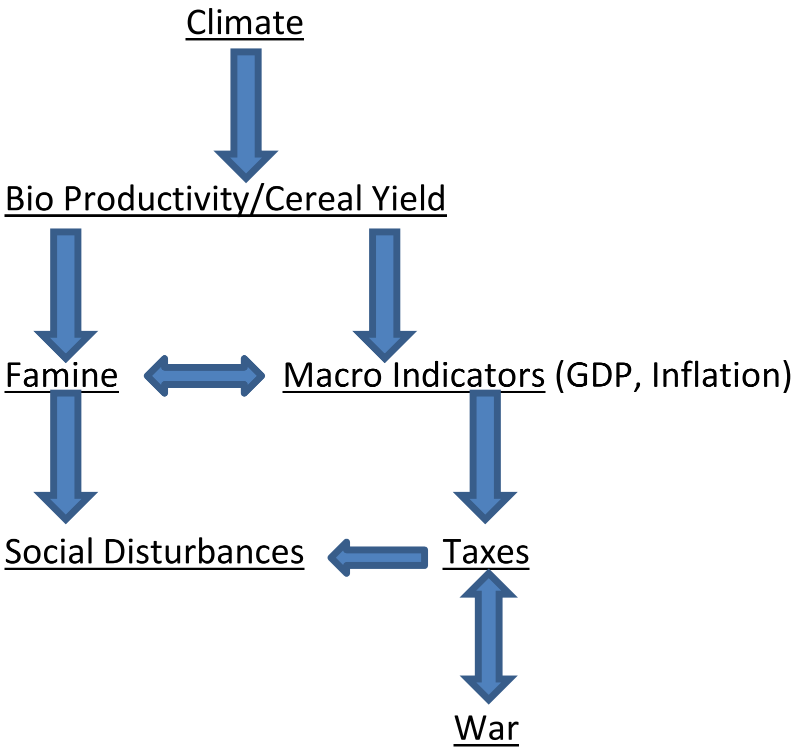
3.1. Hypotheses

In line with previous literature, we hypothesized that human populations are not very different from animal populations regarding the behavior they adopt in times of resource limitations (Zhang et al., 2011). When climate variations reduce agricultural crop yields (see Schlenker and Roberts, 2009) and limit natural resource exploitation and therefore food, warfare can be viewed as an adaptation process to equalize the supply and demand of natural resources.

In this respect, climate change can lead to social disturbances by generating food riots directly. The magnitude of social disturbances is viewed as a main outcome of famine generated by the negative climate variation impact on agricultural productivity (see the seminal paper from Deschennes and Greenstone, 2007, on this relationship) and the occurrence of recurrent subsistence crises during spells of strong cooling. In addition, climate also impacts social conflicts indirectly by potentially intensifying social disequilibrium or ideological divides. When famines occur in times of bad crops with poor macroeconomic indicators (inflation, especially for cereal products and lower production), the opportunity cost of rioting for very poor populations tends to decrease and episodes of famine are therefore likely to increase social disturbances. This channel is reinforced by heavy taxes during the studied period (see section 4 for more details) and by the occurrence of a high number of wars and fears (of famine and conflicts). In one sense, the system is a somewhat self-sustaining vicious circle, since bad macroeconomic indicators, famines, social disturbances and conflicts are reinforced by each other.

Generally, in times of macroeconomic crisis, political leaders choose to conduct wars to get external resources, turn attention away from internal problems and bring people together by fighting common enemies. Incidentally, they increase taxes that may already be very high for farmers, craftspeople and the little people, exacerbating the economic and food subsistence riots. As a consequence, climate-induced economic crises can lead to social crises with riots and social unrest at the same time as wars, with each type of ”conflict” reinforcing each other. Finally, climate variations and their effects by reducing bioproductivity, hence increasing food prices (Zhang et al., 2007, 2011 or Waldinger, 2015), can trigger social unrest directly or reinforce social and political unrest and instability due to social inequalities, high taxes etc... In other words, climate vulnerability can generate economic and social vulnerability, leading to more violence and conflicts both inside the countries (social disturbances and civil wars) and outside (inter-State wars and conflicts). Figure 1 below summarizes the previous causal linkages.

Figure 1: Theoretical hypotheses and causal scheme



3.2. Copula Approach

In order to investigate the possible interdependence between climate and conflicts, we used Copulas to model average and tail dependence and examine transmission and contagion in a quantitative manner. Working with copulas is, in simple terms, to work with the joint marginal distribution of two variables. Thus a positive dependence or positive correlation (change in climate is positively related to conflict number and/or intensity) or a negative dependence with negative correlation coefficients (climate and conflicts are going in opposite directions). Copulas can be viewed as a co-movement of distributions of different variables.

The main interest of this analysis is to work on the whole distribution i.e. not only on the mean dependence, but also on the tail dependence. Dependence between climate and conflicts might exist in the tails only. Using different copulas and so different distributions, it is possible to take asymmetric effects into account: for example, only the negative temperature or precipitation anomalies could be correlated with conflicts.

A copula is a function which links univariate marginal distribution to the multivariate distribution for which the marginal distribution of each variable is uniform. Let X and Y be continuous random variables following a distribution function $F(X, Y)$ and $F_X(X), F_Y(Y)$ =their marginal distributions respectively. Therefore, $U = F_X(X) \in [0, 1]$ and $V = F_Y(Y) \in [0, 1]$. Thus the copula C is the distribution function of (U, V) as below:

$$C(u, v) = P(U \le u, V \le v) = P(X \le F_X^{-1}(u), Y \le F_Y^{-1}(v)) \tag{1}$$

Let F be a bivariate distribution function with F_1 and F_2 the margins. There is therefore a copula C such that:

$$F(X, Y) = C(F_1\,(X)\,,\ F_2(Y)) \tag{2}$$

Furthermore, C is unique if the margins F_1 and F_2 are continuous. Likewise, if C is a copula, then for any $u_1 \epsilon [0, 1]$, the partial derivative $\frac{\partial C}{\partial u}$ exists for all $u_2\ \epsilon [0, 1]$. For such u_1 and u_2 there are:

$$0 \le \frac{\partial C(u_1, u_2)}{\partial u_1} \le 1 \quad \text{and} \quad 0 \le \frac{C(u_1, u_2)}{\partial u_2} \le 1 \tag{3}$$

Moreover, if the copula is sufficiently differentiated, then the copula density may be as follows:

$$c(u_1, u_2) = \frac{\partial \mathrm{C}\ (u_1, u_2)}{\partial u_1 \partial u_2} \tag{4}$$

In case of an absolute continuity of bivariate distribution, copula density can be represented as follows:

$$c(u_1, u_2) = \frac{f(F_1^{-1}\,(u_1)\,,\ \ F_2^{-1}\,(u_2))}{f_1\left(F_1^{-1}\,(u_1)\right) \times f_2(F_2^{-1}\,(u_2))} \tag{5}$$

where f_1 and f_2 denote the marginal densities of variables x and y, respectively.

An appealing feature of the copula is tail dependence, which measures the probability that two variables are in the lower or upper joint tails of their bivariate distribution. The coefficient of upper (right) and lower (left) tail dependence for two random variables X and Y is obtained from the copula as:

$$\lambda_U = Lim_{U \to 1} Pr(Y > F_2^{-1}(u)/X > F_1^{-1}(u)) = Lim_{U \to 1} \frac{1 - 2u + C(u,u)}{1 - u} \tag{6}$$

$$\lambda_L = Lim_{U \to 0} Pr(Y \leq F_2^{-1}(u)/X \leq F_1^{-1}(u)) = Lim_{U \to 0} \frac{C(u,u)}{u} \tag{7}$$

where $\lambda_U, \lambda_L \in [0,1]$. Lower (upper) tail dependence means that $\lambda_L > 0$ ($\lambda_U > 0$) indicates a non-zero probability of observing an extremely small (large) value for one series together with on extremely small (large) value for another series.

1. The Gaussian (Normal) copula is given by:

   $$C_G(u_1, u_2,\ \rho) = \Phi_N(\Phi^{-1}(u_1), \Phi^{-1}(u_2)) \tag{8}$$

   With Φ^{-1} the inverse cumulative distribution of N (0, 1), Φ the cumulative distribution function and ρ the covariance matrix.

2. The Student copula is a copula associated with the bivariate t-distribution. It is defined as follows:

   $$C_t(u_1, u_2, \rho, \vartheta) = t_{\rho,\vartheta}(t_\vartheta^{-1}(u_1), t_\vartheta^{-1}(u_2) \tag{9}$$

   where $t_{\rho,\vartheta}^{-1}$ is the standard distribution with ϑ degrees of freedom; ρ is the correlation and t_ϑ^{-1} is the inverse of the univariate standard student t-distribution function. However, when $\vartheta \to \infty :$ the student copula tends to the normal copula which does not authorize tail dependence.

3. The Gumbel copula was proposed by Gumbel (1960) and is also called the Gumbel-Hougaard copula. Its expression is defined by:

   $$C_\theta(u_1, u_2) = exp((-\ln(u_1))^\theta + (-\ln(u_1))^\theta)^{1/\theta}, 1 \leq \theta\ <\ \infty \tag{10}$$

   where the copula parameter $\theta \geq 1$. It is asymmetric with upper tail dependence: λ_U= 2- $2^{1/\theta}$ and lower tail independence (λ_L= 0).

4. The Clayton copula was introduced by Clayton (1978) and takes the following copula form:

$$C_\theta(u_1, u_2) = ({u_1}^{-\theta} + {u_2}^{-\theta} - 1)^{-1/\theta}, \theta\epsilon[0, \infty] \tag{11}$$

It is asymmetric with lower tail dependence: $\lambda_L = 2^{-1/\theta}$ and upper tail independence (λ_U=0).

The study used the Canonical Maximum likelihood (CML) to estimate the parameter of the copula. We followed the methodology set out in Bedoui and al. 2018. Firstly, we estimated the margins using an empirical distribution:

$$\widehat{F}_i(x) = \frac{1}{T}\sum_{t=1}^{T} 1I_{\{X_i \ll x\}} \quad \forall I = 1, ..., p$$

where I is the indicator function. Then we applied the CML method. The procedure of this was in two steps:

1. Transformation of the initial sample set into uniform variables, using the empirical marginal distribution:
$$\widehat{u}_t = (\widehat{u_1}, ..., \widehat{u_N}) = (\widehat{F_1}(x_1^t), ..., \widehat{F_N}(x_N^t)) \tag{12}$$

2. Estimation of the copula parameters via the following relation:
$$\widehat{\alpha}_{CLM} = argmax \sum_{t=1}^{T} LnC(\widehat{u_1}, \ .... \ , \widehat{u_N}, \alpha) \tag{13}$$

We used a rolling window methodology to deal with the time-varying effect of our copula models. To set it, we ran the estimation process for different sizes of windows. We obtained the likelihood values of each estimation and then worked out the best fit by combining both criteria: maximum likelihood result and economic and financial capture of cycles. We had to take into account the size of our data set and the economic meaning of the computed cycles.

3.3. Data

Temperature and precipitation data There are different sources of climate reconstructions for the last 500 years in Europe and the northern Hemisphere, and even for the last 2,000 years (earlier data is referred to as Paleo data). We chose to work from 1500 onwards and not before in order to use the most relevant data series starting in 1500. In addition, we focused on the Little Ice Age period and on pre-industrial Europe, as in Zhang et al. (2011). For robustness purposes, we used several well-recognized, high-quality sources focusing mainly on annual mean temperatures and precipitations for Europe as a whole, in line with the previous literature (see Zhang et al. in 2007 and 2011 or Tol and Wagner, 2010 for example). The climatic data for 1500–1900 came from the gridded datasets of Luterbacher et al. (2004) for temperature and Pauling et al. (2006) for precipitation; see also Xoplaki et al. (2005).

Our climatic dataset consisted of temperature and precipitation anomalies and was chosen among those most often taken into consideration in a vast multidisciplinary literature: in the vein of Zhang et al. (2007, 2011), EUR_TEMP was constructed as a combination of annual mean temperature reconstruction series for European land areas (25W to 40E and 35N to 70N) from the well-known Luterbacher et al. source and of the reconstruction associated with Osborn and Briffa (2006?); the combination was normalized to homogenize the original variability of the two different series and preserve the amplitude of temperature change (see Zhang et al., 2011, appendix).

NH temperatures (hereafter $Mann_NH$) from Mann and Jones (2003), total temperatures (Temp2006) from Büntgen et al. (2006), precipitation anomalies from Büntgen et al. (2011) (we used AMJ proxy as the most relevant proxy to identify periods of drought or extra rain) were also used for robustness checks and comparison purposes (for example, data for temperatures from Luterbacher et al. (2004) had previously been used by Tol and Wagner (2010)). In addition, we also tested the effects of ENSO and NAO teleconnections. For example, Parker (2013) explained that strong positive ENSO is likely to be behind the years of considerable cooling in the 17th century during the Little Ice Age period.

ENSO and NAO Teleconnection data We added to the previous climate database by collecting ENSO and NAO series. The North Atlantic Oscillation (NAO) is a climate phenomenon in the North Atlantic region, which could drive summer and winter climate in northern and southern areas of Europe. Existing literature has shown that the North Atlantic Oscillation (NAO) is considered to be one of the major modes of variability of the Northern Hemisphere atmosphere (see Hurrell, 1995) and is likely to explain approximately 30% of climate variability over the Euro-Atlantic region (Pavan, 2000). The NAO is traditionally defined as the normalized pressure difference between a station on the Azores and one in Iceland. The NAO index Reconstruction is based on three academic works, multi-proxies by Cook et al (2002), tree-ring records by Glueck et al (2001), and speleothem records by Trouet et al (2009) covering 1500-1800 AD. To increase the reliability of the NAO index, these three curves were standardized first. Then, these three curves were calculated to get the mean value.

The El Nino Southern Oscillation (ENSO) is considered to be the dominant mode of interannual climate variability on Earth, alternating between anomalously warm (El Nino) and cold (La Nina) conditions in the tropical Pacific at intervals of 2-7 years. The amplitude of ENSO variability affects the occurrence and predictability of climate extremes around the world and could have important social and economic effects (see for instance Cashin et al., 2017 and Ubilava, 2017). We used the 1,100 Year ENSO Index Reconstruction from Li et al. (2011) based on the North American Drought Atlas (a database of drought reconstructions based on tree-ring records) to produce a continuous, annually-resolved record of ENSO variability over the past 1,100 years.

Conflicts data Regarding the conflict data, we used three different variables: social disturbances, war and war fatalities. The number of wars was obtained from the Conflict catalogue developed by Brecke (1999) who constructed a long-time-scale dataset to discern patterns in the nature of violent conflict that were not feasible before. The initial sample start date is 1400 but Brecke extends the Conflict Catalog back for regions 3 and 4 (West and East Europe) to the 900-1399 period. As already explained by Zhang et al. (2011), the catalogue documents a total of 582 wars fought over 1500-1800, including all violent conflicts of Richardson's magnitude (32 or more deaths) or higher. As a corrolary, the war fatality index composed by Zhang et al. (2011) is an annual units index; so they developed a ratio from fatalities (when records exist) of each war divided by its duration (number of wars) and finally scaled on a yearly basis.

Social disturbances data were obtained from Sorokin's book (1937), volume III entitled "Social and Cultural Dynamics" that recorded the most important internal disturbances in both Central and Eastern Europe for an aggregate total of 205 social disturbances over our studied period. Political disturbances (modifications of political regime), socioeconomic disturbances (modification of existing economic or social order), national and separatist disturbances, and religious disturbances were recorded. Since the magnitude of each disturbance is provided in great detail by Sorokin, by duration, location, masses involved etc..., the magnitude has been divided by its duration (number of years) to get a magnitude/year ratio and then the annual magnitude is summed up on a yearly basis and finally divided by the number of countries in Europe (Zhang et al., 2011).

4. Results and discussion

We now discuss the results of our copula computations. For each pair of variables - for example temperature anomalies and war - we computed the dependence values over 1500-1800 considering four different distributions: Normal, Clayton, Student and Gumbel. We prioritized the Normal and Student distributions, but Gumbel and Clayton are also useful to analyse extreme shocks in the tails. The Gumbel distribution enables us to focus on positive and negative extreme shocks, while Clayton distribution enables us to only consider negative shocks.

Social Disturbances

We identified several regimes of copula dependence between climate proxies and social disturbances (table 1). To make the reading of the results easier, each line of the table corresponds to a potential sub-period or regime identified by a strong (negative or positive) dependence between climate and conflicts. For temperature proxies (EUR-TEMP, Mann NH, Temp2006), all the dates in the table correspond to a period with a strong negative correlation: in other words, lower temperatures are associated with a higher number of social disturbances (and conversely). For ENSO and NAO teleconnections proxies, the dependence was always found to be positive; however, in the case of the Clayton copula distribution, an extreme negative value of ENSO or NAO was associated with a positive dependence between ENSO/NAO and revolts, so we added some details about the "Copula distribution" term in this case. For example, if ENSO is positively associated to social disturbances, it means that an extremely small ENSO value (a La Nina episode to be precise) is related to an increasing number of social disturbances in Europe.

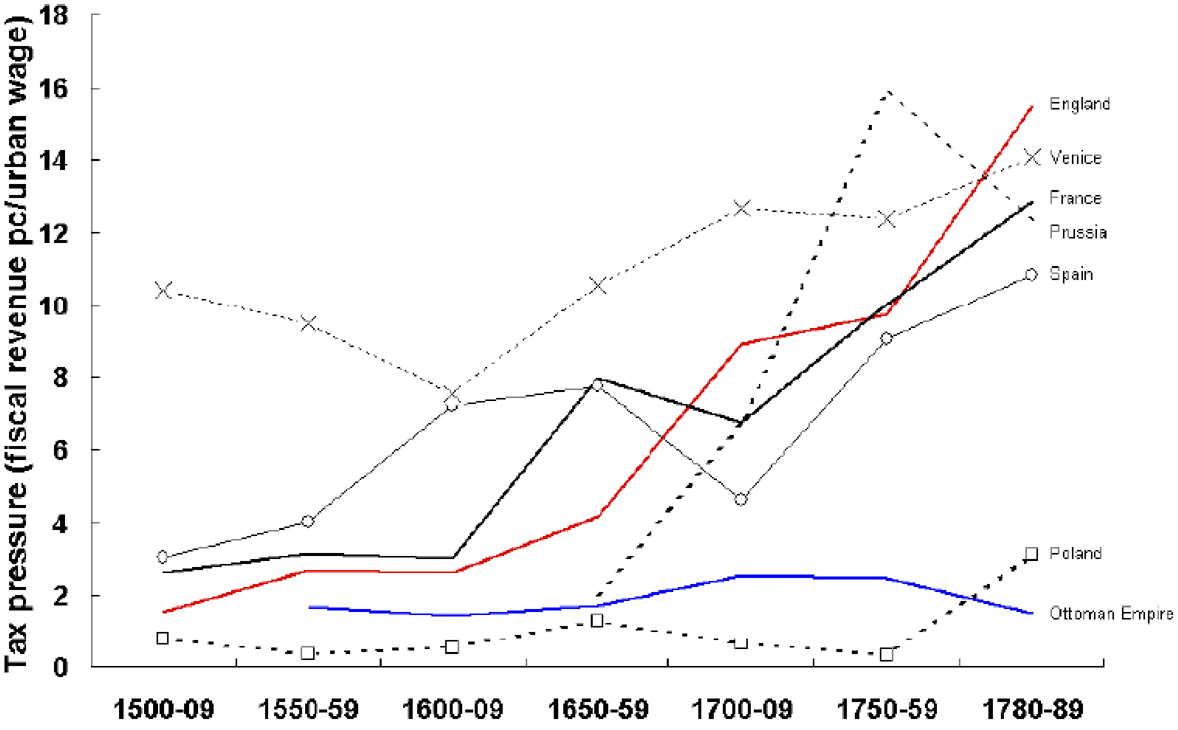
Results from table 1 reveal three main periods of negative dependence between temperatures and the number of social disturbances. Thus, cold periods are likely to increase the number of social riots. Our assumption is that cooling temperatures negatively impact agricultural yield, with low agricultural production and high prices (especially grain prices). During the economic crisis periods provoked by strong cooling periods, the probability of food riots increases. When economic crisis occurs, the government is likely to increase taxes to collect new sources of revenue and thus aggravates the economic and social crisis.

Our results suggest that the negative link between temperatures and social disturbances is mainly in the first-half of the 17th century. However, tax pressure also considerably increased between 1600-1609 and 1650-59, as demonstrated by figure 2 from Karman and Pamuk (2010, 2013), but this was restricted to a few number of countries such as England, France and Spain by Gennaioli and Voth (2015). This tax pressure shift fits with the increase in the negative dependence between climate and social disturbances around the first-half of the 17th century for countries with a high number of revolts. Though we suggest that high tax pressure reinforced the revolts due to food availability problems, we nonetheless did not formally prove the causality here.

When we look at the link between precipitations and social disturbances, the picture is less clear-cut and it is very difficult to pinpoint one significant relationship between the two variables. The only stand-out case is a positive dependence identified regarding the Clayton distribution around 1735-1740. In other words, some low precipitation values (that could correspond to droughts over the period) were associated with increasing social disturbances. But in a more general manner, it is quite difficult to show a link between precipitation and social disturbances.

Finally, we tested the impact of ENSO and NAO teleconnections on conflicts to capture the potential origins of temperature variation effects on violence. The periods 1660-1680 with a peak around 1675 for ENSO and 1640-1660 with a peak around 1650 were clearly remarkable periods. Positive ENSO and NAO values were associated with a high number of social riots and revolts over these periods. Concerning NAO, our result is in line with Lee et al. (2013) that gave the first demonstration that the NAO affected social stability in preindustrial societies. Concerning ENSO, our result is in line with Hsiang et al. (2011) linking

Figure 2: Tax pressure dynamics over 1500-1800



ENSO and conflicts, even though their results do not cover historical but recent (1950-2014) periods.

War and War fatalities

General crisis (economic, social) with increasing social disturbances is likely to generate more external conflicts, as a given country is more likely to declare war on a foreign country to collect some new external revenues. At the same time, money is important for military success and the ruler risks losing fiscal revenues in a war (Gennaioli and Voth, 2015) and so tax pressure is likely to increase in the short run. In addition, declaring war is a means of uniting the people around a common objective and creating a diversion from the food crisis and social disturbances. As a consequence, climate shocks can affect both social disturbances inside the country and external (inter-State) conflicts with an increasing number of wars. Between 1500 and 1700, there was a war between major powers underway in 95% of all years (Gennaioli and Voth, 2015).

Overall, our results suggest a negative dependence between temperature anomalies and war episodes, especially in the first-half of the 17th century. The dependence is particularly concentrated on three main sub-periods: around 1600, in the beginning of the 17th century, and around the 1630-1650 period, with a strong negative peak around 1650 and around 1730. Thus, during these periods, negative temperatures associated with cooling episodes were associated with increasing war events.

When we used global annual precipitations, we again found a negative dependence during the second and third regimes identified previously. When we used AMJ precipitations to focus on droughts episodes, we only found a negative dependence around 1730.

Results for war and war fatalities considering Mann temperatures were along the same lines. The copula time varying analysis led us to detect two main negative peaks with Normal and T-copula distributions. Thus, the average correlation between temperatures and war episodes tended to be near zero, but turned negative in some periods. Results using Luterbacher et al. (temp2006) and Zhang et al. (EUR_TEMP) proxies led to the detection of 3 main regimes and so seem robust to the climate proxy used: in the beginning of the 17th century around 1600, around 1630-1650 and in the mid 1700's (1750-1760 for the first one or 1730-1740 for the second one).

When we substituted the war index by war he fatalities index, we also found two main episodes characterized by an increasing negative dependence between temperatures and war fatalities around 1630-1650 and 1740. Nonetheless, the first episode around 1600 that was identified previously now completely disappeared. Anyway, the relationship between cooling and war is robust. In addition, the precipitation results in relation to the war fatality index confirmed the previous results for the war index.

Regarding precipitation, we found two main periods with an active link between climate and the war fatalities index: around 1630 and around 1730. These periods are very similar to the periods identified for the temperatures. Thus, the dependence between climate and wars covers both cooling and precipitation anomalies. More precisely, we show evidence of both "negative" and "positive" links between precipitation and the war index. A negative link implies that low precipitation and thus drought episodes are associated with a high number of conflicts. On the contrary, "positive" means that an excess of rains is associated with a higher number of more severe conflicts.

Historical perspective and causal scheme

To go further, we wanted to investigate whether the main periods of dependence identified by the copula analysis could be easily explained by narrative historical sources. We also wanted to explain whether the link between climate and food prices was the missing causal link to explain the correlation and possible causality from climate to conflicts.

The figures presented in Appendix A4 show negative dependence between temperatures (EUR_TEMP) and grain prices around 1630 and 1730. The picture is again clearer with the NAO that probably impacted grain prices with a sharply increasing dependence between NAO and grain prices over the 1625-1650 period. Cooling periods are therefore associated with increasing grain prices. As a consequence, the period for which there is a strong link between NAO, temperature anomalies and grain prices coincides with the period for which climate and conflicts are strongly related. There are a number of clues suggesting the existence of a link between climate and conflicts around 1630 and, more largely, over 1630-1650. So NAO temperature grain price conflicts seem to be a plausible scheme over the 1630-1650 period. In contrast, the dependence between ENSO and grain prices is less relevant concerning a potential direct link, since it is concentrated around 1610.

From an historical point of view, the period around 1630 (1630-1650) identified by our quantitative analysis coincides perfectly with a lot of social disturbances and war events in Europe. In Britain, there was the English Civil War (1642-1651) and more generally the Wars of the Three Kingdoms between 1639 and 1651, with several civil conflicts in England, Ireland and Scotland. In France, the so-called Fronde (1648-1653) is perfectly coincident with one significant period identified by our quantitative analysis. Antoine and Michon (2006) explained that the food riots were an important model of violence and public demonstration. France experienced a lot of temporary (or short-term) riots that were linked to years with high grain and bread prices (for example 1630 and 1661-1662, according to Antoine and Michon). Sometimes, fears of a price hike or the dealings of grain merchants were enough to provoke social demonstrations. Based on the studies of Jean Nicolas studies (2002) on the French Revolution or "disorder", some historians mention the occurrence of 200 local revolts in France during the "Ancien Régime". In Spain, according to the same authors, a lot of social disturbances occurred in Andalucia (Granada, Seville, Cordoba) over the period 1645-1652, in Zaragoza (1643) and in Jerez (1664). Some historians have talked about the Spanish Price Revolution linked to the high rate of inflation that occured in the first half of the 17th century across Western Europe, and fears of famine among the population, but also the occurence of new wars and battles, the working conditions of the little people and craftseople or the implementation of supplementary taxes as previously evoked. The role of climate is an initial shock leading to an economic and a social crisis with social disturbances and conflicts via a decrease in agricultural productivity. The decline in agricultural productivity seems to have been an important channel, as outlined by Iyigun et al. (2017b) who empirically demonstrated that an increase in agricultural productivity brought about by the introduction of potatoes dramatically reduced conflict over 1400-1900 by increasing real wages and the opportunity cost of arming. But the effect of cooling on productivity and then on conflict was probably reinforced by the increasing fiscal pressure and by fears of external conflicts and of problems of food availability.

Table 1: Regimes of copula dependence: Social Disturbances

EUR TEMP	Mann NH	Temp2006	Precipitation	Precipitation AMJ	ENSO	NAO
Around 1560 and 1650	-	-	-	-	-	-
Around 1600 (1590-1610)	1593-94 to 1600	1595-1600	-	-	-	-
Around 1650 and Around 1675	1650-1655	1650-1655(60)	-	-	-	-
Around 1735-40 and 1730-40	-	-	1735-1740 (Clayton)	-	1675 (1660-1680)	1650 (1640-1660)

Table 2: Regimes of copula dependence: War

EUR TEMP	Mann NH	Temp2006	Precipitations	Precipitations AMJ	ENSO	NAO
1600	-	1600-1605	-	1580-1600	Around 1605	-
1650	1650	1630-35(1630-1650)	1630-1640 (negative [5])	-	Around 1630	1625-1660
1730-1740	1729-1735	1755 and 1765	1730	Around 1730 (Clayton, positive)	-	Around 1735

Table 3: Regimes of copula dependence: War Fatality

EUR TEMP	Mann NH	Temp2006	Precipitations	Precipitations AMJ	ENSO	NAO
Around 1630 and 1650	1650	1630-1650*	1620-1640 (negative)	Around 1630 (positive)	Around 1635	1630-1660
Around 1730	1729-1735	1740 and 1732-33	Around 1730 (negative)	Around 1730-35 (negative)	-	-

5. Conclusion

The relationship between climate and conflict is a controversial topic that has attracted considerable attention in recent years. In this paper, we used time-varying copula analysis for the first time to investigate the extent to which climate can be considered as a major driver of conflict. We can reaffirm the existence of a link between climate and wars in the spirit of Zhang et al. (2006, 2007), Tol and Wagner (2010) and Burke and Hsiang (2014) and also between climate and social disturbances in the vein of Zhang et al. (2011). However, this is not a uniform relationship. Here, we are able to show which sub-periods over the Little Ice Age (1500-1800) are particularly concerned by this relationship: around 1600, 1630-1650 and 1730. The first two periods - especially the second one - seem to be very reliable considering historical textbooks and historians' studies to explain a potential link between climate and social disturbances and civil conflicts in some European countries in the first-half of the 17th century. The timing of the shift in copula coefficients coincides with the decrease in cereals yield, an increase in inflation, an increase in tax pressure and global crisis, as indicated in Parker (2013).

We have also tried to look behind the direct correlation between climate and conflict by outlining a global causal scheme from climate to social disturbances and war. A decline in agricultural productivity generates a macroeconomic crisis with inflation (especially grain prices) leading to famines. People's fears about food availability generate food riots directly. These social disturbances are then reinforced by heavy and increasing taxes. As a consequence, general crisis (economic, social) with increasing social disturbances is likely to generate more external conflicts. A given country is more likely to declare war on a foreign country to collect some new external revenues. At the same time, money is important for military success and the ruler risks losing fiscal revenues in a war, and so tax pressure is likely to increase in the short run. In addition, declaring war is a way of uniting the people around a common objective and creating a diversion from the food crisis and social disturbances. As a consequence, climate shocks can affect both social disturbances inside the country and external (inter-state) conflicts with an increasing number of wars. A self-sustaining vicious circle is likely to be at work.

Furthermore, we have tried to explain whether ENSO and NAO teleconnections are likely to explain the initial climate variations and thus the likelihood of conflicts. It is clear that the climate teleconnections are associated with increasing conflicts for the 1630-1660 period for wars and a little later (around 1660) for social disturbance events. Hence, ENSO and above all NAO have probably modified the temperature and precipitation dynamics and so activated the causal scheme described previously.

Finally, our study is a novel piece in the scarce literature about long-term climate change impact on society, which is one of the most topical questions for policymakers nowadays. In terms of policy implications in a modern context, this study is important for countries suffering from the climate - not cooling, but warming - in developing countries with pre-industrial economies that are heavily reliant on agriculture like a high number of developing countries (Tol and Wagner, 2010 and Iyigun and al., 2017a). Excess cooling or excess warming is likely to reduce agricultural yield and generate economic and social crisis with increasingly heavy taxes leading to social disturbances and armed conflicts. In our paper, we have shown that the significant links between climate and conflicts were concentrated only in certain sub-periods, probably due to some self-sustained vicious circles between agricultural production, tax burden, people's fears, revolts and inter-State conflicts. The relationship between climate and conflict is not uniform and is dependent on some other underlying factors. Further work is again needed to understand these drivers better in the future.

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7. Appendix

In this appendix, we report all copula plots for the social disturbances, war and war fatalities indices respectively.

A1. Temperature impact on social disturbances, war and war fatalities

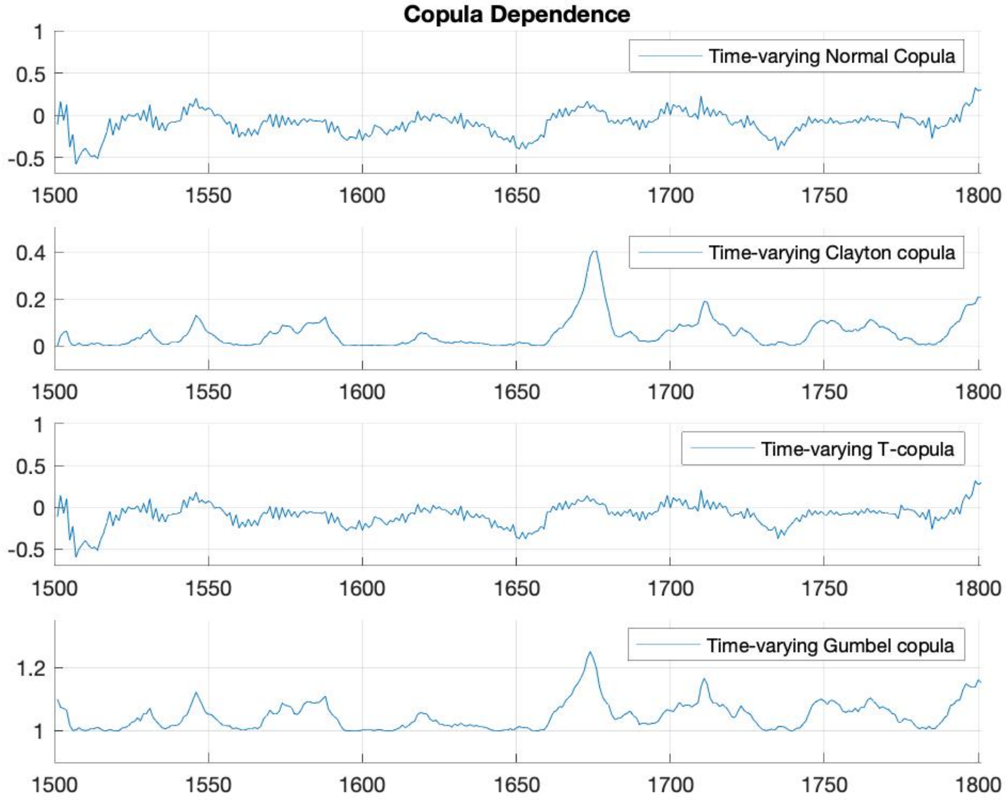

Figure 3: Temperatures from Zhang et al. EUR_TEMP (2011) Social Disturbances

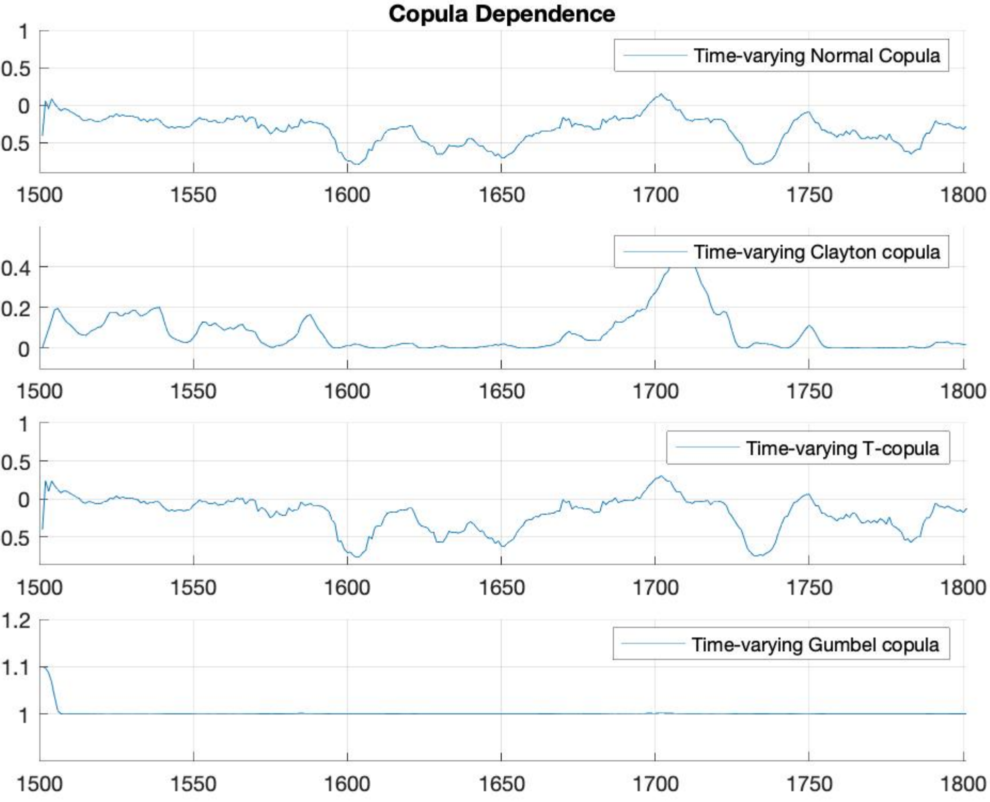

Figure 4: Temperatures from Zhang et al. EUR_TEMP **(2011) War**

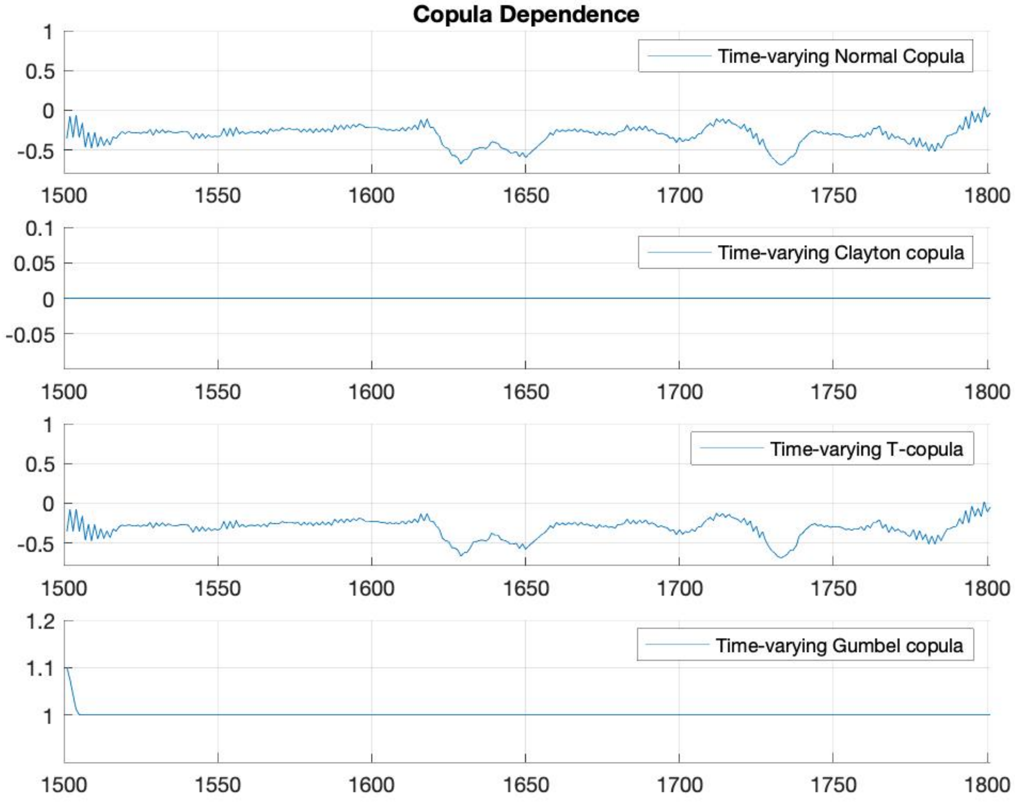

Figure 5: Temperatures from Zhang et al. EUR_TEMP (2011) War fatality

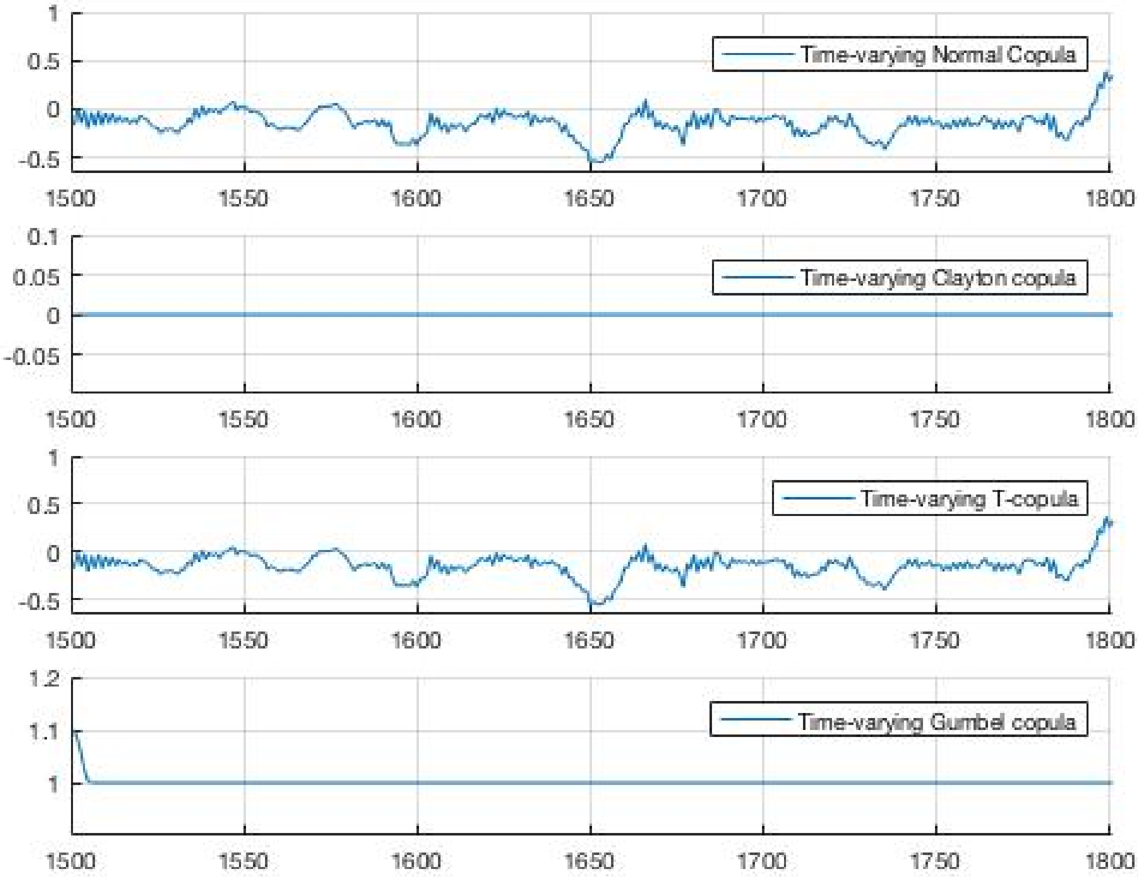

Figure 6: Temperatures from Mann et al. (2006) Social Disturbances

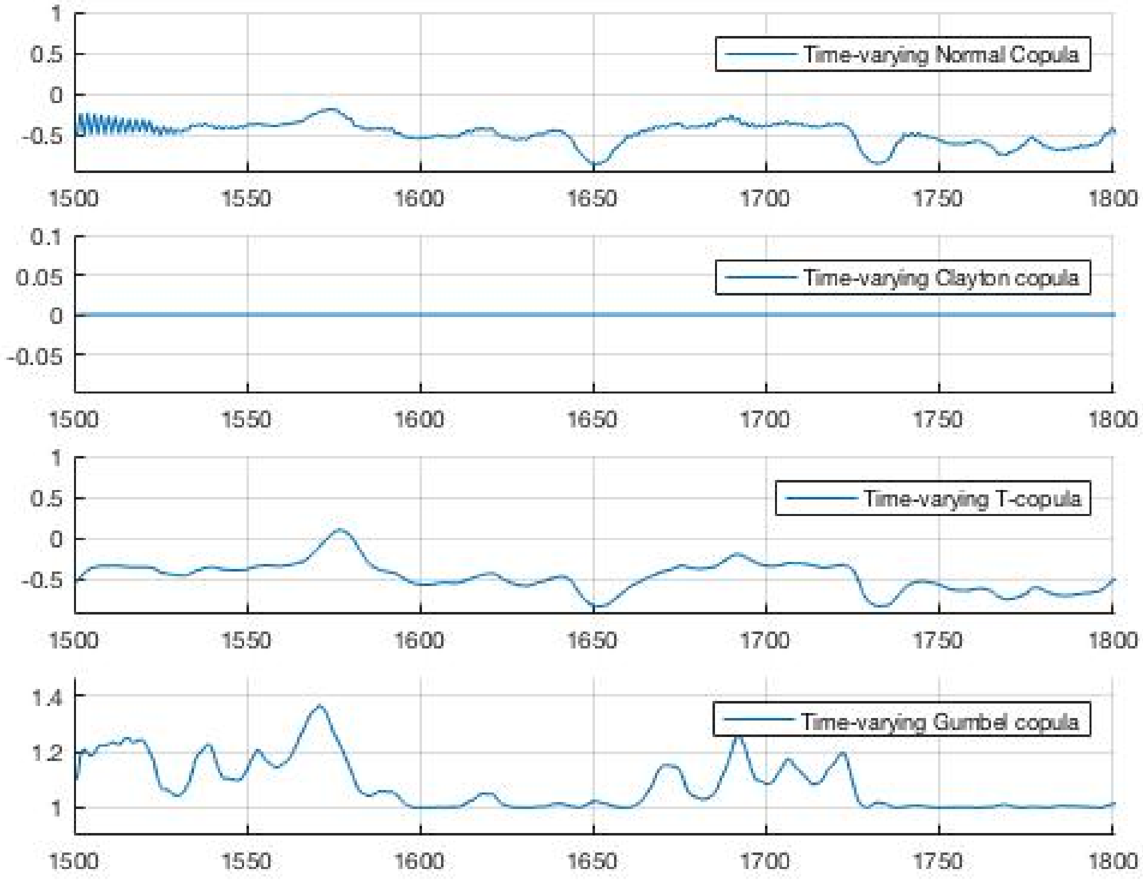

Figure 7: Temperatures from Mann et al. (2006) War

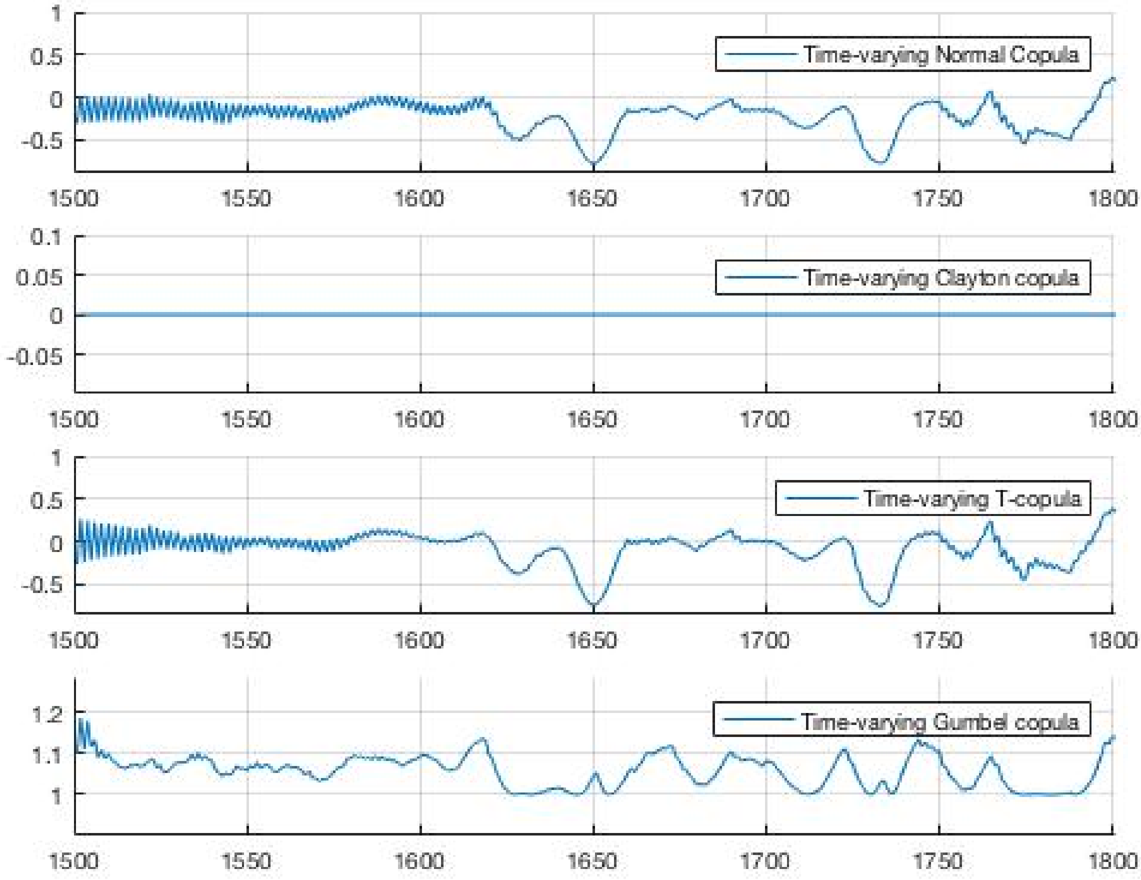

Figure 8: Temperatures Mann et al. (2006) War fatality

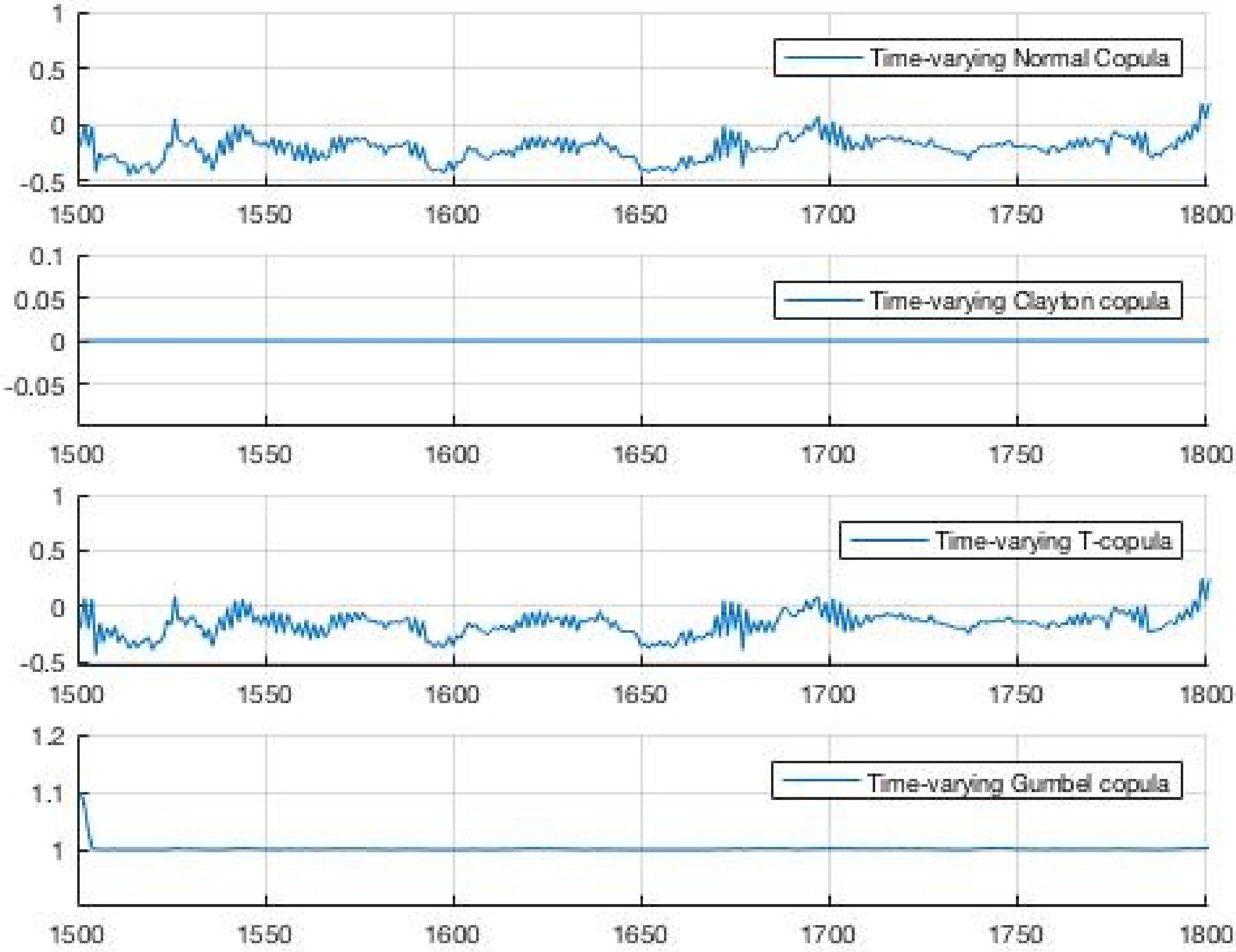

Figure 9: Temperatures from Büntgen et al. (2006) Social Disturbances

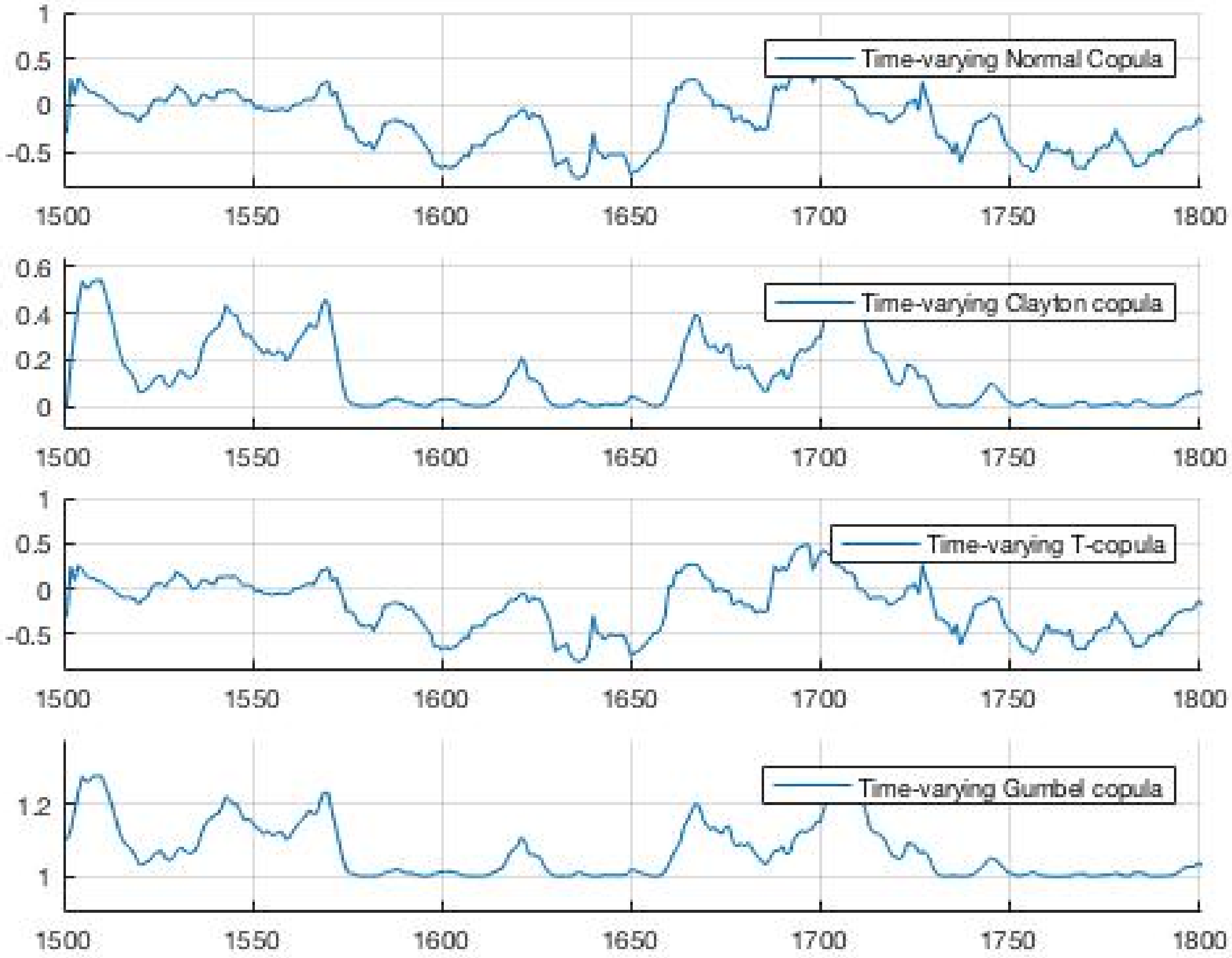

Figure 10: Temperatures from Büntgen et al. (2006) War

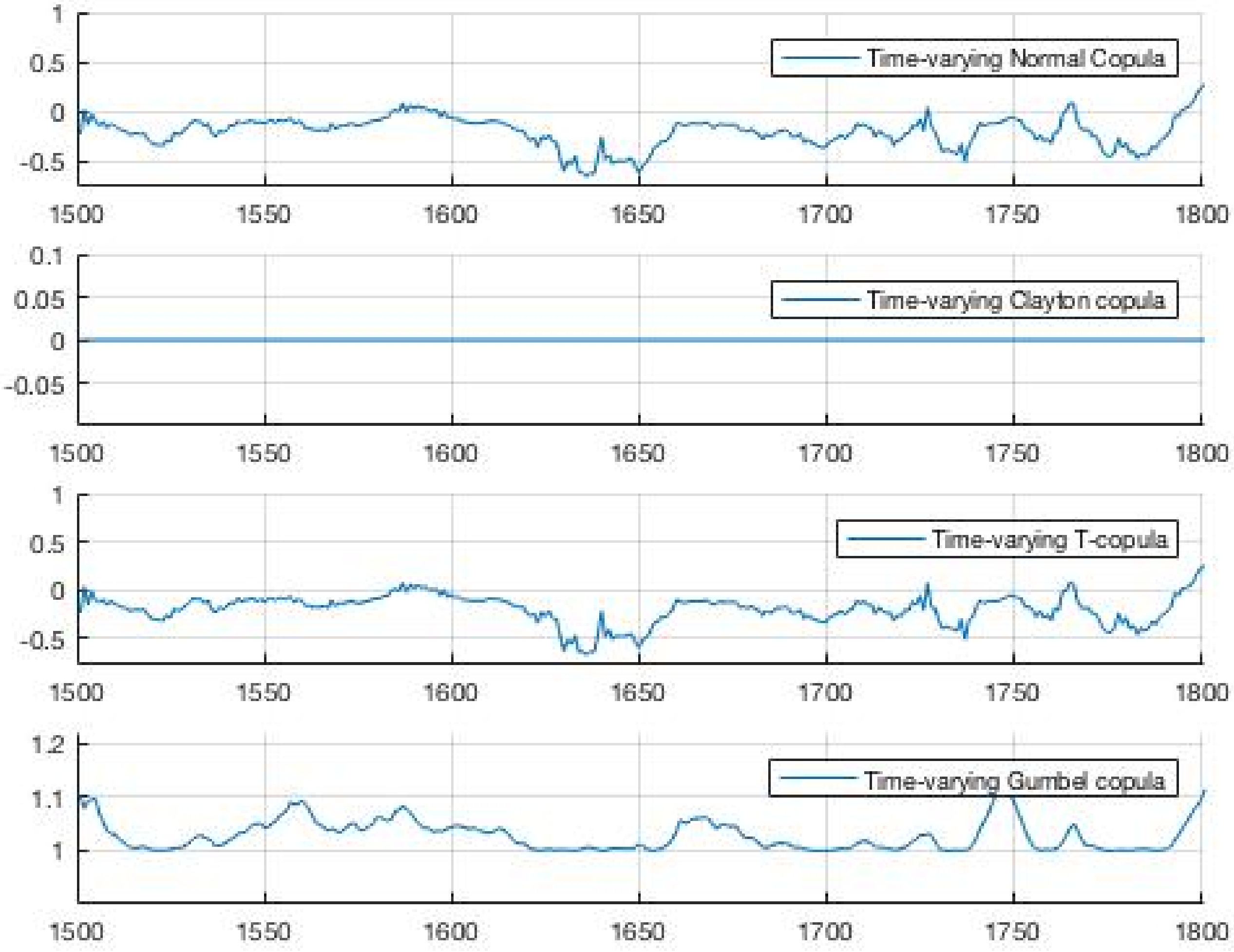

Figure 11: Temperatures Büntgen et al. (2006) War fatality

A2. Precipitations impact on social disturbances, war and war fatality

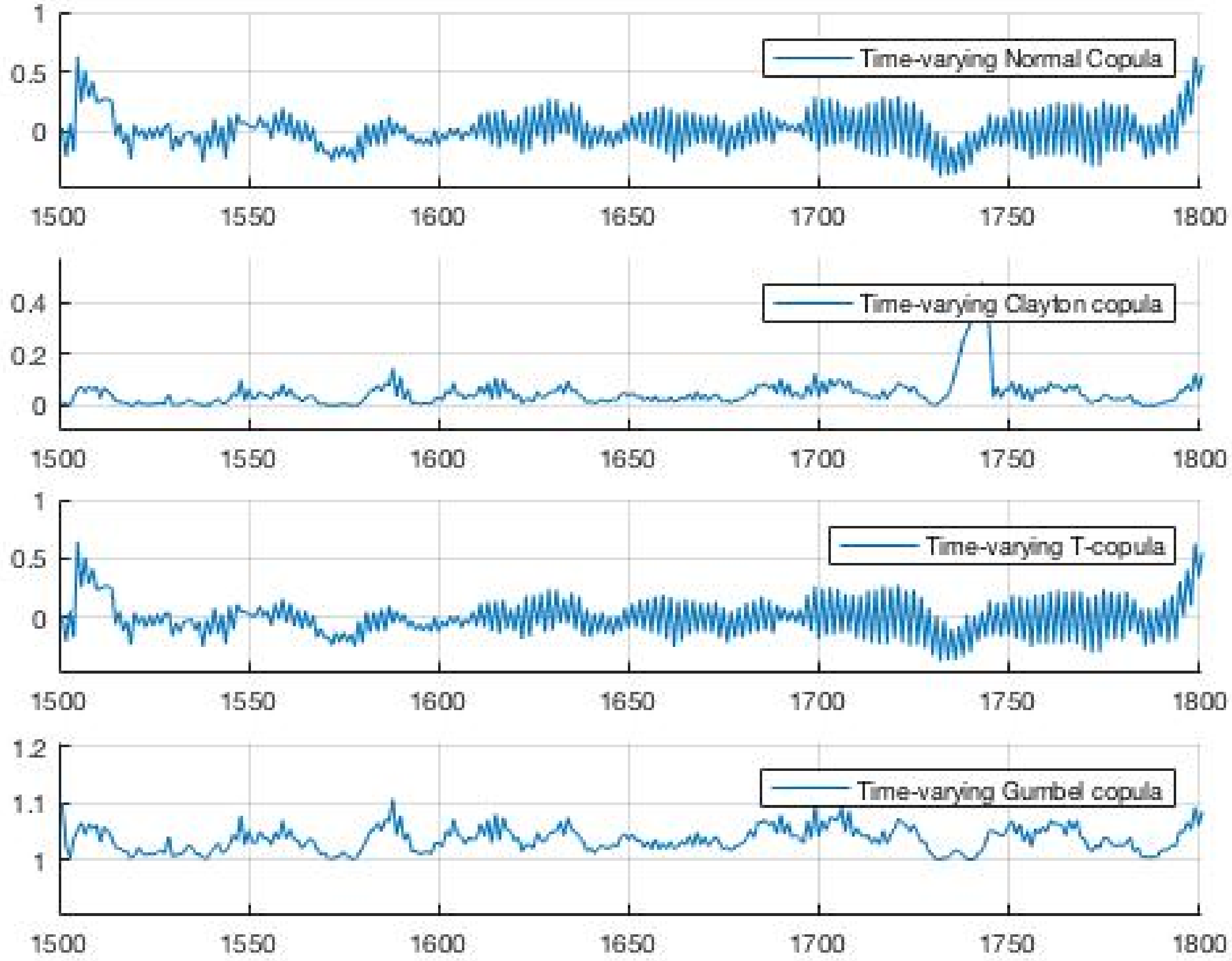

Figure 12: Precipitations Social Disturbances

A3. ENSO and NAO impact on social disturbances, war and war fatalities

A4. Temperaturs, ENSO and NAO impact on grain prices

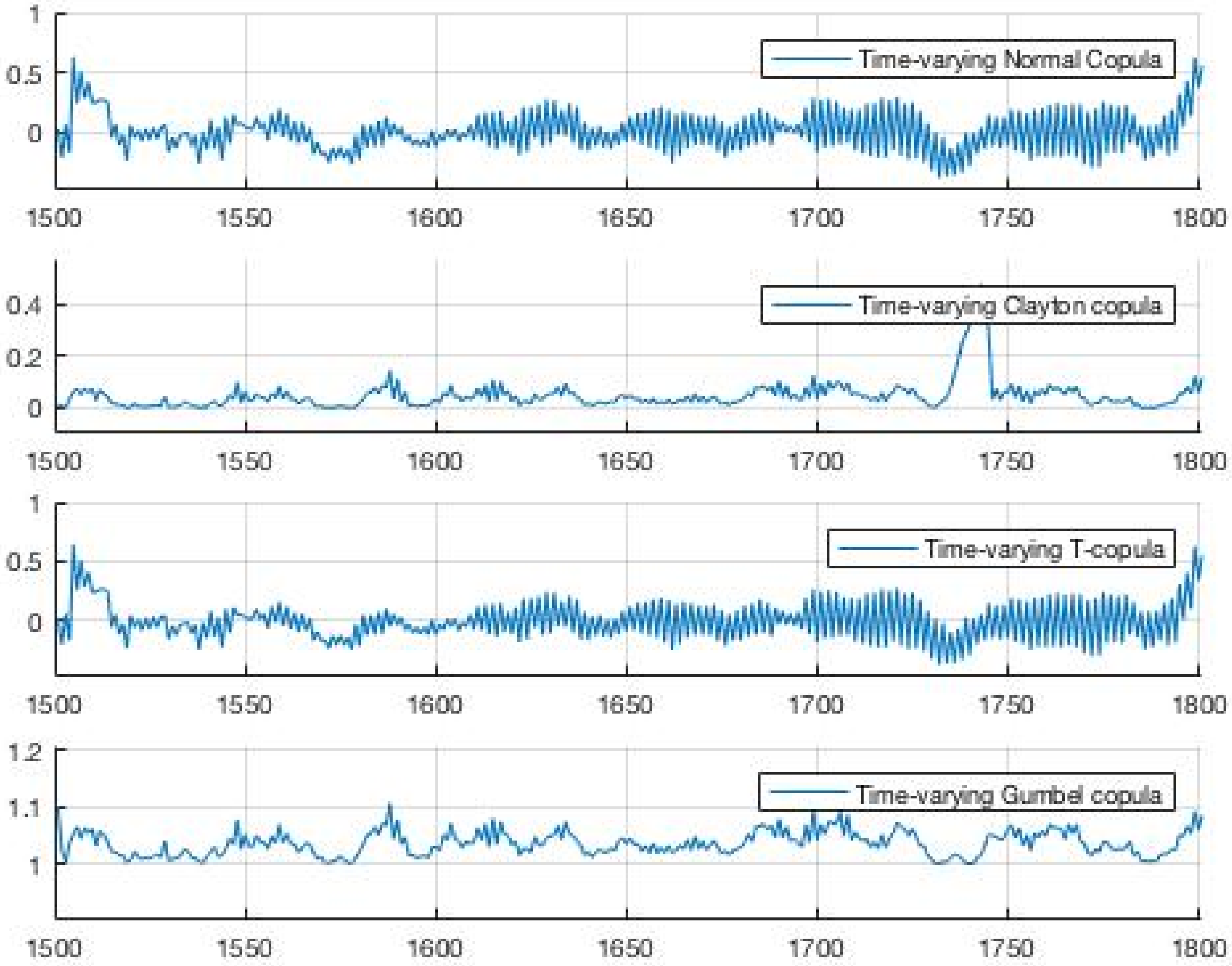

Figure 13: Precipitations War

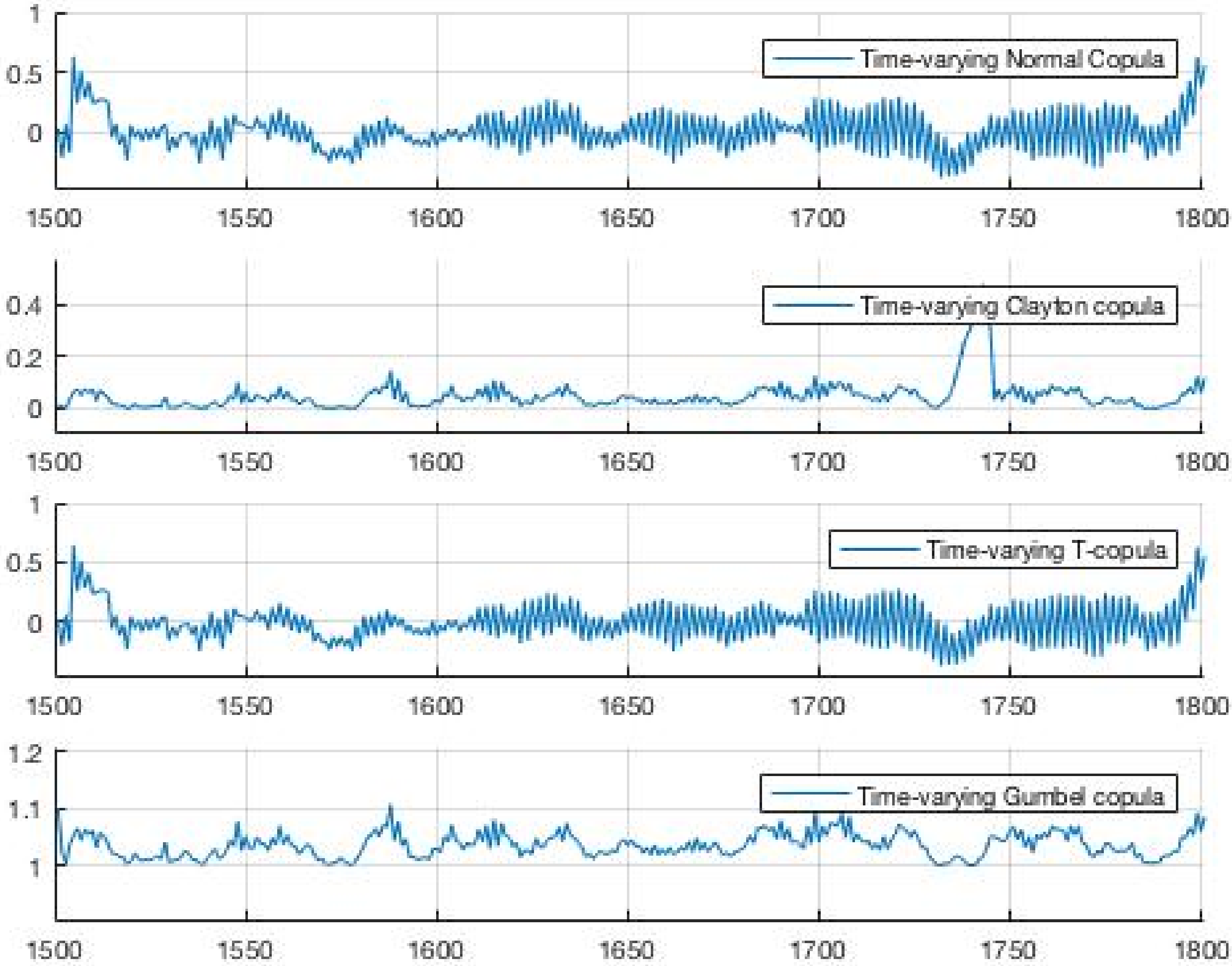

Figure 14: Precipitations War Fatalities

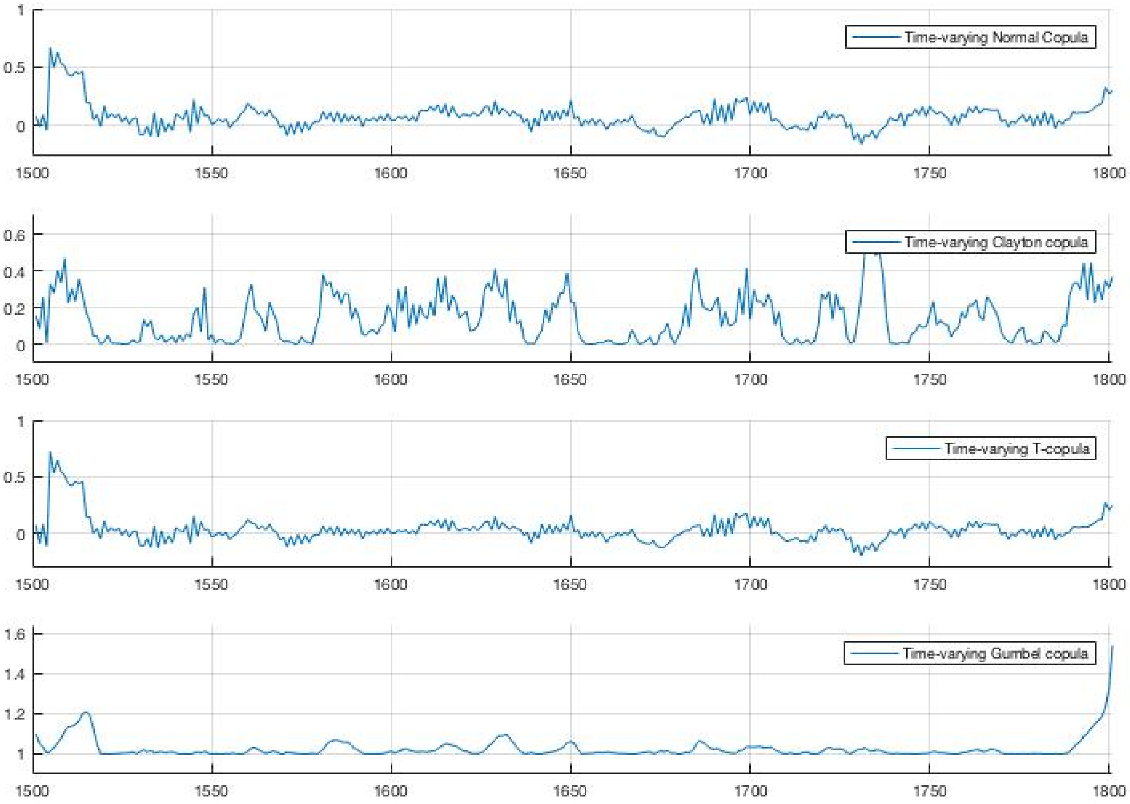

Figure 15: Precipitations AMJ Social Disturbances

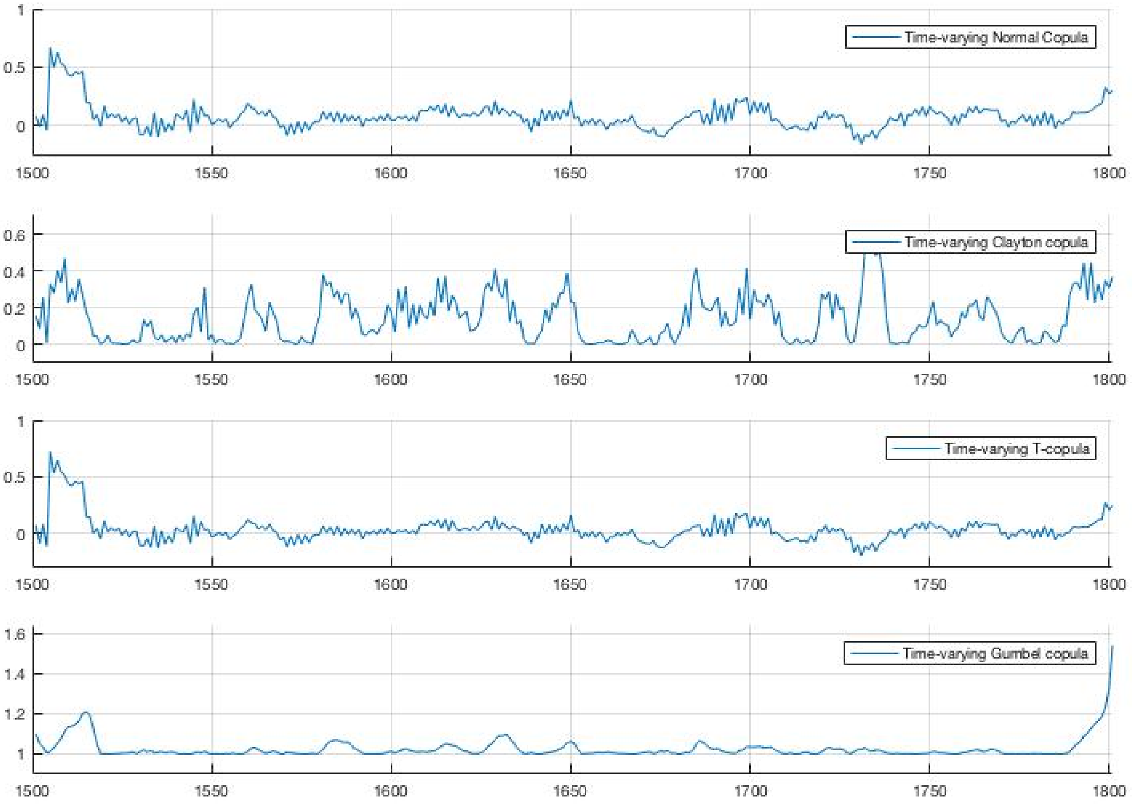

Figure 16: Precipitations AMJ War

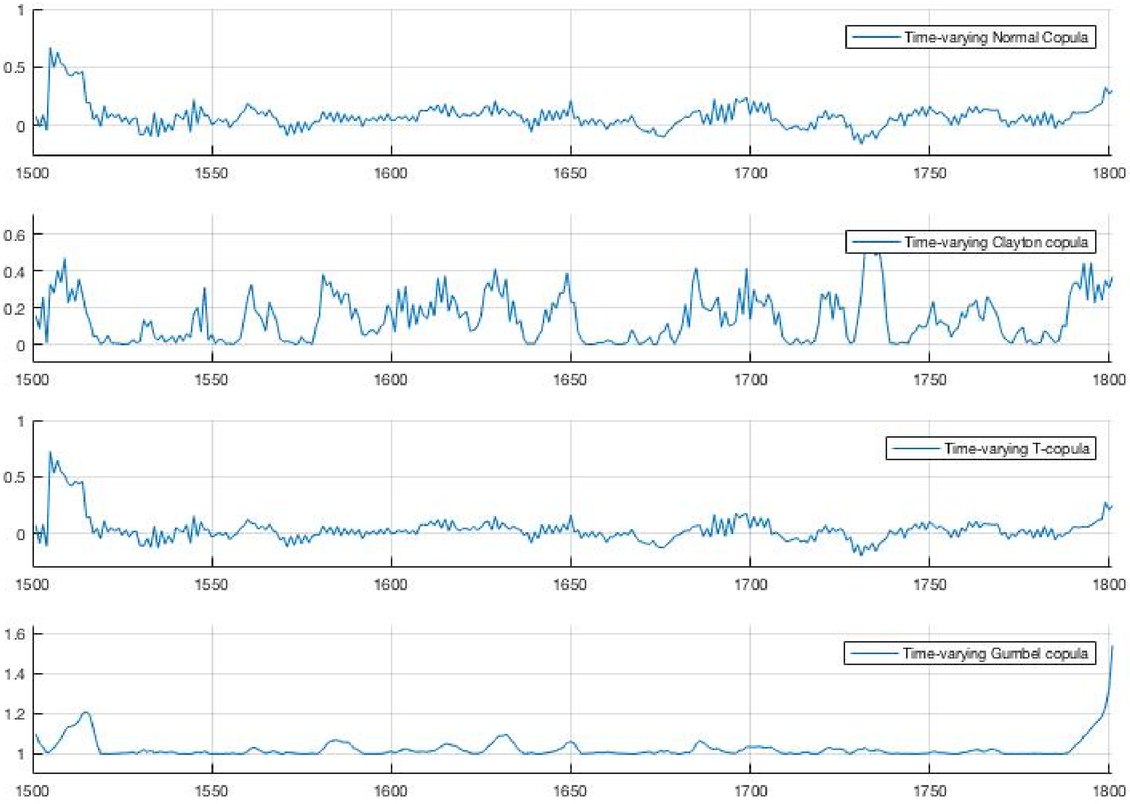

Figure 17: Precipitations AMJ War Fatalities

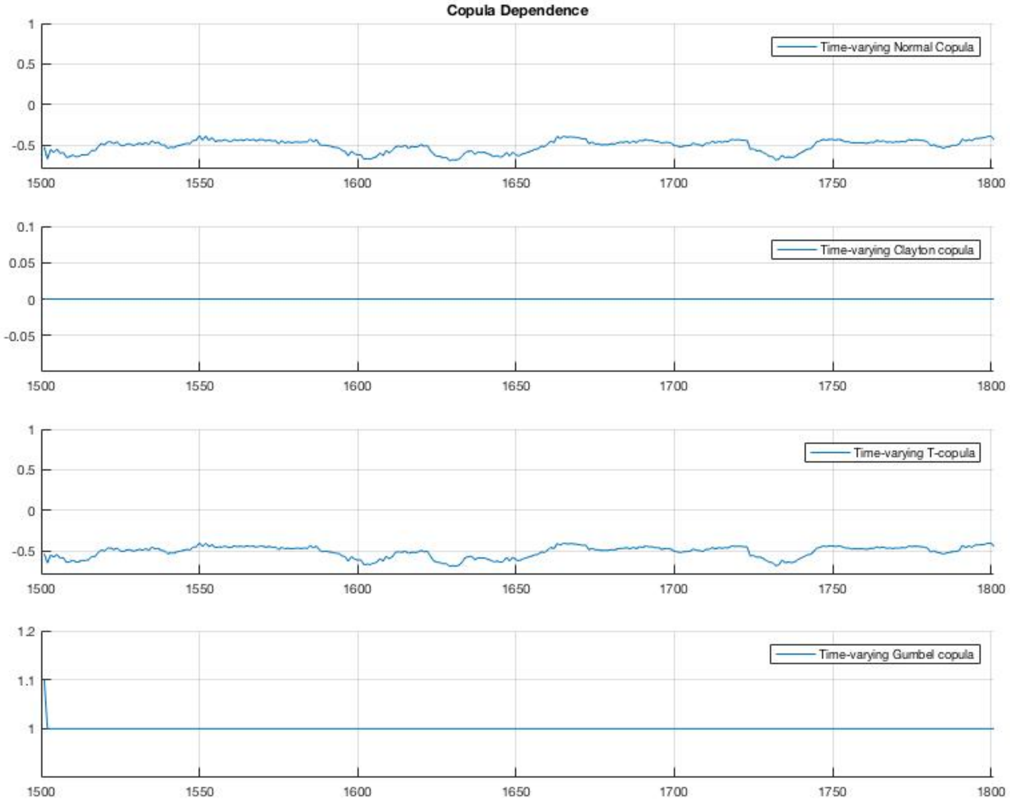

Figure 18: Temperatures EUR_TEMP and grain prices

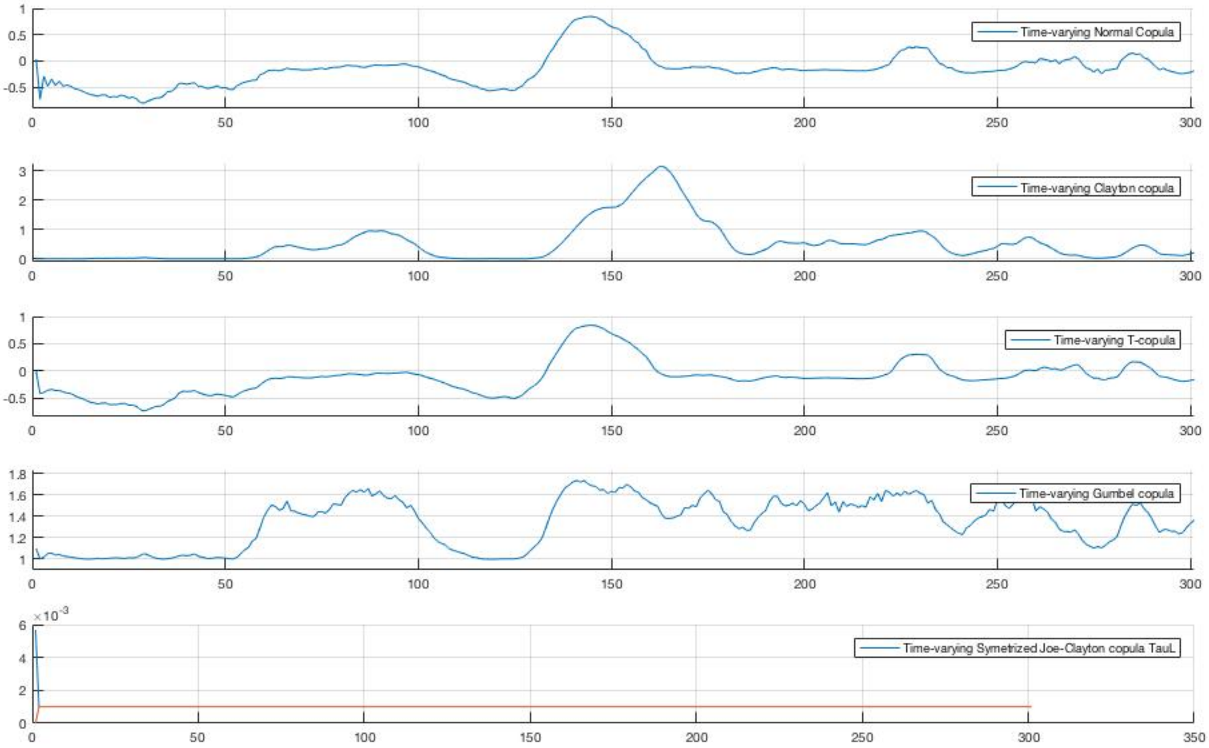

Figure 19: NAO and grain prices

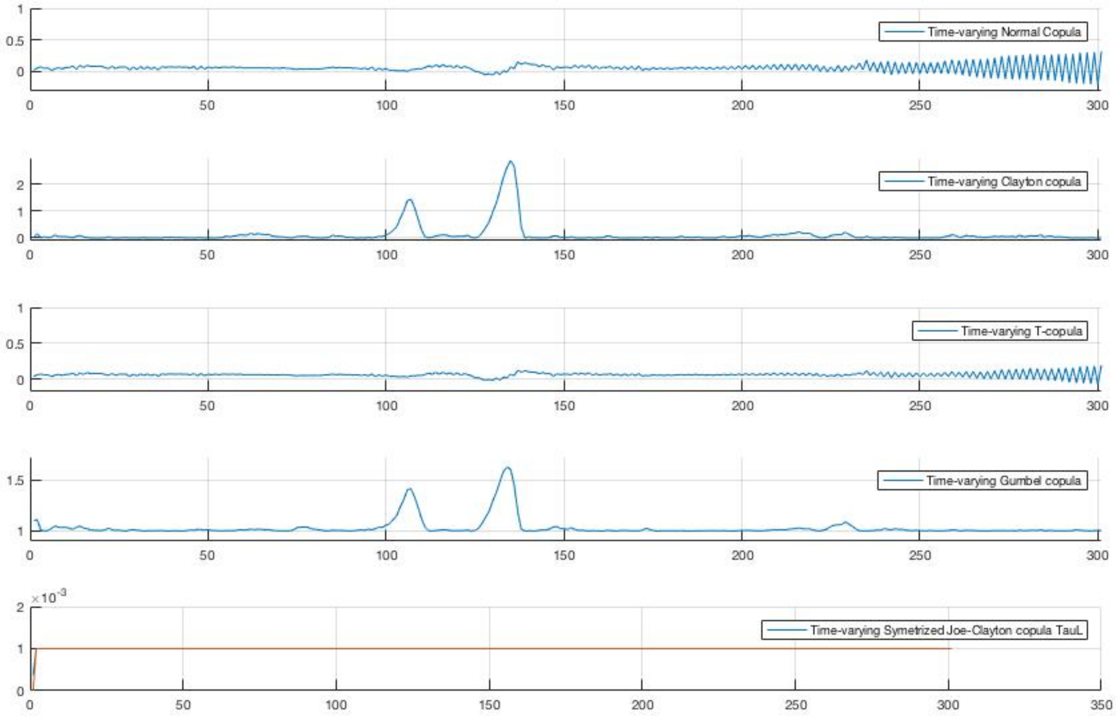

Figure 20: ENSO and grain prices