Climate Variability and Human Migration in the Netherlands, 1865-1937

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Abstract

Human migration is frequently cited as a potential social outcome of climate change and variability, and the effects are often presumed to have been stronger in the past. Yet, few studies of the historical past have tested the relationship between climate and migration directly. In addition, recent studies that link demographic and climate data are not consistent with Malthusian narratives of displacement responses. Using longitudinal individual-level demographic data from the Historical Sample of the Netherlands (HSN) from 1865-1937 and precipitation, temperature, and economic data from the Netherlands that cover the same period, we examine the effects of climate variability on migration. We employ multinomial discrete-time event history models to test multiple key hypotheses about the climatic effects of migration in this context, including whether climate variability increased migration, and whether the strength of these effects declined over the study period as the Netherlands modernized and developed.

Introduction

Climate and Migration

Human migration and involuntary displacement are frequently identified as likely social outcomes of climate change and variability (Black et al. 2011). A small number of recent studies have linked population and climate data to directly test these effects (Dillon et al. 2011; Fussell et al. 2010; Gray & Mueller 2012a & 2012b), with results that are not consistent with common Malthusian narratives of large-scale, long-term displacement (e.g., Myers 2002). These effects are often presumed to have been even stronger in the past, and climate variability is frequently invoked to explain historical population movements (Eriksson et al. 2012; Zhang et al. 2011). To date, however, few studies of the historical past have directly tested the effects of climate variability on human migration, in part due to data limitations (for an exception see Gutmann et al. 2005). To address this issue, we combine historical climate data with a unique dataset capturing the migration of 24,826 individuals in the Netherlands spanning the period 1865-1937. This allows for the estimation of a discrete-time event history model of migration as influenced by climatic, social and economic variables. This work responds to calls for additional quantitative studies of climate and migration (Gemenne 2011), and as well as calls for research on the vulnerability of past societies to climate variation (Pfister 2010).

Migration in 19th and early 20th century Europe: social and economic variation

The study of migration in the past is often hampered by data limitations, as large datasets with individual data on the timing and location of moves are rare. Yet, at times it is possible to reconstruct migration history in the past through the use of historical census, population register, or family reconstitution data. Large-scale studies have examined aggregate migration trends over time while individual-level studies have typically been limited to small areas. Both individual and aggregate studies of human migration have provided insight into some of the important social and economic predictors of mobility in the past, including urbanization, marriage patterns, age, gender, occupation, and household composition. Unlike many previous studies, the Historical Sample of the Netherlands (HSN) allows for individual-level analyses that cover the whole of the Netherlands and include both time-varying and static information on many potential predictors of migration.

Studies of migration in preindustrial Europe have revealed that cities drew migrants from the surrounding countryside (Landers 1993) and migration contributed to growth of urban centers in the 19th and 20th centuries as rural workers were drawn to new opportunities in industrial centers. It is often posited that the primary motivations for migration were economic (Whyte 2008), with individuals moving to seek upward socioeconomic mobility (Long 2005) or as a coping strategy during times of hardship (Kok, Mandemakers & Wals 2005). Temporary labor migration was also common (Kok 1997), whether as part of an age-related pattern of life cycle service (Kussmaul 1981) or seasonal employment (Silvestre 2007).

Despite the strong association between economic motivations and migration, it is also important to understand mobility within the context of individual life events such as marriage (Pooley and D'Cruze 1994). In Northwest Europe, including the Netherlands, marriage was primarily neo-local, meaning that both the bride and groom would move to establish a separate, independent household at the time of marriage (Hajnal 1982). Indeed, distances between the birthplaces of spouses have been used to reconstruct Dutch marriage markets (Ekamper, van Poppel & Mandemakers 2011). Gender also shapes migration patterns, as men and women may undertake moves at different times and for different reasons. For instance, men may be more invested in long-distance labor migration (Brettell 1986) while women may be drawn to domestic work in cities (Bras 2003). Family and household composition also influence migration decisions, as they are an important determinant of household strategies and economic fortunes. For example, the presence and activities of siblings has been shown to shape migration behavior in Belgium and the Netherlands (Bras and Neven 2007).

Climate, agriculture, and economy

Climate has been linked to economic crises in the past (Zhang et al. 2011). One of the ways climate affects the pre-modern economy is through the agricultural sector. Grain prices are closely linked to climatic conditions, although this relationship weakens as global markets develop (Holopainen, Rickard & Helama 2012). Grain prices, in turn, have been used as proxies for short-term economic stress, which has been shown to affect a variety of demographic outcomes, including mortality and fertility (Bengtsson, Campbell & Lee 2004; Tsuya et al. 2010; Allen, Bengtsson & Dribe 2005). Other climatic events, such as storms and flooding, may disrupt economic activity in addition to decreasing agricultural output. The Netherlands specifically was particularly vulnerable to flooding (de Moel et al. 2011) but also experienced significant droughts over the past century (Beersma & Buishand 2004).

The case of the Netherlands in the late 19th and early 20th centuries

The first half of the nineteenth century was a time of economic expansion and prosperity for Dutch farmers. Dairy farming grew and dairy products became an important export. Agricultural improvements and land reclamation increased agricultural productivity, which rivaled parts of England (Van Zanden 1994). Despite the Netherlands’s status as one of the most urbanized European countries of the time, agriculture remained the largest single sector in the economy, with rye as the most important staple grain (De Vries and Van Der Woude 1997). This period of growth ended with the international agriculture crisis of 1878-1895, created by competition from imports from the United States and Canada (Bieleman 2010). The crisis affected the Netherlands by decreasing grain prices and contributed to the accelerated development of modern agricultural practices, such as mechanization and the adoption of new fertilizers (Van Zanden 1994). Aside from international competition, important risks to Dutch agriculture included flooding and soil subsidence. While some specialization in the agricultural sector was occurring, especially in dairy and export gardening, the majority of agricultural output relied on unspecialized household producers, although farm sizes began to increase by the end of the study period.

The nineteenth century Dutch economy was among the most advanced in Europe. Although agriculture was the largest sector, the Dutch economy was more diversified than that of its neighbors. Industrialization occurred later than in Britain, placing the Netherlands in the rare state of possessing an advanced and growing economy before widespread industrial production, a situation that some attribute to the development of Dutch mercantile capitalism (De Vries & Van Der Woude 1997). It has been argued that despite an advanced economy, adjustment to climate variability was not always possible, particularly in the short-run (De Vries & Van Der Woude 1997). However, as transportation networks improved around the turn of the century, the importance of local demand in determining economic growth declined (Van Zanden 1994).

During the study period, 1865-1937, urbanization increased and rural labor became less important, especially for women as life cycle and agricultural service became less common (Kok 1997; Bras 2003). The Dutch population grew in this period as mortality decline outstripped fertility decline. The twin pressures of population growth and agricultural crisis drove rural out-migration from the late 1870s on, whereas before this time, inter-provincial migration was rare (Wintle 2000). Studies of Dutch migration in the late nineteenth and early twentieth century demonstrate that youth migration was common, especially among the unmarried, even while life cycle service declined (Adams, Kasakoff, & Kok 2002). Other work shows that migration in the

Netherlands was not linked to social mobility as measured by occupational status. Instead, short-term, short-distance moves were an economic coping strategy, especially among poorer urban dwellers (Kok, Mandemakers & Wals 2005). Long-distance moves, in contrast, did not appear to be connected with economic deprivation. In this context of changing economic, demographic, and social contexts, migration responded to both individual and aggregate circumstances. Climate variability contributes to individual, household, and national economic prospects, as it affects agricultural output, food prices, and labor market conditions, but to date its role in migration during this period remains unclear.

Malthusian narratives, historical demography, and climate

In discussions of the relationships between climate variability and human migration in the modern world, Malthusian narratives of "climate refugees" are common and assume that these movements will be large-scale, long-distance, permanent, and concentrated among the poor (Myers 2002; Warner et al. 2009). However, contrary to these common assumptions, recent studies suggest that climate-linked movements are likely to be predominantly short-distance and temporary, and that long-distance migration can at times be reduced by climate shocks (Gray & Mueller 2012a & 2012b). These effects are consistent with theoretical perspectives on migration and climate adaptation that emphasize the many possibilities for *in situ* adaption and the many social and economic barriers to migration in low-resource settings (Gray & Mueller 2012b).

Much like the climate-migration literature, many studies of historical populations use Malthusian perspectives as a starting point. Work with aggregate economic (price or wage), mortality, and fertility data explore when and where the positive and preventative checks operated in the past. Industrialization is often viewed as the breaking point between a

Malthusian past and the period of modern economic growth and population expansion (Wrigley & Schofield 1983; Goldstone 1986), although the precise timing of the transition out of Malthusian homeostasis has been called into question (Clark 2005; Nicolini 2007).

However, the Malthusian view of preindustrial and industrializing populations does not receive unanimous support. Some studies have failed to find consistent evidence for Malthusian relationships among living standards and vital rates from pre-modern Europe (Weir 1984; Lee & Anderson 2002; Crafts & Mills 2009). Rather, it appears that Malthusian relationships may vary by the specific mechanisms, length of period, and context examined (Reher & Ortega 2000). Studies using individual-level data have also added nuance to the Malthusian paradigm. For example, work from the EurAsia Project challenges claims that non-western populations were more subject to exogenous pressure and present a picture of complex demographic responses to short-term economic stress driven, in part, by human agency (Bengtsson, Campbell & Lee 2004; Tsuya et al. 2010).

Despite the strong interest in the relationships between historical populations and the economy, few studies have used statistical methods to link migration responses to climate variation in the past. A notable exception is a study of migration and environment in the US Great Plains that demonstrates that the relationships between the environment and migration at the county level can change and become "less Malthusian" over time (Gutmann et al. 2005). We significantly extend that study through the use of a large sample of individual-level data, and we do so over a 70 period in which the Netherlands was experiencing dramatic demographic and economic change.

Data

The Historical Sample of the Netherlands

The Historical Sample of the Netherlands (HSN)[1] is a random sample (0.25-0.75%, depending on birth cohort) of all people born in the Netherlands between 1812 and 1922 (Mandemakers 2002). There is slight oversampling in urban areas, such as Utrecht (Mandemakers 2000). A total of 78,105 individuals, identified in birth records, are included in the database. From this sample of births, 37,137 life courses have been reconstructed. Standardized civil registration of births, deaths, and marriages in the Netherlands began in 1812. While the exact information varies by type of certificate, civil records typically include the name, age, occupation, literacy (can sign or not), place of birth, and marital status of individuals, as well as information on their spouse, parents, and witnesses. These certificates have been linked together to provide both static (birth date) and dynamic (marital status, occupation, place of residence) information. The state of data preservation in the Netherlands is excellent, as two copies of all certificates were made, one for local (municipal) officials and one for the province. Thus, nearly every civil record of birth, death, or marriage filed in the Netherlands remains available to researchers.

In addition to information gathered from certificates of birth, death, and marriage, the HSN has also collected, standardized, and linked all instances in which an individual was found in a population register, making it possible to draw upon all of these sources to reconstruct the life history of an individual. Population registers, begun in the Netherlands in 1850, are continuous records of households (and by the 1930s, individuals) and are the source of the dynamic data used in this study. Household (or population) registers record relationship to the household head, date and place of birth, sex, marital status, occupation, literacy, and religion. The date of entry and exit into the municipality is recorded, and all changes to the household are

[1]Historical Sample of the Netherlands (HSN) Data Set Life Courses Release 2010.01.

updated as they occur, usually within a month. Typically, these updates are dated, but in some instances the timing of the event must be inferred through the order of events or by crosschecking with vital registers. For example, if a household member died, their entry would be crossed out of the register and a note would record the date of death. If an individual moved out of the household, their entry would be crossed out and a note would detail when they left and sometimes the destination. New household members were added to the end of the household list, with notes about when and how they came to be in the household. Comparable systems of household registration were rare in the past (Mandemakers 2002) but are a valuable source of demographic data, as they combined many of the characteristics of vital registration (timing of events) and census data (household location and composition) in a longitudinal form, yet did not replace these types of recording-keeping. In most regions, a household register began during a census year and was updated until the next census year, after which the information was transferred to a new register book.

Household registers have several advantages over linked birth, death, and marriage records and linked census micro-data (see Campbell 2004 for a comparison of historical demographic data types). First, the continuous nature of population registers allows for more precise dating of events, such as entry and exit from a household, which improves data analysis, including the estimation of event-history models, which must be interval-censored in the case of linked decennial censuses. Continuous population registers also provide more information about the changing nature of household composition, much of which could not otherwise be observed between census years. Finally, population registers give some indication about the nature of entries and exits from the household. Thus, it is possible to know whether an individual exited the household because of death, marriage, or migration, while with linked census records, these distinctions may be inferred in only the best cases.

The population registers and civil records included in the HSN allow researchers to track individuals over the life course. With detailed information on moves into and out of households, this dataset is well suited to the study of migration in the past. In cases when the individual moved within the Netherlands, HSN researchers have found their subsequent entries in the population registers. Thus, it is possible to track the distance and the nature (rural-urban, etc) of the move. If the individual leaves the Netherlands, it is typically noted in the register. In addition, the HSN database provides time-varying information on covariates relevant to the study of migration including occupation, marital status, fertility, and household composition.

Climate Data

To place these population movements in their environmental and economic contexts, time-varying data on temperature, precipitation, flooding, grain prices, and economic activity were derived from various sources. Monthly station data on precipitation and mean temperature, from the cities of Hoofddorp and De Bilt respectively, are available from the Royal Netherlands Meteorological Institute for the study period and dating back to 1900 (KNMI 2013). These data were aggregated into total annual rainfall and mean annual temperature. Daily data on water levels for the city of Arnhem are available from the Dutch Ministry of Infrastructure and the Environment for the study period and dating back to 1900 (Rijkswaterstaat 2013). These data were aggregated to the annual scale by deriving the maximum water level in each year, capturing both flooding and persistent low flows due to upstream drought. Because these data are each available for only one location, they capture national conditions rather than site-specific conditions. To account for this temporal clustering, we allow an underlying nonlinear time trend and cluster the standard errors at the year level as described below. The time series of these three variables (averaged over years *t* to *t*-4) along with the total rate of migration (short, long and international moves) are displayed in Figure 1.

Annual data from 1800-1913 on the price of rye, the size of the agricultural economy, and the size of the national economy were extracted from the historical estimates of Smits et al. (2000). The rye price is negatively correlated with temperature over this interval, and the agricultural and total GDPs are negatively correlated with the level of flooding (Table 1). To estimate the climatic component of these variables for the study period, we first used OLS regression to separately predict the rye price, agricultural GDP and national GDP as a function of current and lagged climate variables for the period 1800-1913, taking advantage of the longer time series available for all of these variables (Appendix 1). After excluding non-significant sets of variables, this revealed the rye price to be a nonlinear function of temperature, precipitation and the interaction between the two ($R^2 = 0.48$), and the agricultural and total GDP to be a nonlinear function of temperature and flooding ($R^2 = 0.42, 0.48$). In a second step we used these equations to predict the climate-driven component of these three economic variables for our study period (1865-1937). We refer to these values as the rye index, agricultural index and economic index, and we include them as alternative specifications of the climate variables as described below.

Analysis

Person-year Dataset

To investigate the influence of climate variation on migration, the HSN data were used to create a person-year dataset on both migrants and non-migrants. The dataset contains time-varying and time-invariant variables at the individual, household, municipality, and national levels (Table 2). Each case represents a year in the life of a person at risk for migration. Non-climate predictors are lagged by one year to avoid endogeneity with the migration decision. Following preliminary analyses (described below), climate variables were averaged over a five-year period (*t* to *t*-4) to allow the potential for various time lags. Individuals age 15 and over are considered to be at risk for migration. Individuals that are no longer at risk for migration, such as those who have died, are lost to follow-up, or have moved to a different system of registration,[2] are right-censored. After exclusions for age and missing person-years, the dataset comprises 24,826 individuals at risk for migration during the study period, totaling 510,876 person-years of observation.

Migration is a change of residence, as noted in household registers, and is defined as four mutually exclusive outcomes at the person-year scale. Short moves (N=13,140) are moves between municipalities, but within provinces. Long moves (N=7,478) are moves between provinces. International moves (N=670) occur when an individual is noted in the register to have left the Netherlands for a foreign location. Attrition (N=5,576) occurs when an individual cannot be located in historical records, but without a corresponding change in registration system. Non-migration (N=484,012 person-years) includes individuals with a constant place of residence and those who moved, but remained within the same municipality.

Statistical Models

[2]The models specified in this paper include household-level variables. When individuals are transferred to a system of registration that does not include household information, such as personal rather than household cards, they are right-censored.

The data are analyzed using a multinomial, discrete-time event history model. This model is appropriate to examine a mutually exclusive set of competing risks using discrete measurements of time (Allison 1984). Multinomial outcomes include short moves (within provinces), long moves (between provinces), international moves, and attrition, while the reference category is non-migration. The log-odds of experiencing a migration event of type *r* relative to no migration (event *s*) are given by

$$\log\left(\frac{\pi_{rit}}{\pi_{sit}}\right) = \beta_r X_{it-1} + t + t^2$$

where π_{rit} are the odds of migration type *r* for individual *i* in year *t*; π_{sit} are the odds of no migration; X_{it-1} is a vector of predictor variables for individual *i* in year *t-1*; β_r is a vector of parameters for the effects of the independent variables on migration type *r*; and the migration types, *r*, are short moves, long moves, international moves, and attrition. The parameters of this model are presented in exponentiated form (e^{β}) as odds ratios. The odds ratios can be interpreted as the multiplicative effects of a one-unit increase in the predictor variable on the odds of that type of migration relative to the odds of no migration. All models are clustered on the year (Huber 1981) and include a non-linear (quadratic) time trend, accounting for shared temporal context. We extend this model by testing alternative specifications of the climate variables and estimating separate models by sex, age groups, residence in municipality of birth, occupational groups, rural/urban location, region, and period. Control variables include social and economic factors that may influence migration behavior, including sex, age, marital status, household composition, occupation, and place of residence.

Results

The results of the event history analysis are presented in Tables 3 and 4. Table 3 presents the main model and control variables and Table 4 presents alternate specifications of climate measurements and models estimated separately by selected sub-groups (controls not shown). We first discuss the climate variables in both the main model and alternate specifications. Then, we briefly discuss the results for the control variables.

Climate variation is an important predictor of migration, with temperature and flooding representing the best specifications using a joint F-test (Table 5, Models 1, 3). Mean temperature in the preceding 5 years is a negative, significant predictor of short-distance moves, with the odds of these moves decreasing by 25% with each 1 C° increase in the five-year temperature (Table 3; Table 4, Model 1). Single-year specifications of temperature (Table 4, Model 7), also suggest that a five-year average is optimal. A non-linear specification of temperature (Table 4, Model 8) is compatible with the results of the five-year average: short moves are associated with lower temperatures. Other climate measurements, including flooding, rainfall, and the economic indices also had jointly significant effects on migration (Table 4, Models 2-6). Long- and short-distance migration increase with flooding and rainfall, although the odds-ratio does not reach statistical significance for short moves in the rainfall model. International moves decrease with flooding. When the climate-predicted price of rye is high, short and long moves increase. Higher agricultural and economic indices are associated with fewer short and long moves and more international moves.

Examining various subpopulations separately reveals that flooding has stronger influence on the migration of rural dwellers than urban dwellers and temperature is a significant predictor of long moves among rural dwellers but not urban dwellers (Table 4, Models 33-4, 17-8). There are also differences in the effects of flooding and temperature in two periods, 1865-1920 and

1921-1937 (Table 4, Models 21-2 and 37-8). Flooding is a more important predictor of migration in the later period, while the effects of temperature on migration vary by type of move in each period. Other alternative specifications show only slight differences between sub-populations in migration responses to climate variation.

Attrition is associated with temperature, flooding, and the agricultural index. The determinants of attrition appear most similar to the determinants of international migration (Table 4, Models 1-6). This suggests that some of the attrition represents migration where the migrants are lost to follow-up. The similarities between attrition and migration are a limitation of this study.

With respect to the control variables (Table 3), women are more likely than men to become short-distance movers, but are less likely to undertake long-distance or international moves. Age and marital status are important predictors of migration. The young and unmarried are more likely to make all types of moves. Individuals in households headed by professional and white-collar workers are more likely to migrate over long distances than blue-collar and farm workers. Urban dwellers make more long-distance and international moves than rural dwellers, but fewer short-distance moves.

Discussion

In summary, the results reveal that short moves decrease with temperature, and short and long moves increase with flooding while international moves decrease with flooding. Similar patterns are found for the other climate variables. Cold temperatures are associated with higher rye prices, presumably by lowering yields (Appendix 1). This induces short-distance migration, likely because living standards are under downward pressure. Flooding increases short- and long-distance migration, as it may disrupt economic activity, reduce agricultural GDP, and place downward pressure on living standards. However, international migration, which is costly, decreases with flooding. These findings are consistent with a conventional Malthusian narrative of migration responses to climate variation, but with some complexities noted in other studies. In the case of temperature, short-distance moves are more influenced by climate variability than long distance moves, a finding consistent with work by Gray et al. in contemporary Bangladesh (Gray & Mueller 2012b). Costly moves, in this case, international migration, decrease after environmental shocks (in this case flooding), which as also been observed in contemporary Ecuador and Ethiopia (Gray & Mueller 2012a; Gray & Bilsborrow 2013).

The findings for urban and rural dwellers and occupational categories are also consistent with a Malthusian perspective. The migration of rural dwellers, whose economic prospects are more closely linked to agricultural output, is more strongly affected by climate than that of urban dwellers. The differences in the influence of climate the two periods also conform to the expectation that climate may become a less important predictor of migration over time as agricultural markets expand and local conditions exert less influence on the price of food. Flooding, in contrast, can disrupt economic activity regardless of the size or integration of markets. Indeed, we find that the effects of flooding are more important in the later period while the effects of temperature are mixed, with the direction of the temperature effect on international moves changing from negative to positive in the two periods. Put another way, cold conditions restrict costly international migration in the early period, but this effect weakens over time.

This study is consistent with prior work on predictors of migration in the HSN. The results for the control variables make sense in this social and historical context. For instance, we find that young, unmarried people are more likely to move than entire families or households and professionals are more likely to make long-distance moves than lower status workers are (Adams, Kasakoff, & Kok 2002; Bras 2003; Kok 2004; Kok 1997).

Limitations of this work include the significant association between some climate variables and attrition. The cause of this association is uncertain. This study also does not consider local, within-municipality moves, which are difficult to detect with the available data. These very short moves were common, especially among the poor in urban areas (Kok, Mandemakers, & Wals 2005). Therefore, our focus on moves between municipalities, provinces, and countries overlooks short, within-municipality moves, which may also be responsive to climate variability.

Even in times of population growth, agricultural crisis, and modernization that characterize the study period, not all migration types are not associated with unfavorable climate conditions, but rather only short and within-country moves are affected. Costly international moves, in contrast, are associated with favorable conditions. These results suggest that the ability of households to send migrants, particularly international migrants, can be constrained by resources, and that these constraints are relaxed in times of favorable climates and agricultural plenty. This is particularly true for rural dwellers, who are closely tied to the agricultural economy. This study adds to the growing literature in historical demography that demonstrates variation and complexity in demographic responses to economic stress, especially when comparing population sub-groups and considering change in responses over time. These results are also congruent with recent studies of contemporary populations, which have also found complex and counterintuitive effects of climate on migration (Dillon et al. 2011; Gray & Mueller 2012a & 2012b), and indicate that these patterns extend further into the past than has previously been documented.

Figures and Tables

Figure 1. Migration, rainfall, temperature, and flooding over time.

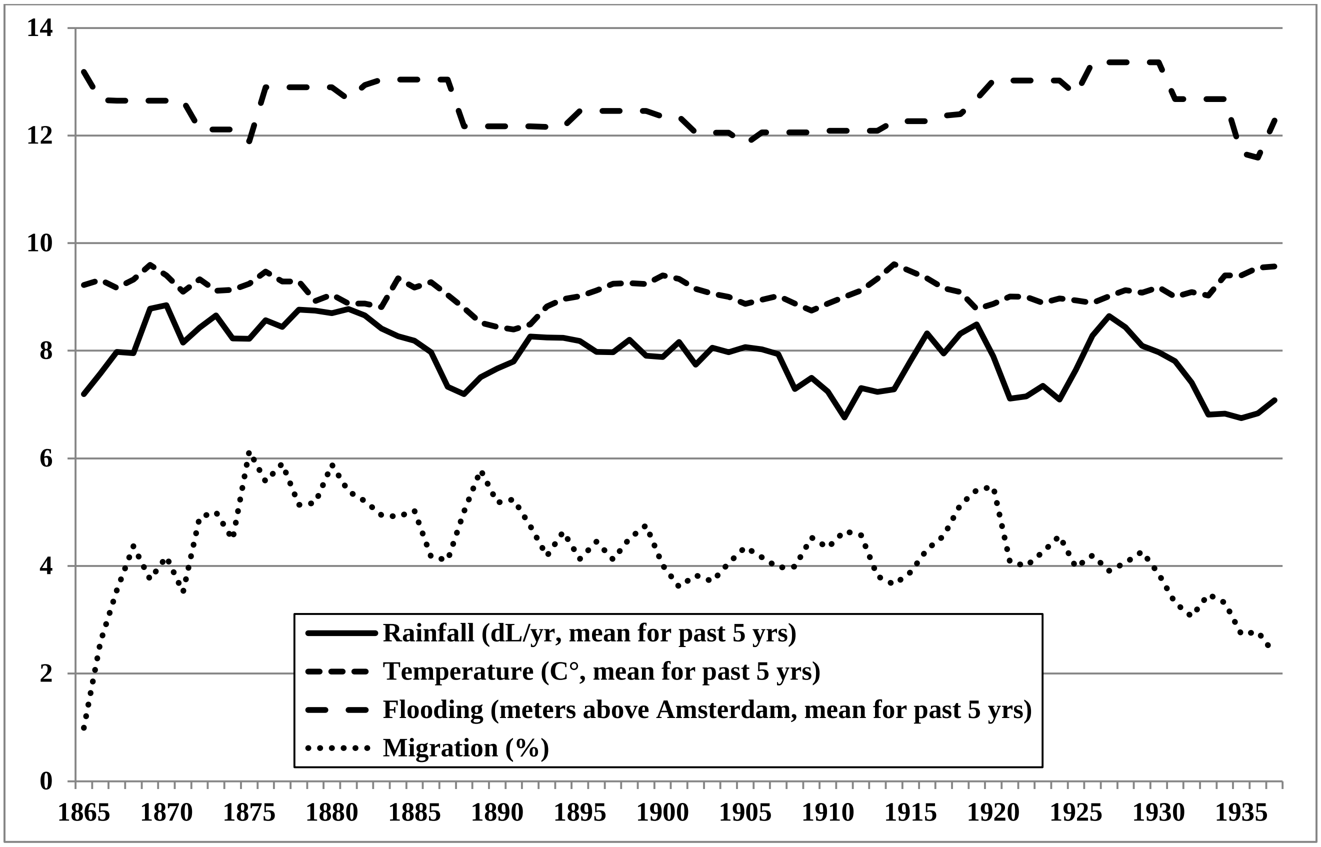

Table 1. Correlations between climate and economic variables.

	Temperature		Rainfall		Flooding		Rye price	Agricultural GDP		National GDP
Temperature	*1.00*									
Rainfall	0.48	***	*1.00*							
Flooding	0.07		0.05		*1.00*					
Rye price	-0.39	***	-0.13		-0.01		*1.00*			
Agricultural GDP	0.12		0.19	+	-0.50	***	0.13	*1.00*		
National GDP	0.05		0.03		-0.63	***	-0.10	0.92	***	*1.00*

N = 114 years

+ $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 2. Descriptive statistics for the person-year dataset.

Variable	Unit	Level	Time-varying	Mean	SD	Min	Max	Notes
Outcome								
Short move	0/1	Indiv	Yes	0.026	0.158	0	1	Different municipality, same province in year t+1
Long move	0/1	Indiv	Yes	0.015	0.120	0	1	Different province in year t+1
International move	0/1	Indiv	Yes	0.001	0.036	0	1	Outside of the Netherlands in year t+1
Attrition	0/1	Indiv	Yes	0.011	0.104	0	1	Missing location in year t+1
Climate variables								
Temperature	C°	Nation	Yes	9.1	0.2	8.4	9.6	Mean monthly temperature over previous 5 years
Rainfall	dm	Nation	Yes	7.7	0.5	6.8	8.8	Mean annual rainfall over previous 5 years
Flooding	m	Nation	Yes	12.5	0.5	11.6	13.4	Maximum flood height over previous 5 years
Rye price index	fl./hl	Nation	Yes	6.0	1.0	3.4	8.2	Rye price predicted by climate variables
Agricultural index	100 mill. fl.	Nation	Yes	2.3	0.2	1.5	2.6	Agricultural GDP predicted by climate variables
Economic index	100 mill. fl.	Nation	Yes	11.7	1.4	5.5	13.9	National GDP predicted by climate variables
Control variables								
Female	0/1	Indiv	No	0.50	0.50	0	1	Reference is male
Age 20-24	0/1	Indiv	Yes	0.19	0.39	0	1	Reference is age 15-19
Age 25-29	0/1	Indiv	Yes	0.16	0.37	0	1	Reference is age 15-19
Age 30-34	0/1	Indiv	Yes	0.14	0.35	0	1	Reference is age 15-19
Age 35-39	0/1	Indiv	Yes	0.12	0.32	0	1	Reference is age 15-19
Age 40-44	0/1	Indiv	Yes	0.10	0.29	0	1	Reference is age 15-19
Age 45-49	0/1	Indiv	Yes	0.07	0.26	0	1	Reference is age 15-19
Married	0/1	Indiv	Yes	0.33	0.47	0	1	Reference is not currently married (including widowed)
Marital status DK	0/1	Indiv	Yes	0.08	0.27	0	1	Reference is not currently married (including widowed)
Child of head	0/1	Indiv	Yes	0.39	0.49	0	1	Reference is household head or spouse
Other relation	0/1	Indiv	Yes	0.05	0.22	0	1	Reference is household head or spouse
Relation to head DK	0/1	Indiv	Yes	0.03	0.17	0	1	Reference is household head or spouse
Child present	0/1	Indiv	Yes	0.38	0.49	0	1	Biological child of this person is present in household
Place of birth	0/1	Indiv	Yes	0.60	0.49	0	1	Resident in municipality of birth
Catholic	0/1	Indiv	Yes	0.33	0.47	0	1	Reference is Protestant
Other religion	0/1	Indiv	Yes	0.07	0.25	0	1	Reference is Protestant
Religion DK	0/1	Indiv	Yes	0.02	0.15	0	1	Reference is Protestant
Female head	0/1	HH	Yes	0.13	0.33	0	1	Reference is male head
Gender of head DK	0/1	HH	Yes	0.00	0.03	0	1	Reference is male head
Age of head	years	HH	Yes	45.1	13.3	1	100	
Age of head DK	0/1	HH	Yes	0.00	0.03	0	1	
Adult males	#	HH	Yes	1.91	1.37	0	21	Males age 15+ in household
Adult females	#	HH	Yes	1.87	1.27	0	21	Females ages 15+ in household
Minors	#	HH	Yes	1.67	1.91	0	13	Males and females ages 0-14 in household
Professional	0/1	HH	Yes	0.06	0.24	0	1	Occupation of head, reference is blue collar
White collar	0/1	HH	Yes	0.17	0.38	0	1	Occupation of head, reference is blue collar
Farm	0/1	HH	Yes	0.18	0.38	0	1	Occupation of head, reference is blue collar
Occupation DK	0/1	HH	Yes	0.06	0.23	0	1	Occupation of head, reference is blue collar
Urban	0/1	Muni	Yes	0.42	0.49	0	1	Reference is rural
Year	NA	Nation	Yes	1913	16	1865	1937	

N = 510,876 person-years

1/0 indicates a dichotomous variable; # indicates a count variable.

DK=Don't know/missing value, Indiv = Individual, HH = Household, Muni=Municipality, Nation=National

Control variables also include indicators for the province of residence, not shown.

Table 3. Results from the multinomial event history model of migration (odds ratios and significance tests).

Predictor	Short move		Long move		International		Attrition	
Temperature	0.75	***	0.87	+	0.72		1.34	*
Female	1.05	*	0.91	***	0.69	***	0.99	
Age 20-24	0.96	+	1.12	**	2.08	***	1.39	***
Age 25-29	0.72	***	0.80	***	2.08	***	1.26	***
Age 30-34	0.41	***	0.45	***	1.41	+	0.93	
Age 35-39	0.24	***	0.26	***	1.90	***	0.65	***
Age 40-44	0.18	***	0.18	***	0.90		0.51	***
Age 45-49	0.14	***	0.12	***	0.90		0.44	***
Married	0.92	**	0.88	***	0.79	*	0.71	***
Marital status DK	1.11	***	1.18	***	1.01		1.22	***
Child of head	0.17	***	0.14	***	1.09		0.48	***
Other relation	0.41	***	0.36	***	1.02		1.01	
Relation to head DK	0.34	***	0.29	***	0.56	+	1.25	**
Child present	0.53	***	0.47	***	0.64	***	0.36	***
Place of birth	0.41	***	0.37	***	0.86	+	0.70	***
Catholic	0.95	*	0.90	**	1.20	*	0.95	
Other religion	0.86	**	1.16	**	1.42	*	0.98	
Religion DK	0.92		0.99		1.19		1.15	
Female head	0.90	***	0.97		1.24	+	1.11	**
Gender of head DK	0.57		0.15	**	1.43		1.26	
Age of head	1.06	***	1.08	***	1.02		1.00	
(Age of head)^2	1.00	***	1.00	***	1.00		1.00	
Age of head DK	2.03	*	2.84	**	0.00	***	1.85	
Adult males	0.94	***	0.93	***	1.04		0.98	*
Adult females	0.94	***	0.96	**	0.89	*	0.94	***
Minors	0.97	**	0.97	***	1.00		1.00	
Professional	0.97		1.84	***	2.15	***	1.24	***
White collar	1.02		1.34	***	0.98		1.00	
Farm	0.97		0.60	***	0.89		0.84	***
Occupation DK	0.90	*	1.23	***	1.58	*	1.07	
Urban	0.47	***	1.25	***	1.28	*	0.81	***
Year	2.19	***	2.31	**	0.88		0.07	***
(Year)^2	1.00	***	1.00	**	1.00		1.00	***

Province indicators included but not shown.

+ $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 4. Results from the multinomial model with alternative specifications (odds ratios and significance tests).

Model	Predictor	Short move		Long move		International		Attrition		Joint test	
1	Temperature	0.75	***	0.87	+	0.72		1.34	*	30.3	***
2	Rainfall	1.06	+	1.17	**	0.77	+	0.94		15.3	**
3	Flooding	1.13	***	1.16	***	0.76	*	0.85	***	22.1	***
4	Rye price index	1.05	*	1.07	***	1.04		0.98		12.4	**
5	Agricultural index	0.86	**	0.80	***	1.40	*	1.15	*	19.8	***
6	Economic index	0.98	+	0.97	**	1.07	*	1.01		15.0	**
7	Temperature, t	0.96		0.94		1.07		1.00		48.4	***
	Temperature, t-1	0.92	*	0.94	+	0.90		1.08	+		
	Temperature, t-2	0.93	**	0.98		0.88		1.08			
	Temperature, t-3	0.94	+	1.00		0.92		1.12	+		
	Temperature, t-4	0.97		1.00		0.96		1.02			
8	Temperature, second quintile	0.90	*	0.99		0.85		0.93		81.4	***
	Temperature, third quintile	0.86	**	1.03		0.72		0.95			
	Temperature, fourth quintile	0.91	+	1.03		0.80		1.00			
	Temperature, fifth quintile	0.78	***	0.88		0.64	+	1.13			
9	Temperature, women only	0.79	***	0.86	*	0.64		1.47	**	17.4	***
10	Temperature, men only	0.71	***	0.89		0.79		1.23		18.6	***
11	Temperature, age<25 only	0.83	*	0.96		0.67		1.27	+	8.7	*
12	Temperature, age>=25 only	0.66	***	0.78	**	0.80		1.42	*	38.4	***
13	Temperature, in birthplace	0.71	***	0.84		0.63	+	1.18		28.3	***
14	Temperature, out of birthplace	0.79	***	0.89		0.89		1.56	**	14.9	**
15	Temperature, blue collar only	0.77	***	0.90		0.67		1.41	*	19.2	***
16	Temperature, other occupations	0.74	***	0.84	*	0.73		1.27		27.2	***
17	Temperature, urban only	0.75	***	0.93		1.05		1.25		16.0	**
18	Temperature, rural only	0.76	***	0.82	*	0.55	+	1.41	*	21.1	***
19	Temperature, western region	0.74	***	0.98		0.80		1.30	*	37.0	***
20	Temperature, rest of country	0.77	*	0.76	**	0.63		1.38	*	14.6	**
21	Temperature, 1865-1920	0.75	***	0.90		0.49	**	1.05		40.5	***
22	Temperature, 1921-1937	0.66	**	0.67	*	4.59	+	3.59	***	13.5	**
23	Flooding, t	1.04	+	1.06	*	0.92		1.02		35.2	**
	Flooding, t-1	1.04	+	1.06	**	0.97		0.96			
	Flooding, t-2	1.04	**	1.04	*	0.93		0.95	+		
	Flooding, t-3	1.05	+	1.06	*	0.87		0.95			
	Flooding, t-4	1.02		1.04	+	1.01		0.95			
24	Flooding, second quintile	1.13	*	1.01		0.91		0.91		57.1	***
	Flooding, third quintile	1.05		1.07		0.64	*	1.00			
	Flooding, fourth quintile	1.21	***	1.20	*	0.50	***	0.68	***		
	Flooding, fifth quintile	1.20	***	1.19	***	0.64	**	0.84	***		
25	Flooding, women only	1.11	**	1.16	***	0.82		0.86	**	22.7	***
26	Flooding, men only	1.16	***	1.14	**	0.73	**	0.84	**	16.8	***
27	Flooding, age<25 only	1.05		1.14	*	0.79		0.83	**	5.4	
28	Flooding, age>=25 only	1.24	***	1.19	***	0.76	+	0.88	*	33.0	***
29	Flooding, in birthplace	1.16	**	1.13	*	0.81		0.88	*	13.4	**
30	Flooding, out of birthplace	1.12	**	1.17	***	0.73	**	0.82	***	23.6	***
31	Flooding, blue collar only	1.11	*	1.22	***	0.88		0.85	**	16.5	***
32	Flooding, other occupations	1.16	***	1.12	***	0.72	*	0.85	**	18.9	***
33	Flooding, urban only	1.09	+	1.11	*	0.76	*	0.88	*	10.5	*
34	Flooding, rural only	1.15	**	1.20	***	0.75		0.83	***	25.1	***
35	Flooding, western region	1.14	***	1.12	**	0.75	*	0.83	***	22.6	***
36	Flooding, rest of country	1.13	**	1.21	***	0.81		0.87	*	18.9	***
37	Flooding, 1865-1920	1.06		1.05		0.70		1.04		3.2	
38	Flooding, 1921-1937	1.18	***	1.23	***	1.00		0.83	*	35.7	***

Models also includes control variables, not shown.

The joint test is a Wald test of the three migration coefficients shown, excluding attrition.

In quartile specifications, the first quartile is the reference category.

+ $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

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References

Adams, J.W., Kasakoff, A., & Kok, J. (2002). Migration over the life course in the XIXth century Netherlands and the American North: A comparative analysis based on genealogies and population registers. Annals of Demographic History, 2, 5-27.

Allen, R. C., Bengtsson, T., & Dribe, M., eds. (2005). *Living Standards In The Past*. Oxford University Press, USA.

Allison, P. (1984). *Event History Analysis*. Thousand Oaks, CA: Sage Publications.

Beersma, J. J., & Buishand, T. A. (2004). Joint probability of precipitation and discharge deficits in the Netherlands. *Water Resources Research*, 40(12): W12508.

Bengtsson, T., Campbell, C., & Lee, J. Z., eds. (2004). *Life Under Pressure: Mortality and Living Standards in Europe and Asia, 1700-1900*. Cambridge: MIT.

Bieleman, J. (2010). *Five Centuries of Farming: A Short History of Dutch Agriculture, 1500-2000* (Vol. 8). Wageningen: Wageningen Academic Pub.

Black, R., Bennett, S., Thomas, S., & Beddington, J. (2011). Climate change: Migration as adaptation. Nature, 478, 447–449.

Bras, H. (2003). Maids to the city: Migration patterns of female domestic servants from the province of Zeeland, the Netherlands (1850-1950). The History of the Family, 8(2), 217-246.

Bras, H., & Neven, M. (2007). The effects of siblings on the migration of women in two rural areas of Belgium and the Netherlands, 1829–1940. *Population Studies*, *61*(1), 53–71.

Brettell, C. B. (1986). *Men Who Migrate, Women Who Wait: Population and History in a Portuguese Parish*. Princeton, NJ: Princeton University Press.

Campbell, C. (2004). Appendix: Sources and measures. In *Life Under Pressure: Mortality and Living Standards in Europe and Asia, 1700-1900*, T. Bengtsson, C. Campbell, and J. Z. Lee, eds. pp. 441-476. Cambridge, MA: MIT Press.

Clark, G. (2005). The Condition of the Working Class in England, 1209-2004. *Journal of Political Economy*, *113*(6), 1307–1340.

Crafts, N., & Mills, T. C. (2009). From Malthus to Solow: How did the Malthusian economy really evolve? *Journal of Macroeconomics*, *31*(1), 68–93.

de Moel, H., Aerts, J. C., & Koomen, E. (2011). Development of flood exposure in the Netherlands during the 20th and 21st century. *Global Environmental Change*, 21(2), 620-627.

De Vries, J., & Van de Woude, A. (1997). *The First Modern Economy: Success, Failure, and Preserverance of the Dutch Economy, 1500-1815*. Cambridge: Cambridge University Press.

Dillon, A., Mueller, V., & Salau, S. (2011). Migratory responses to agricultural risk in northern Nigeria. American Journal of Agricultural Economics, 93 (4), 1048-1061.

Eriksson, A., L. Betti, A. Friend, S. Lycett, J. Singarayer, N. Cramon-Taubadel, P. Valdes, F. Balloux, & A. Manica. (2012). Late Pleistocene climate change and the global expansion of anatomically modern humans. Proceedings of the National Academy of Sciences, doi:10.1073/pnas.1209494109

Ekamper, P., van Poppel, F., & Mandemakers, K. (2011). *Widening Horizons? The Geography of the Marriage Market in Nineteenth and Early-Twentieth Century Netherlands*. (E. R. Merchant, G. D. Deane, M. P. GUTMANN, & K. M. Sylvester, Eds.) (pp. 115–160). Dordrecht: Springer Netherlands.

Fussell, E., Sastry, N., & VanLandingham, M. (2010). Race, socioeconomic status, and return migration to New Orleans after Hurricane Katrina. Population and Environment, 31 (1-3), 20–42.

Gemenne, F. (2011). Why the numbers don't add up: A review of estimates and predictions of people displaced by environmental changes. Global Environmental Change, 21, S41-S49.

Goldstone, J. A. (1986). The demographic revolution in England: a re-examination. *Population Studies*, *40*(1), 5–33.

Gray, C. & Bilsborrow, R. (2013). Environmental influences on human migration in rural Ecuador. Demography 50(4): 1217-1241.

Gray, C., & Mueller, V. (2012a). Drought and population mobility in rural Ethiopia. World Development, 40 (1), 134–145.

Gray, C., & Mueller, V. (2012b). Natural disasters and population mobility in Bangladesh. Proceedings of the National Academy of Sciences, 109 (16), 6000-6005.

Gutmann, M., Deane, G., Lauster, N., & Peri, A. (2005). Two population-environment regimes in the Great Plains of the United States, 1930-1990. Population and Environment, 27 (2), 191-225.

Hajnal, J. (1982). Two kinds of preindustrial household formation systems. *Population and development review*, *8*(3), 449–494.

Holopainen, J., Rickard, I. J., & Helama, S. (2012). Climatic signatures in crops and grain prices in 19th-century Sweden. *The Holocene*. doi:10.1177/0959683611434220

Huber, P. (1981). *Robust Statistics*. Wiley, New York.

International Institute for Social History (IISH). (2010). Historical Sample of the Netherlands (HSN). Data Set Life Courses Release 2010.01. http://www.iisg.nl/hsn/index.html

KNMI. (2013). *KNMI Climate Explorer*. Last accessed March 5, 2013. http://climexp.knmi.nl/

Kok, J. (1997). Youth labor migration and its family setting, The Netherlands 1850-1940. The History of the Family, 2(4), 507-526.

Kok, J. (2004). Choices and constraints in the migration of families: The central Netherlands, 1850-1940. The History of the Family, 9(2), 137-158.

Kok, J., Mandemakers, K., & Wals, H. (2005). City nomads: Changing residence as a coping strategy, Amsterdam, 1890-1940. Social Science History, 29(1), 15-43.

Kussmaul, A. (1981). *Servants in Husbandry in Early Modern England*. Cambridge: Cambridge University Press.

Landers, J. (1993). *Death and the Metropolis: Studies in the Demographic History of London 1670-1830.* Cambridge: Cambridge University Press.

Long, J. (2005). Rural-urban migration and socioeconomic mobility in Victorian Britain. *The Journal of Economic History*, *65*(01), 1–35.

Mandemakers, K. (2000). Historical Sample of the Netherlands. In *Handbook of International Historical Microdata for Population Research*, P. K. Hall, R. McCaa, & G. Thorvaldsen, eds. Minneapolis: Minnesota Population Center.

Mandemakers, K. (2002). Building life course datasets from population registers by the Historical Sample of the Netherlands (HSN). History and Computing, 14(1+2), 87-107.

Myers, N. (2002). Environmental refugees: A growing phenomenon of the 21st century. *Philosophical Transactions of The Royal Society B* 357 (1420), 609-613.

Nicolini, E. A. (2007). Was Malthus right? A VAR analysis of economic and demographic interactions in pre-industrial England. *European Review of Economic History*, *11*(1), 99–121.

Pfister, C. (2010). The vulnerability of past societies to climatic variation: a new focus for historical climatology in the twenty-first century. Climatic Change 100:25–31.

Pooley, C. G., & D'Cruze, S. (1994). Migration and urbanization in northwest England circa 1760–1830. *Social History*, *19*(3), 339–358.

Reher, D. S., & Ortega, J. A. (2000). Malthus Revisited: Exploring Medium-Range Interactions between Economic and Demographic Forces in Historic Europe. In T. Bengtsson & O. Saito (Eds.), *Population and Economy: From Hunger to Modern Economic Growth* (pp. 183–212). Cambridge: Cambridge University Press.

Rijkswaterstaat. (2013). *Water Base*. Last accessed July 22, 2013. http://live.waterbase.nl/

Silvestre, J. (2007). Temporary Internal Migrations in Spain, 1860-1930. *Social Science History*, *31*(4), 539–574.

Smits,J., Horlings ,E. & van Zanden, J. *Dutch GNP and its Components*, *1800-1913*. http://nationalaccounts.niwi.knaw.nl/

Tsuya, N. O., Feng, W., Alter, G., & Lee, J. Z. (Eds.). (2010). *Prudence and Pressure: Reproduction and Human Agency in Europe and Asia, 1700-1900*. Cambridge: MIT Press Books.

Vicente-Serrano, S., S. Beguería, & J. López-Moreno. (2010). A multiscalar drought index sensitive to global warming: The Standardized Precipitation Evapotranspiration Index. Journal of Climate 23, 1696–1718.

Warner, K., Ehrhart, C., de Sherbinin, A., Adamo, S., & Chai-Onn, T. (2009). *In search of shelter: Mapping the effects of climate change on human migration and displacement*. www.ciesin.columbia.edu/documents/clim-migr-report-june09_final.pdf

Whyte, I. (2004). Migration and settlement. Pp. 273-286 in *A Companion to Nineteenth Century Britain*, C. Williams, ed. Oxford: Blackwell.

Wintle, M. (2000). *An Economic and Social History of the Netherlands, 1800-1920*. Cambridge: Cambridge University Press.

Wrigley, E. A., & Schofield, R. (1989). *The Population History of England, 1541-1871*. Cambridge: Cambridge University Press.

Van Zanden, J. L. (1994). *The transformation of European agriculture in the nineteenth century*. Amsterdam: Vu Univ Pr Amsterdam.

Van Zanden, J. L. (2010). *National Accounts of the Netherlands*. Netherlands: N.W. Posthumus Instituut and DANS. http://nationalaccounts.niwi.knaw.nl/start.htm

Zhang, D., H. Lee, C. Wang, B. Li, Q. Pei, J. Zhang, & Y. An. (2011). The causality analysis of climate change and large-scale human crisis. Proceedings of the National Academy of Sciences, 108 (42), 17296-17301

Appendix 1. OLS models of the effects of climate variables on economic variables (coefficients and significance tests)

Predictor	Rye price		Agricultural GDP		National GDP	
Temperature, t	-8.94	*	3.83	*	24.77	*
Temperature^2, t	0.29		-0.21	*	-1.38	*
Temperature, t-1	-15.24	***	3.08	+	32.38	**
Temperature^2, t-1	0.71	***	-0.17	+	-1.82	**
Temperature, t-2	-12.39	***	3.16	+	29.10	**
Temperature^2, t-2	0.58	**	-0.18	*	-1.65	**
Temperature, t-3	-5.45		4.50	**	35.75	***
Temperature^2, t-3	0.16		-0.25	**	-2.01	***
Temperature, t-4	-2.49		3.89	*	30.18	**
Temperature^2, t-4	-0.06		-0.22	*	-1.70	**
Rainfall, t	-3.85	**				
Rainfall, t-1	-2.65	*				
Rainfall, t-2	-1.60					
Rainfall, t-3	-2.65	+				
Rainfall, t-4	-4.02	**				
Rain X temp, t	0.44	**				
Rain X temp, t-1	0.33	*				
Rain X temp, t-2	0.22					
Rain X temp, t-3	0.30	*				
Rain X temp, t-4	0.43	**				
Flooding, t			-0.24	**	-1.31	*
Flooding, t-1			-0.13		-0.70	
Flooding, t-2			-0.17	+	-0.83	
Flooding, t-3			-0.15		-0.53	
Flooding, t-4			-0.23	*	-0.84	+
Constant	265	***	-69	***	-613	***
N	114		107		102	
R-squared	0.48		0.42		0.48	