How did the North Atlantic Oscillation Affect the Historical Development of Sweden?

Preliminary Results

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Introduction

A growing body of research points to the wide ranging impacts the weather can have on important economic and social outcomes (Dell et al., 2014). In their review of the existing literature, Dell et al. (2014) uncover effects of temperature, precipitation and extreme weather events on a diverse set of outcomes, including output, labour productivity, health, crime and conflict. Further, a number of authors have presented evidence in support of theories which argue that the trajectory of a country's economic development, over the long-run, can be influenced by factors deeply rooted in history (Nunn, 2013). In this paper I will investigate the impact of one particular climate phenomenon, the North Atlantic Oscillation, on long-run development in Sweden.

Background

The North Atlantic Oscillation is the dominant pattern of atmospheric circulation variability over the North Atlantic basin (Luterbacher et al., 2001). It constitutes a back-and-forth switching between two modes; positive and negative. These modes are defined by a sea-level, atmospheric pressure differential between a low pressure system over Iceland and a high pressure system over the Azores (Rodwell et al.,1999). This gradient is always low-high, but a measure of NAO intensity reflects the strength of the gradient. The positive mode corresponds to a strong low over Iceland and a strong high over the Azores, while a negative mode results from a weak Icelandic low and weak Azores high.

The mode of the NAO is highly influential in determining winter climate conditions in Western Europe and Scandinavia. The pressure differential between the 'Azores high' and the 'Icelandic low' affects the track and intensity of the North Atlantic jet stream; the surface westerly winds that travel from the East coast US to Western Europe (Hurrell, 1995). In turn, this affects heat and moisture transport, which governs temperature and precipitation realizations (Walker & Bliss, 1932). A positive phase of the NAO is associated with warmer and wetter than average winters in Scandinavia, while a negative NAO is associated with colder and drier winters (Visbeck et al., 2001).

Data

The NAO index

Here, the chosen measure of NAO intensity is the index created by Luterbacher et al. (2002). This index is constructed by, first, calculating the mean sea-level atmospheric pressure over four grid points, on a 5° x 5° longitude-latitude grid, for each of the Azores and

Iceland. The standardized (1901-1980) difference between these two averages is then computed to give the index. Luterbacher et al's original reconstruction (1999) yielded a time series of this NAO index extending back to 1675, at monthly resolution. For the post-1780 period, sea-level pressure data was obtained from the National Center for Atmospheric Research (Trenberth & Paolino, 1980). However, instrumental data was not available for the 1675- 1780 time period, and so the reconstruction is based on estimations of temperature, precipitation and other paleo-environmental indices, calculated from proxy observational data of ice, snow, tree-rings and phenological and biological features (Jones et al., 1999; Luterbacher et al., 1999). The reconstruction was later extended back to 1659 (Luterbacher et al., 2001), using additional predictors from various data collection sites in Western Eurasia.

Since the NAO is responsible for much of the variability in weather in the North Atlantic region, particularly throughout the boreal winter (Scaife et al, 2014; Visbeck et al, 2001), for this analysis we create three measures to capture winter realizations of the state of the NAO. The DJFM average is the mean of Luterbacher's monthly NAO index for the months January, February, March and the December of the preceding year. Similarly, the DJFM max. and min. correspond to the maximum and minimum values of the same index for the winter months, respectively. For Sweden, an increase in each index corresponds to a move towards a warmer and wetter winter and away from a colder and drier winter. Figure 1, a time series plot of the winter average, shows that fluctuations between the positive and negative mode do not follow any particular periodicity; they can range from inter-annual to inter-decadal.

Outcome variables

In order to explore the path of development experienced by Sweden, we focus on two main categories of outcome variables: output and demographics.

Output

The output data used here is that presented by Edvinsson (2005). Nominal gross output is given in millions of Swedish Krona for three different industries- agriculture & hunting, forestry & logging, fishing- and covers the time period 1800- 1994. Figure 2 displays a time series plot of output by industry.

Demographics

We consider a further variable, the number of live births per 1000 persons, which can be found in the Lund University Macroeconomic and Demographic Database. Observations are available for the time period 1749-1998. Figure 3 displays a plot of this time series.

Model

In order to estimate the causal effect of the NAO on the outcome under consideration, we exploit a natural experiment created by the random, year-to-year variation in the phase of the NAO. The unit of observation acts as its own counterfactual in that it is compared to itself at different points in time; before and after 'treatment', i.e. climatic change (Hsiang et al., 2013). In this case, the identifying assumption is that climate conditions are exogenously determined by the climate system. We argue that this is a reasonable assumption when considering the NAO, since fluctuations between the positive and negative modes do not display any periodicity. It is, therefore, hard to believe that human behaviour can be adapted in anticipation of a particular state of the NAO, which would be problematic in that it would introduce endogeneity to the system. Further, the NAO was not even discovered until the 1920s, which supports our argument that humans were not predicting the state of the NAO and then adjusting responses accordingly.

For each outcome variable we estimate the three following models:

$$\ln\_outcome_t = \beta_0 + \beta_1 . nao\_DJFM\_av_t + \beta_2 . nao\_year\_av_t + \beta_3 . year_t + \beta_4 year_t^2 + \varepsilon_t$$

$$\ln\_outcome_t = \beta_0 + \beta_1 . nao\_DJFM\_max_t + \beta_2 . nao\_year\_av_t + \beta_3 . year_t + \beta_4 year_t^2 + \varepsilon_t$$

$$\ln\_outcome_t = \beta_0 + \beta_1 . nao\_DJFM\_min_t + \beta_2 . nao\_year\_av_t + \beta_3 . year_t + \beta_4 year_t^2 + \varepsilon_t$$

Where t indexes the year of observation.

The quadratic time trend in this model accounts for other time-trending variables, such as economic growth or demographic changes, which could be correlated with both the climate and the outcome variable. Its inclusion is motivated by figures 2 and 3, which display evidence suggestive of strong time trends. The annual average of the NAO index is also included as a control variable. This means that the coefficient of interest, β_1, measures the effect of winter deviations from the average state of the NAO.

Hypotheses

We begin by considering the effect of the NAO on output in several different industries in Sweden.

Agriculture & Hunting

Over the time period for which we have output data, Sweden's agricultural sector has been dominated by grain production (Saifi & Drake, 2008). We hypothesize that the winter mode of the NAO affected agricultural output during this period, due to the effect of climate conditions on yields of winter varieties of grains. Such crops are planted in the autumn and harvested in the spring and so the winter climate affects their growth phase. Previous work finds a positive relationship between winter maximum temperatures and winter wheat yields in the UK, Denmark and Sweden (Landau et al., 1998, 2000; Olesen et al., 2000; Enquist, 1929). Similar results can be expected for other overwintering field crops, including winter rye and barley (Vico et al., 2014). Therefore, when the outcome variable is agricultural output, we expect to see a positive coefficient β_1. The same result is hypothesized for each of the three NAO indices- winter maximum, winter minimum and winter average- since an increase in each measure corresponds to a move towards warmer and wetter winter conditions in Sweden. We expect winter conditions to be especially important to yields in this context because the northern limit for cultivation of winter grain varieties passes through Sweden (Holmer, 2008), with the limiting factor beyond this latitude being lower temperatures.

Forestry & Logging

Similar arguments apply to Sweden's forestry and logging industry. There exits extensive evidence of a strong positive correlation between tree growth and temperature in Sweden (Schweingruber et al., 1988; Briffa, 1994; Lindholm & Eronen, 2000), especially in the North of the country where growth is occurring at the ecological limits (Hughes, 2002). Therefore, we hypothesize that warmer and wetter winters will increase output from this industry, and so we expect to see a positive coefficient β_1 for each of the three NAO indices.

Fishing

The probable net effect of the NAO on commercial fishing output is less clear. Temperature has been shown to have both direct and indirect effects on fish biomass (Linderholm et al., 2014), with the direction of the effect also ambiguous. Dependent on the optimum range for each particular species of fish, increasing temperature may either increase or decrease biomass, with mechanisms including the impact on survival during early life stages (Genner et al., 2009), growth rate (Brander, 1995), time of spawning (Page and Frank, 1989), feeding (McKenzie, 1934, 1938) and predator-prey relationships. Predicting the effect of the NAO on fishing output for Sweden as a whole is further complicated by the heterogeneity of potential effects by latitude (Brunel and Boucher, 2007), as well as the possibility for institutional factors to effect fishing intensity and to interact with climatic factors.

Demographics

Next we consider the demographic outcome variable. Although we are not able to identify specific channels through which the NAO affects the number of live births per 1000 persons, we suggest a couple of possible mechanisms.

Firstly, as discussed above, we expect output in both the agricultural and logging industries to be positively correlated with the NAO index. Sweden did not begin to industrialize until the late 19^{th} century (Lagerlof, 2015) and so it is reasonable to suppose that Malthusian dynamics could be at play in this pre-industrial period. If so, then we would expect a rise in income to be accompanied by a rise in the number of live births, and so we hypothesize a positive relationship between the NAO index and the number of live births per 1000 people. Secondly, there is evidence to suggest that climate conditions during the mother's pregnancy effect fetal health and that extremes of temperature may even result in fetal loss (Catalano et al, 2008; Bruckner et al., 2014). During the Swedish winter, pregnant women are most at risk of exposure to extreme lows of temperature, and so we hypothesize a positive relationship between the NAO index and the number of live births per 1000 people. Since both of these mechanisms result in a positive relationship between the number of live births per 1000 persons and the NAO indices, we expect to see positive B1 coefficients.

Finally, we will investigate heterogeneity in the impact of the NAO on live births, during different phases of Sweden's economic development. A key component of the demographic transition model is the decline in birth rate, which accompanies a country's transition from a pre-industrial to an industrialized economy (Dribe & Scalone, 2014). There is evidence to suggest that this phase of Sweden's economic development occurred around the late 19th/ early 20th century. In his 2012 work "An Economic History of Modern Sweden", Schön posits that the period of breakthrough to modern industrial society occurred between 1890 and 1930 (Schon, 2012). Figure 3 shows that, consistent with demographic transition theory, the decline in live births per 1000 persons in Sweden occurred concurrently with this economic transition.

We hypothesize that prior to the transition, the NAO would have impacted live births in the ways discussed above. However, we expect to see a breakdown in the relationship following the transition to modernity. This is because, in a pre-industrial society the population is much more dependent on output from primary economic activities, such as agriculture and forestry. Therefore, the role of Malthusian dynamics is expected to be more pronounced during this period. Whereas, after the transition to a modern industrial society, income is less closely coupled to these primary economic activities, which are most sensitive to climate fluctuations. Additionally, the technological progress associated with the transition to modernity may allow for the possibility to mitigate the adverse in utero health effects of temperature extremes.

Results

Output

In table 1 we estimate the effect of the NAO on output from agriculture and hunting, over the period 1800- 1994. In line with our hypothesis, we see that there is a statistically significant, positive relationship for both the winter average NAO index (column 1) and the winter maximum NAO index (column 2) with output in this sector. This is interpreted as a positive effect of warmer and wetter winters on output in the agriculture and hunting industry. However, the coefficient on the winter minimum index (column 3) is not statistically significant.

The NAO index is not a measure of temperature alone, rather a summary statistic reflecting the climatic conditions induced by the mode of the NAO. However, as a benchmark for interpreting the magnitude of our estimates, a 1-unit increase in the NAO index is associated with an increase of winter sea-surface temperature by .045°C. And, our results show that each unit increase in the winter average of the NAO index causes a 6.8% increase in output from agriculture and hunting, while a 1-unit increase in the winter maximum NAO index increases output by 5.3%.

Meanwhile, the annual average of the NAO index is not statistically significant in any of our three models. This suggests that it is winter climate conditions alone driving the effect we see on output. But, the time trend is statistically significant in all three models and so must be retained to account for other time-trending covariates of the NAO and output.

Similar results apply to output in the forestry and logging industry. Table 2 shows that, again, there is a positive relationship for both the winter average NAO index (column 1) and the winter maximum NAO index (column 2) with output from forestry and logging, as hypothesized, but a statistically insignificant coefficient on the winter minimum NAO index (column 3). Additionally, the magnitude of the effects are similar to those in agriculture. A 1-

unit increase in the winter average NAO index increases forestry and logging output by 6.8%, while a 1-unit increase in the winter maximum NAO index increases output by 5.3%. Again we see that the annual average of the NAO index is not significant, but that the time trend is.

In table 3 we present estimation results for the effect of the NAO on output in the commercial fishing industry. Here we see that none of the coefficients on the winter average, winter maximum or winter minimum NAO indices are statistically significant. As discussed above, this may be explained by counterbalancing effects of an increase in the NAO index, both within marine ecosystems and across regions within Sweden.

Demographics

Moving on to our demographic outcome variable, we find that the number of live births per 1000 people is increasing in all three of the NAO indices- winter average, winter maximum and winter minimum. Table 4 shows that a 1-unit increase in the winter average NAO index (column 1), winter maximum NAO index (column 2) and winter minimum index (column 3) cause a 3.3%, 1.4% and 2.1% increase in the number of live births per 1000 people, respectively. This is consistent with our hypothesized effect of a move towards warmer and wetter winters in Sweden.

In this case, the time trend is statistically significant for all three indices, but the annual average NAO index is statistically significant only in the first model, where we look at the effect of the winter average NAO index. The negative coefficient on the annual average NAO index tells us that, at the level of the year, a more positive NAO mode decreases the number of live births, but the positive coefficient on the winter average NAO index reflects that winter deviations from the annual average, in the positive direction, increase the number of live births. This is consistent with the proposed mechanism, which says that temperatures at either extremes can have a negative effect on live births. It is possible that the effect of the annual average NAO index is driven by the detrimentally high summer temperatures associated with an increase in the NAO index, whereas an increase in the NAO index over the winter months corresponds to a decrease in risk from low temperatures.

The decomposition of these findings into the pre-industrial and industrialized phases of Sweden's development are presented in table 5. In columns 1, 3 and 5 we estimate the models for the period 1749- 1890, whilst in columns 2, 4 and 6 we estimate the same three models for the period 1891- 1998. As hypothesized, the positive effect of the NAO winter average index on live births holds for the pre-industrial period, but breaks down after the transition to a modern industrial economy. Figure 4 depicts this relationship, showing that detrended log live births per 1000 people tracks the NAO winter average index much more closely before 1890, than after 1890. Similarly, for the NAO winter minimum index. However, the coefficient on the winter maximum NAO index is not statistically significant for either period.

In conclusion, we have shown the NAO to have effects on a number of important outcomes over a historical time frame in Sweden. We find that a more positive mode of the NAO increases output in both the agriculture & hunting and the forestry & logging industries, but has no effect on output in the fishing industry.

Additionally, we have shown that a more positive mode of the NAO increases the number of live births per 1000 people. We break this result down to pre-industrial and industrialized phases of Sweden's economic development, finding that the relationship holds prior to the transition to modernity, but not after the transition.

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Tables & Figures

Table 1- The effect of the NAO on log output from the agriculture & hunting industry.

VARIABLES	(1) Agriculture & Hunting output	(2) Agriculture & Hunting output	(3) Agriculture & Hunting output
NAO winter average	0.068***		
	(0.023)		
NAO winter max		0.053***	
		(0.019)	
NAO winter min			0.016
			(0.016)
NAO annual average	-0.024	-0.004	0.027
	(0.040)	(0.036)	(0.038)
year	-0.366***	-0.361***	-0.363***
	(0.029)	(0.029)	(0.030)
year^2	0.000***	0.000***	0.000***
	(0.000)	(0.000)	(0.000)
Constant	324.314***	319.532***	321.416***
	(28.008)	(27.891)	(28.858)
Observations	195	195	195
R-squared	0.980	0.980	0.979

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 2- The effect of the NAO on log output from the forestry & logging industry.

VARIABLES	(1) Forestry & Logging output	(2) Forestry & Logging output	(3) Forestry & Logging output
NAO winter average	0.067**		
	(0.033)		
NAO winter max		0.049*	
		(0.027)	
NAO winter min			0.030
			(0.021)
NAO annual average	-0.034	-0.012	-0.001
	(0.063)	(0.059)	(0.056)
year	-0.358***	-0.353***	-0.358***
	(0.033)	(0.033)	(0.033)
year^2	0.000***	0.000***	0.000***
	(0.000)	(0.000)	(0.000)
Constant	308.989***	304.239***	308.299***
	(30.954)	(30.906)	(31.412)
Observations	195	195	195
R-squared	0.976	0.976	0.976

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 3- The effect of the NAO on log output from the fishing industry.			
	(1)	(2)	(3)
VARIABLES	Log fishing output	Log fishing output	Log fishing output
NAO winter average	-0.005		
	(0.033)		
NAO winter max		0.006	
		(0.025)	
NAO winter min			-0.025
			(0.024)
NAO annual average	-0.016	-0.027	0.007
	(0.051)	(0.045)	(0.048)
year	-0.277***	-0.277***	-0.273***
	(0.043)	(0.042)	(0.043)
year^2	0.000***	0.000***	0.000***
	(0.000)	(0.000)	(0.000)
Constant	229.918***	230.369***	226.704***
	(40.668)	(40.239)	(41.378)
Observations	195	195	195
R-squared	0.974	0.974	0.974

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 4- The effect of the NAO on log live births per 1000 people in Sweden.			
	(1)	(2)	(3)
VARIABLES	Log live births per 1000 people	Log live births per 1000 people	Log live births per 1000 people
NAO winter average	0.033***		
	(0.008)		
NAO winter max		0.014*	
		(0.007)	
NAO winter min			0.021***
			(0.006)
NAO annual average	-0.032**	-0.013	-0.022
	(0.015)	(0.015)	(0.014)
year	0.098***	0.100***	0.098***
	(0.005)	(0.005)	(0.005)
year^2	-0.000***	-0.000***	-0.000***
	(0.000)	(0.000)	(0.000)
Constant	-84.402***	-85.898***	-84.276***
	(4.809)	(4.921)	(4.889)
Observations	250	250	250
R-squared	0.925	0.922	0.924

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 5- The effect of the NAO on log live births per 1000 people in Sweden, pre-1890 (1), (3) & (5) and post-1890 (2), (4) & (6).

VARIABLES	(1) Log live births per 1000 people	(2) Log live births per 1000 people	(3) Log live births per 1000 people	(4) Log live births per 1000 people	(5) Log live births per 1000 people	(6) Log live births per 1000 people
NAO winter average	0.021***	0.013				
	(0.007)	(0.012)				
NAO winter max			0.011	0.003		
			(0.007)	(0.011)		
NAO winter min					0.009**	0.011
					(0.005)	(0.009)
NAO annual average	-0.023*	0.005	-0.014	0.016	-0.013	0.004
	(0.013)	(0.024)	(0.014)	(0.023)	(0.012)	(0.023)
year	0.009	-0.224***	0.004	-0.233***	0.008	-0.224***
	(0.012)	(0.052)	(0.012)	(0.052)	(0.013)	(0.052)
year^2	-0.000	0.000***	-0.000	0.000***	-0.000	0.000***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Constant	-3.312	228.536***	0.473	236.987***	-2.911	229.133***
	(11.244)	(50.391)	(11.324)	(50.733)	(11.545)	(49.984)
Observations	141	108	141	108	141	108
R-squared	0.314	0.857	0.289	0.856	0.292	0.858

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Figure 1: Time series plot of the winter average NAO index.

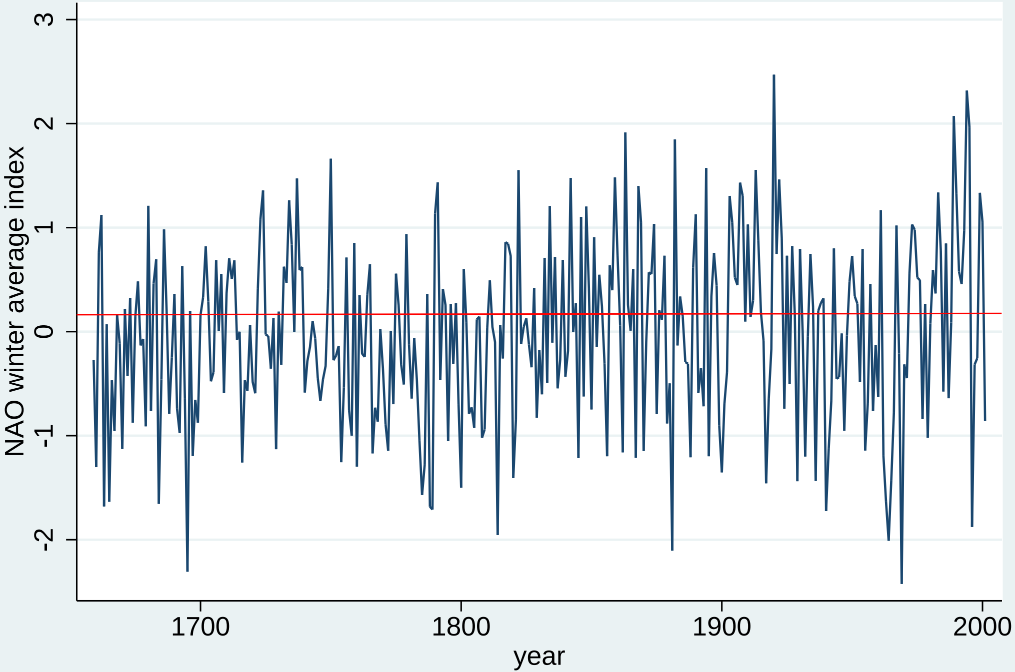

Figure 2: Time series plot of Swedish output.

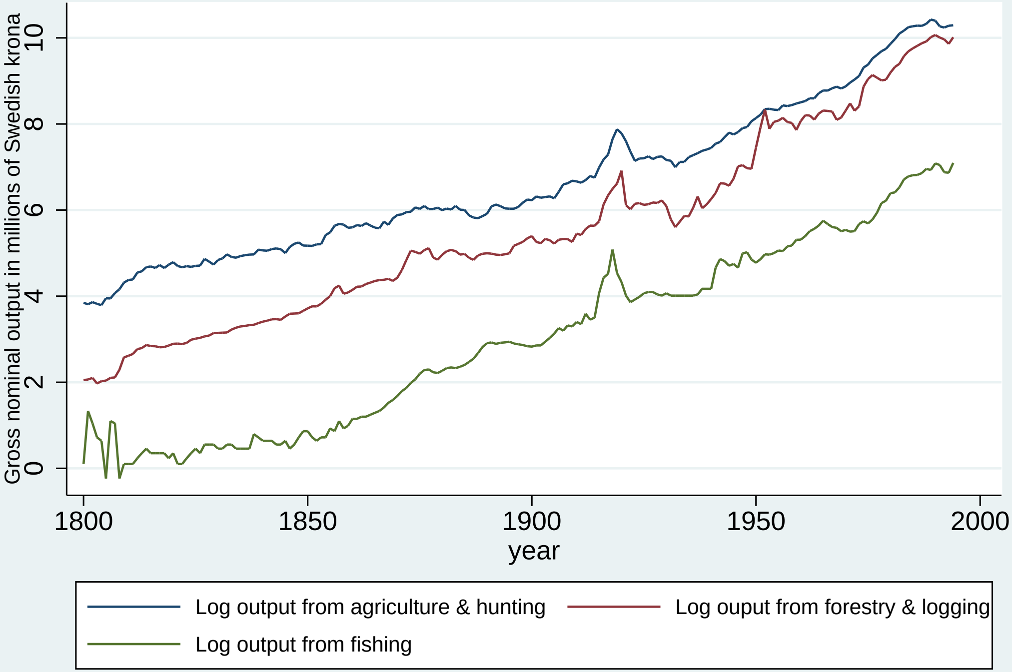

Figure 3: Time series plot of log live births per 1000 persons in Sweden.

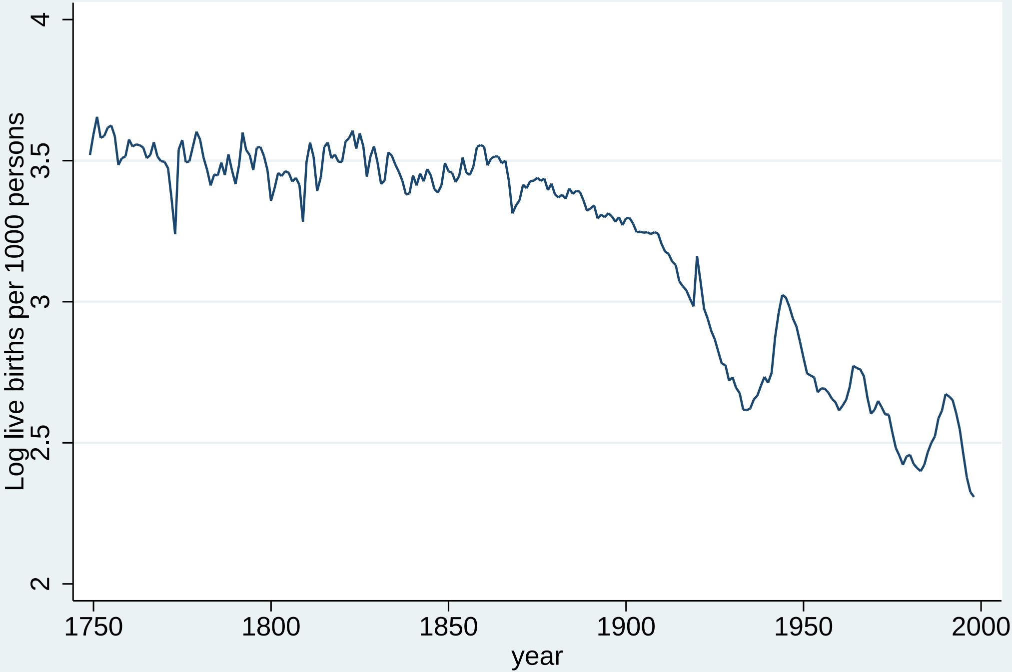

Figure 4: The relationship between the NAO winter average index and the birth rate in Sweden, pre- and post-1890.