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The association between network centrality and standard of living in a historical agrarian population

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Abstract

Objective—The aim of this study is to investigate the relationship between network centrality and living standards as measured by fertility and mortality responses to short-term economic stress.

Methods—Cox proportional hazard models estimate the effects of staple grain price variation and eigenvector and beta centrality within marriage and labor networks on the timing of births and child (1-14) mortality in a historical demographic dataset from North Orkney, Scotland 1851-1911.

Results—Households that are peripheral to the marriage and labor network experience lower chances of a birth when food prices are high. The fertility of more central households is less sensitive to price changes. A similar, but weaker, pattern holds also for child mortality, which is also sensitive to price fluctuations, although the social gradient is not as clear.

Conclusions—Marriage and labor network centrality is an indicator of standard of living in this remote, agricultural population. Households that are firmly embedded in the network are able to overcome and adjust to short-term economic stress without demographic consequences, while those at the edges of the community experienced delayed reproduction in poor years consistent with unplanned responses to stress.

Keywords

Fertility; mortality; historical demography; network analysis; economic stress

Introduction

Recent work in anthropology has highlighted multiple domains of wealth, inequality, and inheritance in cross-cultural perspective (Bowles, Smith, & Borgerhoff Mulder, 2010; Mulder et al., 2009; Smith et al., 2010). One of the categories of wealth used by this group, relational wealth, refers to an individual's position in social networks, including the number and status of their connections (Bowles et al., 2010). While network ties can be passed between the generations, the intergenerational transmission of this form of wealth is not as strong as other types of wealth, especially material wealth. Further, the degree of inequality is lower for relational wealth than material wealth across production systems, including

agriculture (Shenk et al., 2010). Despite weaker intergenerational transmission and reduced inequality relative to material wealth, relational wealth may contribute to variation in living standards and wellbeing.

The social gradient in health has been observed so consistently that social conditions are considered a determinant of health and health inequalities (Link & Phelan, 1995; Marmot, 2005). While some of the social gradient can be attributed to variation in income, wealth, and other material measures of socioeconomic status, it is likely that social ties also contribute to the health gradient, whether independently or in connection to other factors. Indeed, the concepts of social capital and social resources, which mirror some of the components of relational wealth, posit that information and resources can be accessed and mobilized through direct and indirect ties (Coleman, 1988; Lin, 1999).

Social ties are associated with measures of health and wellbeing, including survival, obesity, and mental health, among others (Ellwardt, van Tilburg, Aartsen, Wittek, & Steverink, 2015; Holt-Lunstad, Smith, & Layton, 2010; la Haye, Robins, Mohr, & Wilson, 2010; Perry & Pescosolido, 2015; Shor, Roelfs, & Yogeve, 2013). This typically robust relationship has been observed across cultures, sex, age groups, and relationship types. Hypothesized mechanisms that link relationships with others to wellbeing include social support, social influence, social engagement and attachment, access to resources, and person-to-person contact (Berkman et al., 2000; Smith & Christakis, 2008). In some contexts, social network connections have been observed to buffer the relationship between low socioeconomic status and poor health, while in other settings, networks may intensify the relationship (Cattell, 2001; Cornwell, 2014; Perkins, Subramanian, & Christakis, 2015; Rook, 2014). Further, social isolation, which is negatively associated with health, has been found to vary within societies and between urban and rural regions, with rural residents reporting stronger than expected social connectedness (Henning-Smith, Moscovice, & Kozhimannil, 2019).

By many measures, human wellbeing improved over the last 300 years throughout much of the world. Life expectancies have improved, as have biological measures such as adult height and deaths from communicable disease, and economic indicators such as income per capita (Floud, Fogel, Harris, & Hong, 2011; Fogel, 2004; Gage, 2005). While there exists a range of measures, indices, and concepts available in the literature to describe and quantify wellbeing, this study adopts the comparative, historical approach developed by the EurAsia Project (Bengtsson, 2004), which bears some similarities to Amartya Sen's (1987) concept of standard of living.

Rather than focusing on traditional economic definitions of living standards that rely on measures of income, goods, or utility, this concept of standard of living examines an individual or household's ability to overcome short-term economic stress, measured by yearly variation in food prices. If a person or household cannot achieve their life plans, including having children and surviving, during times of economic stress, then they are said to have a low standard of living. On the other hand, if recurring short-term fluctuations in the environment do not affect the ability to meet these goals, then the standard of living is higher relative to those whose demographic behavior is negatively affected by price variations.

There exists a range of economic and demographic responses to short-term economic stress in rural, agrarian societies, some of which might be affected by local social networks. In poor years, a household would first spend down savings and sell non-essential items. This would be followed by attempts to borrow from others, which could include other households in their social network. Some might apply for poor relief, but in Scotland during this period relief was limited to certain groups, such as orphans, widows with children, elders without adult children, and people with disabilities (Mitchison, 1974). Households could attempt to adjust their composition and labor supply through the out-migration of certain family members or firing servants. Social network ties may help households seeking to find new work or send out labor migrants, as they can be sources of information about employment opportunities (Granovetter, 1973). Consumption may be postponed, with births and marriages delayed until economic conditions improve. Finally, the most desperate households would be required to reduce or reallocate consumption, including reducing food consumption. These responses have been described in terms of a social ladder (Bengtsson, Campbell, & Lee, 2004). The number of steps a household moves along the ladder of responses \ to smooth consumption in poor years is an indicator of living standards. If a household can weather a bad year by spending savings, it can be considered better off than a household that must delay childbearing or engage in activities that increase mortality risk, such as reduced food consumption, after other attempts to smooth consumption have failed. This definition of standard of living was developed for the comparative analysis of historical agricultural populations in Europe and East Asia that are part of market economies, as it relies on annual variation in the price of staple grains (Bengtsson, Campbell, & Lee, 2004; Lundh & Karosu, 2014; Tsuya, Feng, Alter, & Lee, 2010). However, it is possible that similar measures could be developed for other production systems. For example, short-term variation in rainfall or species abundance might be more appropriate in some contexts.

Mortality risk is tied to short-term economic stress through two primary mechanisms: nutrition and exposure. Nutrition, immune function, and infectious disease interact to affect mortality risk (Fogel, 2004; Rotberg & Rabb, 1985). Exposure to disease may be increased by other attempts to reduce consumption, such as postponing medical and personal care, reducing heating costs, and labor migration. Migration, especially to urban centers, increases exposure to new pathogens (Alter & Oris, 2000). Mechanisms that link short-term stress and fertility are often described in terms of the proximate determinants of fertility framework (Bongaarts, 1978). These mechanisms include the deliberate control of fertility, physiological responses to stress that reduce fecundity including anovulation and spontaneous abortion, and reduction of intercourse frequency through spousal separation during labor migration and loss of libido (Tsuya et al., 2010).

This study examines social position in two types of social networks and standard of living in a historical agricultural population, North Orkney, Scotland. Prior work in this population demonstrates that inequality in access to land, proxied by occupation sector, is associated with different demographic responses to short-term food price fluctuations, with non-agricultural workers more vulnerable to economic stress than those working in agriculture (Jennings, Quaranta, & Bengtsson, 2017). The network approach used here goes beyond occupational sector to assess relative position in the community's economic and social networks through measures of network centrality. This technique offers a perspective on

local social relationships that has relevance to uncovering inequality in living standards. Further, this approach may be applied to other historical populations with similar documentary sources and incomplete data on alternate socioeconomic measures such as wages or taxes. More broadly, the data requirements for this approach include longitudinal individual-level data on the timing of births and deaths and information about social networks and short-term economic stress appropriate for the study context.

Study Population and Data

The North Orkney Population History Project (NOPH) takes a multidisciplinary approach to the study of population and landscape change from 1750 to the present in the six northernmost islands of Orkney, Scotland (Jennings, Sparks, & Murtha, forthcoming). The demographic component of the project includes civil records of births, deaths, and marriages from 1855 to the present and micro-level census data from 1851-1911. The techniques of nominal linkage and family reconstitution are used to construct individual life courses and coresidential and familial ties among the inhabitants of the study area. This demographic database is supplemented by rich contextual information, including food price series, historical and modern maps, archaeological surveys, land use data, and ethnographic interviews (Jennings, 2010; Murtha et al., 2008; Sparks, 2007).

The study period, 1851-1911, is determined by the earliest census usable for individual-level historical demographic analysis and the latest census made public after the 100-year embargo imposed on the release of individual census data by the United Kingdom. During this period, the inhabitants of the Northern Isles practiced smallholder mixed agriculture, fishing, and rural trades (Fenton, 1997; Thomson, 2008). The majority of those employed in agriculture worked as tenant farmers or agricultural laborers. There were few owner-occupiers during the study period. Absentee landowners rented parcels, often with long-term leases, to local farmers or hired laborers annually or seasonally to work larger holdings under the supervision of a farm manager. Settlement is rural and dispersed, with one or two small villages on the larger islands. The remote location and absence of elite landowners flattens the socioeconomic structure of the islands relative to Mainland Orkney, the site of the largest nearby settlements, and mainland Scotland.

Previous research on this population used historical listings of occupations to assess socioeconomic structure and its effects on mortality and fertility (Jennings et al., 2017; Sparks, 2009; Sparks, Wood, & Johnson, 2013). Efforts have been made to standardize historical occupations and link them to social status in comparative analyses (Lambert, Zijdeman, van Leeuwen, Maas, & Prandy, 2013; Schulz & Maas, 2010; Van De Putte & Miles, 2005; van Leeuwen, Maas, & Miles, 2002). However, there are drawbacks to the use of occupation as an indicator of social structure in this context. Occupations are seldom recorded for women during the study period. It is common for individuals to have more than one listed occupation, and it is often unclear how to assign primary and secondary employments in these cases. Even in modern times, Orcadians often hold several jobs. The reconstruction of social structure is further complicated by record availability and content. Many commonly used historical demographic measures of socioeconomic status are not available or inappropriate for use in Orkney. There are no direct indicators of income,

wages, or monetary wealth during the study period. Tax records are not available for individuals, but the NOPH team has digitized records of the taxable value of landholdings. These land valuations cover only those with access to owned or leased land, so those not employed in agriculture are seldom captured in these records. The interpretation of valuations is not clear in the case of large farms that hired many agricultural servants and provided these workers with a dwelling and small parcel of land. The total valuation of the farm is listed, but not the portion assigned to each laborer, so the appropriate division of the total valuation for each household is not certain. There are few indicators of educational attainment or literacy available during the study period.

This study uses position within two social networks as an indicator of social structure. If network position is related to status and access to resources within the community, it should behave similarly to other measures of social standing, such as occupation, in statistical models of demographic behavior. In 19th century Europe, marriage and labor networks shaped social relations and may have influenced, and been influenced by, access to economic and social resources, including trust, help, information, and reputation. Marriage linked the households of brides and grooms in both social and economic terms and resources may have been more likely to flow between households connected by a marriage than those without this shared bond.

Labor networks formed by the exchange of life-cycle servants represent another dimension of social structure within the community. Like marriage ties, the exchange of servants involves social and economic considerations. Life-cycle servants were a common feature of preindustrial life throughout Northwest Europe. Young men and women left their household of origin to work in another household in the years between adolescence and marriage. These servants lived and worked as part of the household of the family that hired them in exchange for room, board, and wages (Kussmaul, 1981). For these young people, service was a short-term occupation that provided useful experience, but was not an apprenticeship or long-term career (Whittle, 2000; 2005). Life-cycle servants tended to flow among households of low and middle status, rather than strictly from lower-status households to elite households as in the case of career servants such as butlers and maids (Jennings, 2010; Jennings, Wood, & Johnson, 2011). While this is not to say that no servants were exchanged across socioeconomic boundaries, the majority of life-cycle servants found themselves working in households fairly similar to the ones they were raised in. The practice of service was ubiquitous, and an important driver of migration of young people out of their household of origin, allowing some independence from parents and broadening social contacts (Dribe, 2000; Ewan, 2004; Laslett & Wall, 1974; Lundh, 1999; 2004). Servant hiring occurred at annual fairs, where social and kin networks were essential to the hiring process as sources of information about open positions and the character and reputation of both parties (Goldberg, 1992; Kitchen, 1981). The sending of children to work as servants and the hiring of servants established both social and economic ties between households.

These two forms of ties, marriage and service, reflect integration or embeddedness within the community and had social and economic consequences for each household. The two kinds of tie are further linked as service ties could increase the chances of future marriage ties between households, or marriage may prepare the way for future service relationships.

Both networks reveal aspects of the social structure of this rural community and the formation of social capital and social resources in a region where access to land and other resources is limited and the standard of living is relatively low (Jennings et al., 2017).

Data for the fertility and mortality models come from individual life courses reconstituted from vital records of births, deaths, and marriages. For births and child deaths, 70% of birth records could be linked to the parents and 81% of child deaths could be linked to the birth record of the child. Most linkage failures are attributed to inability to distinguish names or to events that occurred outside of the study area or study period. Under-registration of births and deaths is minimal in this dataset (Jennings et al., 2017). Out-migration cannot be accounted for in most family reconstitution studies, including this one, and is a limitation of this analysis. Indeed, temporary labor migration of some household members or permanent out-migration of entire households may have been responses to short-term economic stress. In the case of out-migration, these households would not be captured in the data. However, the literature on migration as a response to economic and environmental stress suggests that some of the poorest households may be unable to muster the resources to migrate (Gray & Mueller, 2012a; 2010b; Jennings & Gray, 2015).

Grain prices were obtained from archival records of annual county-level market prices (Mitchison, 1965). These prices refer to the harvest year from November 1 of year t to October 31 of year $t+1$. The time series is complete, with no missing years in the study period. In the study period, the most important staple grains for both food and drink in Orkney were oats and bere, a form of barley suited to local climate conditions (Fenton, 1997). Orcadians supplemented their diet of oats and bere with turnips, potatoes, garden crops, and animal products (primarily from cattle, sheep, pigs, and poultry). Wheat and rye were not grown in Orkney, as they cannot tolerate the cool, damp, and windy climate. Grain was not a major export of the islands, and the balance of grain exports and imports was highly variable from year to year (Thomson, 2008). Livestock, primarily fed from hay, silage, and grazing, represented the largest share of Orkney's agricultural exports in the mid-to late-19th century. The price series for oats and bere are strongly correlated within Orkney and between Orkney and the price series from Edinburgh. This is an indication that county grain prices are largely determined by exogenous conditions, such as weather, that affected arable production in similar ways across a broad region (Richards, 1984). The models presented here use the oatmeal time series, but the findings are robust to substituting the bere time series. For households engaged in farming and producing a surplus, high grain prices were favorable, as they improved household income and the rates at which rents were converted. In contrast, households engaged in other work were obligated to purchase some or all of their food at market prices and would be adversely affected by high grain prices if their income was not sufficient to buffer regular price fluctuations.

Methods

The sampling frame of households for both networks is drawn from complete count decennial census returns from 1851-1911. This provides a list of all eligible households ($N=814$) in the study area so that network isolates, those households with no ties of marriage or service, can be included in the analysis. Incoming or outgoing marriage or labor ties from

outside of the study area are excluded from the analytic sample, as covariates cannot be identified for individuals, households, and events beyond the study area. This is a limitation to the study, as the exclusion of marriages and servant exchanges outside of North Orkney reduces the total number of ties and may be non-random.

The marriage network contains the marriage ties of all brides and grooms with households of origin in the study area that could be identified in civil marriage records from 1855-1911 (N=1088). This period marks the beginning of civil registers of vital events in Scotland and the end of publicly available census microdata. The labor network is constructed from decennial census microdata from 1851-1911. Life-cycle servants are identified by their relationship to the head of household. Nominal linkage is then used to find the household of origin for servants born and working in the study area (N=396). Servants not born in the study are excluded from analysis. The census captures observations of individuals who were servants at the time of enumeration. This sampling will miss individuals who worked as servants in non-census years, but there is little reason to believe that this 10-year censoring would exclude individuals from the sample systematically. Instead, it would reduce the overall size and density of the labor network.

The joint network of marriage and servant ties is used as it increases the size and density of this sparse network (Figure 1; Table 1). Each network is recorded as a matrix where values of the rows and columns indicate sending or receiving of a tie between households, known as adjacency matrix. The adjacency matrices are added together to produce a single matrix that is valued and undirected. The value signifies the count of the number of marriage and service ties. The network was symmetrized, as including undirected ties would place more directional weight on values that include at least one servant tie, potentially emphasizing servant relationships over marriage relationships, as servant ties are directed while marriage ties are not directed.

Many measures of network centrality are available. Centrality measures quantify properties of a node's position in a network. Central nodes are often interpreted as well-connected, popular, prominent, or influential. The simplest measure of centrality is degree centrality, or the number of ties a node has to other nodes. Other measures of centrality account for network structure beyond direct ties. This study selects from among three centrality measures that include some information about network structure beyond immediate ties: eigenvector centrality (Bonacich, 1972) beta centrality, also known as Bonacich's power (Bonacich, 1987), and a continuous core-periphery score (Borgatti & Everett, 1999). Each of these measures captures a slightly different aspect of what it means to be central or embedded in a network, but they all are concerned with the relative position of households and include some characteristics of the ties of the other households they are connected to.

The eigenvector centrality of household i is the number of adjacent, or directly connected, households (j) to a household i , weighted by centrality (e_j), where x_{ij} is the (i, j) entry of the adjacency matrix, e is the eigenvector centrality score, and λ is a proportionality constant that is the largest eigenvalue of the adjacency matrix (many λ values could result in a non-zero solution, but taking largest eigenvalue ensures that the solution is unique and positive):

$$e_i = \lambda \sum_j x_{ij} e_j$$

Households with high eigenvector centrality are linked to other households that are themselves well connected while households with low eigenvector centrality are linked to households that have few connections.

Beta centrality of household i in adjacency matrix A is represented by:

$$c_i = \sum_j A_{ij} (\alpha + \beta c_j)$$

where α is a normalization parameter and β is a weighting factor that attenuates the effect of households indirectly tied to i by length of walk. Higher beta centrality scores indicate that a household is better connected and central within the network. Low centrality scores indicate the opposite. The β parameter may be specified as positive or negative. Positive values of β give more weight to ties to well-connected households. Negative values of β give more weight to ties to less-connected households. Higher absolute values of β increase the weight given to households further away in the network. Put another way, beta centrality considers the effect of both direct and indirect connections. Positive β values specify that connections to popular households will increase status, while negative β values specify that status will increase if a household's connections have fewer alternative connections. A negative β form of the measure is more akin to monopoly power over other households' connectivity, while the positive value reflects connections to popular or central households. Lastly, a continuous measure of coreness is generated by fitting a core-periphery model to the adjacency matrix and estimating the closeness to the core of each household as described by Borgatti and Everett (1999). High values indicate closeness to the modeled core while low values indicate peripheral position.

The centrality scores are correlated with each other. To avoid multicollinearity one measure is selected for the fertility model and mortality model using model fit assessed by the Bayesian information criterion (BIC). There is no strong *a priori* reason to prefer one measure to another in this context or to assume that the same measure would provide the best fit in both the mortality and fertility models. Only BIC minimizing models are reported in detail, but the magnitude and direction of results are robust to other specifications of the centrality variable, with hazard ratio estimates of the main effect of the centrality variable ranging between 1.079 and 1.053 in the fertility models and 0.874 and 0.947 in the mortality models, for example (Table 2). Other covariates fall within a similar range of variation in models with different centrality variable specifications. Eigenvector centrality produces the best fit in fertility models and negative beta centrality fits best in the mortality models. Centrality scores are calculated for the complete network of ties formed over the entire study period. Longitudinal analysis of the network would result in low network density such that the majority of households appear as isolates, especially early in the study period. This is a limitation of the study, as social dynamics cannot be traced over time. Therefore, network centrality scores are taken as time-invariant indicators of status in the community.

The centrality measures are used as predictor variables in event-history models of fertility and child (ages 1-14) mortality between 1855 and 1911. Cox proportional hazard models are used to assess the relationship between oatmeal prices and the timing of births and deaths (Allison, 1984; Cox, 1972). The model can be expressed as:

$$h_i(a) = h_0(a) \exp \left(\sum_k \beta_k x_{ik} \right)$$

Where $h_i(a)$ is the hazard of an event for individual i at age a , $h_0(a)$ is the baseline hazard, x_{ik} is the observed value of the k -th covariate in individual i and β_k is the estimated regression coefficient of covariate k .

Separate models are estimated for mortality and fertility. Both sets of models passed tests of the proportional hazards assumption based on Schoenfeld residuals (Grambsch & Therneau, 1994; Schoenfeld, 1982), the interaction of analysis time with model covariates, and the link test (Cleves, Gould, & Gutierrez, 2004). Oatmeal prices were detrended by taking the natural log of price and applying a Hodrick-Prescott (HP) filter with a filtering factor of 6.25, the value used to remove trends from yearly series (Hodrick & Prescott, 1997). Detrending is necessary to evaluate the effect of short-term price shocks. Current prices and prices lagged by one year are included in all models to account for events occurring within 24 months of a harvest. To assess the relationship between price variation and network centrality, an interaction term is included. Continuous variables are mean-centered and centrality measures are standardized.

Fertility models are estimated for second- and higher-order births using Cox proportional hazards models. First births are correlated with the timing of marriage and excluded from analysis. Women enter observation at the birth of their first child. Women exit observation at their date of death, the death of their spouse, or if neither of these are observed, the last death of a child under age 15. When none of those events are observed, the date of the birth of the last child is used as the last observation. Women are censored at age 50 to account for the end of the reproductive period. To reduce the possible effects of unobserved out-migration, women exit observation after six years have passed since the birth of her last child if it occurs before age 50 or any other censoring event. The findings presented here are robust to including only women with a completely observed fertility period, meaning from birth or marriage until death or the death of their spouse. A binary variable indicating the occupation sector (agriculture or non-agriculture) of the husband or, if missing, the household head is included despite its weaknesses in this context, as farmers tend to experience higher fertility than non-farmers, even during the demographic transition (Dribe, Hacker, & Scalone, 2014; Hacker, 2016; Sparks, 2009). A time-varying series of indicator variables are generated for the age of the woman to account for age-related variation in fertility. A time-varying indicator variable for the vital status of the previous child controls for the association between the early death of the previous child and shortened subsequent birth interval. A linear term for year controls for period effects. Robust standard errors are estimated by clustering over the mother's identifier to adjust for unobserved shared traits of

a mother across all of her fertility events. Table 3 presents summary statistics for the fertility analysis.

Mortality models are estimated for children aged 1-14 years. Infants are excluded from analysis, as infant mortality responses to food prices are potentially buffered by breastfeeding practices. Adult mortality is also excluded, as calculating accurate exposure time for adults is difficult in family reconstitution studies. Subjects enter observation on their first birthday and exit at death or upon reaching age 15. For children that survive to age 15, only those with an observed death or death of parent after age 15 are included in the sample to reduce the effects of unobserved out-migration from the study area. Age 15 is chosen because children are unlikely to have left their household of origin before this age. The measures of occupation and period are the same as in the fertility models and the sex of the child is included as a control. Robust standard errors are estimated by clustering over a family identifier to adjust for unobserved shared characteristics among siblings. Summary statistics are presented in Table 3.

Results

Fertility timing responds to variation in food prices (Table 4). Hazard ratios are reported in the table. In the main effects model, a 10% increase in lagged oatmeal price is associated with a 4.4% decrease in fertility. There is no effect of current prices. The lagged response is typically interpreted as a failure to either anticipate poor years, or to adjust fertility behavior accordingly (Bengtsson & Dribe, 2006). Fertility responses that occur without deliberate adjustment will be lagged by at least 9 months, and up to 12-15 months after a food price increase as economic stress in rural societies is highest in the spring after a poor harvest. Planned adjustments in anticipation of future challenging conditions would have an immediate effect in the current year. These responses could be as short as six months, as individuals could gather a rough sense of future prices by assessing growing conditions in the months leading up to the harvest and the setting of prices shortly thereafter. Households with high eigenvector scores that are more central to the network experience shorter birth intervals. Agricultural occupation of the husband or household head is associated with higher fertility, a finding consistent with the literature from 19th century Northwest Europe and North America. Estimates of the other individual-level control variables are consistent with the fertility literature, as older mothers are less likely to experience a birth and the birth intervals following the death of the previous child are shorter (Tsuya et al., 2010). The negative effect of time is consistent with the fertility decline that occurred during this period. The interaction of eigenvector centrality and lagged oatmeal price is positive and statistically significant, but the interaction term for centrality and current prices is not. A contour plot of the predicted relative hazards associated with the interaction indicates that the fertility of households with low centrality scores on the periphery of the network is the most sensitive to changes in oatmeal prices (Figure 2). The fertility of the most central households is relatively unaffected by price fluctuations.

The child mortality model is underpowered in comparison to the fertility model, but the direction of estimated hazard ratios are broadly consistent with the expected association of network centrality with mortality response to short term economic fluctuation. Further,

fertility responses may be more apparent than mortality responses in these models as they include both deliberate and unplanned responses to economic stress, while mortality responses are indirect effects of the elevated mortality risk associated with reduced consumption and increased exposure to disease (Tsuya et al., 2010). The mortality risk for children increases by 16% when the current, but not lagged price of oatmeal increases by 10% in the main model (Table 5). Children from more central households experience lower risk of mortality than children from peripheral households, but the effect is not statistically significant ($p=0.09$). Unlike fertility, mortality responses are expected to occur in the current year and without a 9-month or longer lag. The absence of a lagged effect suggests that bad years did not have a lasting effect or that households were able to recover quickly after conditions improved. The mortality of children in households engaged in agriculture is lower than households outside of the agricultural sector, a finding consistent with prior research in this population and in Northwest Europe more generally, although the estimated hazard ratio fails to reach statistical significance. The negative effect of time is consistent with the mortality decline that occurred during the study period. For a full comparison with the fertility model, interaction terms between beta centrality and current and lagged prices are included. The direction of the covariates follows the pattern established in the fertility models, suggesting that the child mortality of peripheral households is more sensitive to unfavorable price fluctuations, but with the caveat that the estimated hazard ratios fail to obtain statistical significance.

Discussion

The concept of relational wealth considers the advantages that are conferred by ties with others and position within networks. In most historical demographic research, social and economic status are measured by listings of occupations, taxes, wages, and literacy, to name but a few. However, relational wealth is seldom investigated systematically. If one's position in the social network of a community is indeed a form of wealth, then it should be associated with standard of living, measured here by demographic responses to short-term economic stress. Social connections can buffer the effects of challenging economic times, as households that are well connected may have greater access to the support, resources, and information that may flow through these networks. Network ties may provide resources and support to households who seek assistance to cover shortfalls or smooth consumption during times of economic stress. They may also be sources of information employment opportunities for those seeking local work or labor migration as a way to cope with short-term stress.

The findings of event-history models of demographic responses to short-term economic stress support the expectation that embeddedness within local marriage and labor networks confers advantages in terms of standard of living. Households at the periphery of these networks experience lower living standards, as high food prices in the lagged year are associated with longer birth intervals. This lagged effect is consistent with fertility responses to stress that are not the result of deliberate planning, which would have a more rapid effect in the current year. The well-connected households in the community do not experience such price-related disruptions as they grew their families, an indication of higher living standards. More central households may be better able to borrow from others in times of need or call

for assistance to help with provisioning children or replacing the labor of new mothers. These resources could prevent the kinds of consumption smoothing responses that would delay fertility, such as labor migration and reduced food consumption. Indeed, their fertility is not very responsive to changes in economic conditions, suggesting that they were able to weather short-term stress while still achieving longer-term goals, including reproduction. These findings are consistent with studies from nineteenth century Europe and Asia that demonstrate inequality in standard of living across the Eurasian continent and in a range of social and economic contexts (Bengtsson et al., 2004; Tsuya et al., 2010). In addition, this network approach to the measurement of social structure may be applicable to other contexts where relational information is available, but other commonly used measures, such as wages, do not exist or are incomplete.

The mortality models suffer from fewer observed events. With respect to living standards in this period, the inhabitants of the Northern Islands were near the edge of subsistence, as even a relatively small increase in prices was associated with higher risk of child mortality. However, the social gradient with respect to network centrality is less clear in the mortality models than in the fertility models. While these results should not be over-interpreted given sample limitations, the general pattern of associations is consistent with the mortality response to short term stress observed in analyses focused on occupational sector (Jennings et al., 2017). Central network positions may be advantageous as they could improve the chances of assistance during times of stress or information about work opportunities. This support might buffer a central household so that during poor years, these households would be less likely to resort to measures that reduce food intake and increase exposure to disease and experience the associated risk of elevated mortality. In other work using a blockmodeling approach to network position, there is a clearer relationship between local social ties and the risk of child mortality (Jennings, 2017; 2018). However, the centrality approach employed here has advantages over blockmodels, as it allows for continuous measurement of network position and is less deterministic.

While this study uses network position as a proxy for socioeconomic status, it is possible that socioeconomic status could result in more central network positions. Occupation sector of the household head (agricultural vs. non-agricultural) is weakly correlated with network centrality measures. Unfortunately, a more refined status variable is not available in this dataset. Therefore, while centrality measures perform similarly to status measures used in other historical demographic analyses from Northwest Europe, it is not possible to determine to what extent the observed effects of network position indicate access to resources via the network or whether status itself affects network position through the preferential formation of ties to higher-status households. This remains a topic for future study using datasets with more precise measures of, and higher community variance in, socioeconomic status.

In this context, variation in relational wealth, measured by position within networks with social and economic meaning, is associated with variation in standard of living. It is firmly established that in most societies, “wealth buys health”. In the remote, rural population of North Orkney characterized by a flattened socioeconomic distribution, relational wealth is associated with wellbeing in terms of the ability to anticipate, adjust to, and overcome short-term economic stress, especially with respect to fertility timing.

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Figure 1.
Network map of the joint marriage and servant network, 1851–1911. Isolates removed for visual clarity. Source: NOPH database.

Figure 2.

Contour plot of the interaction of eigenvector centrality and oatmeal price effects on fertility timing. Contour lines indicate predicted relative hazards. Source: NOPH database

Table 1.
Descriptive measures of the marriage and servant networks. Source: NOPH database.

	Marriage	Servant
Count of Households	814	814
Count of Ties	1088	396
Count of Unconnected Households (Isolates)	208	450
Avg. Number of Ties per Household (Degree)	1.337	0.486
Density I	0.002	0.001

I Number of observed ties divided by the number of all possible ties

Table 2.

Hazard ratio estimates of centrality scores and BIC for models fitted with main effects. Plus and minus indicate the sign of the beta parameter. Source: NOPH database.

Centrality measure	Fertility Models		Mortality Models	
	Hazard Ratio	BIC	Hazard Ratio	BIC
Eigenvector	1.071	21396.82	0.9581	4138.39
Coreness	1.079	21396.85	0.9346	4138.07
Beta Centrality (-)	1.052	21401.77	0.8712	4137.45
Beta Centrality (+)	1.073	21396.83	0.9422	4140.27

Table 3.

Summary statistics for models of mortality and fertility. Percentages are the percent of person-years. Sources: NOPH database and grain prices archived at Orkney Library and Archive.

<i>Fertility Model</i>		<i>Mortality Model</i>		
Standardized eigenvector centrality (min, max)	-2.479, 1.282	Standardized beta centrality (min, max)	-2.055, 6.293	
Mean oatmeal price, logged, detrended (SD)	-0.0002 (0.082)	Mean oatmeal price, logged, detrended (SD)	0.0006 (0.078)	
Mean lagged oatmeal price, logged, detrended (SD)	-0.001 (0.083)	Mean lagged oatmeal price, logged, detrended (SD)	0.0020 (0.079)	
Percent previous child alive	96.18	Percent female	51.07	
Percent previous child dead	3.82	Percent male	48.90	
Percent agricultural occupation	58.86	Percent agricultural occupation	58.44	
Percent non-agricultural occupation	41.14	Percent non-agricultural occupation	41.56	
Percent age 15–24	24.54			
Percent age 25–29	40.05			
Percent age 30–34	22.78			
Percent age 35–39	9.19			
Percent age 40–49	3.45			
Person-years of observation	5369.15	Person-years of observation	49497.31	
Individuals	1020	Individuals	4293	
Births	1572	Deaths	248	

Cox proportional hazard models of the timing of second and higher order births. Robust standard errors clustered over mother's identifier. Controls for age of woman not shown. Source: NOPH database.

Table 4.

	Main Effects Model		Interaction Model	
	Hazard ratio	p-value	Hazard ratio	p-value
Eigenvector Centrality	1.065	0.003	1.071	0.002
Current Oat Price	1.012	0.961	1.026	0.915
Eigenvector Centrality X Current price	–	–	0.912	0.748
Lagged Oat Price	0.625	0.050	0.605	0.037
Eigenvector Centrality X Lagged price	–	–	2.017	0.013
Previous child died (1=yes; 0=no)	1.754	<0.001	1.746	<0.001
Agricultural Occupation (1=yes; 0=no)	1.059	0.149	1.058	0.156
Non-Agricultural Occupation, ref.	1.000	–	1.000	–
Year	0.997	0.010	0.997	0.009
N Women	1020		1020	
N Births	1572		1572	

Note: Controls for age of woman not shown

Table 5.

Cox proportional hazard models of child (1-14) mortality. Robust standard errors clustered over family identifier. Source: NOPH database.

	<u>Main Effects Model</u>		<u>Interaction Model</u>	
	Hazard ratio	p-value	Hazard ratio	p-value
Beta Centrality	0.874	0.090	0.871	0.085
Current Oat Price	4.748	0.053	4.398	0.069
Beta Centrality X Current Price	–	–	0.511	0.504
Lagged Oat Price	0.776	0.745	0.699	0.651
Beta Centrality X Lagged Price	–	–	0.418	0.364
Male	0.898	0.390	0.898	0.392
female, ref.	1.000	–	1.000	–
Agricultural Occupation	0.830	0.150	0.830	0.150
Non-Agricultural Occupation, ref.	1.000	–	1.000	–
Year	0.988	0.006	0.989	0.007
N Children	4293		4293	
N Deaths	248		248	