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Farming and Fighting: An Empirical Analysis of the Ecological-Evolutionary Theory of the Incidence of Warfare

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I. Introduction

Recent anthropological research on the causes of war falls roughly into two schools (Nolan 2003:19; Otterbein 2000:800): one which concludes that sociopolitical factors are the primary determinants of war (e.g., Otterbein 1970), and another which argues that environmental and technological factors are primary (e.g., Nolan 2003). Both "schools" have developed testable hypotheses about the conditions making a society more likely to go to war (Otterbein 2000:802). In this study we retest two hypotheses initially tested by Nolan (2003): first, more productive subsistence technology leads to more war; and second, higher population density leads to more war.

Both hypotheses come from ecological-evolutionary theory, which asserts that subsistence technology is the single most important factor affecting how societies are organized and how they interact with one another (Nolan 2003:20). Ecological-evolutionary theory predicts warfare is more frequent in societies with more productive subsistence technology for three main reasons. First, armies need to eat; a society with unproductive subsistence technology would not have the food stock to sustain soldiers in a prolonged conflict. Second, food stores make for attractive targets; hence, societies with more productive subsistence technology are more likely to be attacked. And third, fixed investments in fields and structures give a society with more productive subsistence technology a strong incentive to defend its territory from attackers.

The subsistence technology type that has probably sparked the most controversy is hunter-gatherers (Otterbein 2000). Some have claimed that, compared to other societies, hunter-gatherers are relatively peaceful (Lee and DeVore 1968:9, Service 1966, Steward 1968:334, Turnbull 1968:341) while others disagree (Ember 1978, Keeley 1996). Ecological-evolutionary theorists tend towards the 'relatively peaceful' side of the debate. Nolan (2003:21), for example, argues that hunter-gatherers usually lack the resources to sustain them during long periods of warfare. Likewise, they have little to be plundered and find it feasible to walk away from a confrontation and move to a new area.

Ecological-evolutionary theorists expect the frequency of warfare to be higher among horticulturalists than among hunter-gatherers. Horticulturalists own more resources than hunting-gathering societies, and are more attractive targets. While hunter-gatherers can with relative ease walk away from an attack and move to a new location (one of the primary means of conflict resolution in such societies), horticulturalists are more likely to defend their lands and structures (Nolan 2003:21). And since metal tools make horticulturalists more productive, and metal weapons make warriors more deadly, horticulturalists are expected to have even higher rates of warfare if they have learned to use metal (Nolan 2003:21). Slavery has a similar effect in increasing the frequency of war: armies can capture slaves, which can then be used to produce food, which can be used to feed armies, which can then capture more slaves – thus creating a positive-feedback warfare-slavery system (Nolan 2003:21).

Ecological-evolutionary theorists expect plow agriculturalists ("agrarians") to have even higher frequencies of external warfare than horticulturalists (Nolan 2003:21), since they have more productive subsistence technology, which compounds the warfare incentives affecting horticulturalists. Agrarians are even more reliant on their land than horticulturalists and therefore even less likely to walk away from a confrontation; they can produce even larger and more diverse food stores - further incentivizing plunderers; their larger food stores can feed larger armies; and slavery becomes even more profitable as more productive technology increases the returns to labor. For these reasons, most previous studies of the ecological-evolutionary theory of warfare have supported the idea that as subsistence technology becomes more productive, the frequency of warfare increases.

The hypothesis of a positive correlation between population density and warfare is based upon the notion that, within a given subsistence technology type, increases in population density will increase the pressure on a society's resources, thus motivating a society to plunder the resources and conqueror the arable lands of its neighbors. Hence, some studies (e.g., Kelly 2000) maintain that the frequency of warfare will increase as population density increases. Other studies (e.g., Nolan 2003:24; Keeley 1996:202) argue for a cubic relationship – claiming that warfare increases, decreases, and finally increases again across categories of increasing population density. In his study of precontact Polynesia, Younger (2008:931) finds a negative relationship between population density and violence. Thus, there is by no means a consensus within the literature about this relationship.

II. Methodological problems of previous studies

In a 2003 paper published in *Sociological Theory*, Patrick D. Nolan sets out to test whether certain modes of subsistence are "structurally conducive" to warfare (Nolan 2003:20). Using variables from the Standard Cross-Cultural Sample (Murdock and White 1969; White et al. 2009), Nolan produces a number of contingency tables, examining whether the frequency of warfare varies across four subsistence modes (foraging; simple horticulture; advanced horticulture; and agrarian) and by population density. He finds that societies with advanced horticulture or agrarian subsistence engage in warfare much more frequently than those with foraging or simple horticulture. He also finds that high population densities are associated with more war in societies with foraging or agrarian subsistence, but not in those with horticulture.

While we find much of value in Nolan's theoretical discussion, there are serious problems with his empirical analysis. First, in adopting a contingency table approach, Nolan chooses a method that requires *reducing* the variation found in the original SCCS variables, in order to have relatively few cells in each table. Thus he takes a measure of frequency of warfare (SCCS *v1648*), available in the SCCS with 18 discrete values, and turns it into a dummy variable, with only two discrete values. Likewise, he employs only four general subsistence categories, a feat he manages by lumping hunting with gathering, and discarding 54 of the 186 SCCS societies that subsist as mounted hunters, fishers, pastoralists, or rely equally on two or more subsistence modes (Nolan 2003:30; Nolan and Lenski 2004:372-373). Particularly problematic is the removal of relatively warlike pastoralists and mounted hunters from his sample. Table 1 compares Nolan's categories with the categories given in SCCS *v858*.

Table 1: Comparison of Patrick Nolan's subsistence technology categories with SCCS variable v858 "Subsistence Type - Ecological Classification".

v858: Subsistence Type – Ecological Classification	Hunting & Gathering	Simple Horticulture	Advanced Horticulture	Agrarian	other
Gathering	9	0	0	0	0
Hunting and/or marine animals	8	0	0	0	1
Fishing	6	0	0	0	6
Anadromous fishing (spawning fish)	0	0	0	0	8
Mounted hunting	0	0	0	0	5
Pastoralism	0	0	2	0	16
Shifting cultivation, digging sticks or wooden hoes	3	17	5	1	7
Shifting cultivation, with metal hoes	0	3	16	0	0
Horticultural gardens or tree fruits	1	9	2	0	6
Intensive agriculture, with no plow	0	5	13	1	4
Intensive agriculture, with plow	0	1	2	28	1

Notes: Nolan's taxonomy based on Nolan and Lenski (2004:372-373). SCCS variable v858 created by Doug White, based on work by Karen and Jeffrey Paige.

The four subsistence taxonomies presented in the SCCS provide much richer detail: variable *v246* has seven categories; variable *v833* has eight; variable *v858* has 11; and combining variables *v833* (dominant subsistence mode) and *v834* (subsidiary subsistence mode) gives 28 categories. But even more variation can be found by using variables *v814-v819*, which provide actual ordinal measures of the percentage dependence on each category of agriculture, domestic animals, fishing, hunting, gathering, and trade. Variation is the great friend of any statistical analysis, and the SCCS contains variables that provide abundant variation on subsistence technology. That Nolan reformulates his variables to *reduce* variation is due simply to his choice of technique—contingency tables work well only when there are relatively few cells in the table.

Contingency tables also limit the analysis to pairwise relationships between variables, and at best can be modified to fit a three-way relationship. When there are confounding variables, as there always are, the results from a pairwise analysis will be biased. It is on this count that multivariate models provide their greatest advantage: one can control for the effects of other variables and thus produce unbiased estimates. And because multivariate methods consider a large set of variables, one can gain a sense of how important a particular relationship is in the grander scheme of things.

Galton's problem—the confounding effect of cultural transmission—is a major methodological issue in empirical studies using cross-cultural survey data. There are no effective ways to control for Galton's problem within a contingency table framework and Nolan wisely does not try. Dow (2007) has developed an effective way of modeling Galton's problem within a multivariate model framework, which provides yet another advantage to multivariate methods over contingency tables.

Finally, there is the problem of missing data. As shown by Dow and Eff (2009a, 2009b), dropping observations for which data values are missing can lead to bias, even within a multivariate modeling context. Nolan dropped observations that were not even missing—removing 54 societies that did not fit neatly into his subsistence taxonomy categories (Nolan 2003:30; Nolan and Lenski 2004:372-373). The appropriate way to handle missing data is the technique of multiple imputation (Dow and Eff 2009b).

Nolan's empirical work does not do justice to his theoretical discussion. In what follows, we investigate the role of subsistence technology and population density in causing war, using contemporary best-practice statistical methods.

III. Methodology

Variable selection

The data used in this study comes from the Standard Cross-Cultural Sample (Murdock and White, 1969). Our dependent variable *v1650* measures the frequency of *external* warfare (warfare with other societies). Previous studies of the ecological-evolutionary theory of warfare (i.e. as in Nolan 2003 and Lenski and Lenski 1978), used variable *v1648*, which measures the *overall* frequency of warfare. Since the causes for internal (or civil) warfare are believed to be different from the causes of external warfare, we make this distinction. The coders of *v1650* use a scale from 1 to 17 with larger values representing a higher frequency of external warfare (Ember and Ember, 1992a).[1] Figure 1 shows the location of the SCCS societies; larger and darker points represent higher values of *v1650*, while the circled X's indicate societies with missing values.

Table 2 shows the descriptive statistics for all the variables used in this study. Since our main objective is to test the ecological-evolutionary theory of the incidence of warfare, our primary variables of interest are those dealing with subsistence technology. Rather than using discrete categories of subsistence technology such as hunting and gathering, horticulture, and agrarian, we use the proportion of subsistence derived from each of five types of activities: agriculture (*v814*), domesticated animals (*v815*), fishing (*v816*), hunting (v817), gathering (*v818*), and trade (*v819*). This specification allows for much more variation.

We make every effort to specify our model in a way consistent with Nolan's theoretical perspective. Regarding the relationship between the frequency of warfare and population density, Nolan states that:

> " …the impact of density on societies has always been acknowledged to be highly conditioned by the level and type of technology that they rely on for their subsistence… Thus, across levels of technology, density is not an accurate indicator of population pressure… To see if population pressure is related to the frequency of warfare, it is imperative to look at the effects of density within categories of subsistence technology (Nolan 2003:24)."

Nolan thus argues that population density has a differently calibrated effect within each subsistence category. We attempt to model this by using interaction terms between subsistence activities and population density, as well as population density by itself, as independent variables. Since there are several good measures of population density

[1] The original code contained values 1 through 5 and was used in a number of published studies (Ember and Ember 1992b; Ember et al. 1992; Ember and Ember 1994). The code was subsequently revised to values between 1 and 17 by Carol Ember, Melvin Ember, and J. Patrick Gray (Carol Ember, personal communication).

within the SCCS, we create a composite variable for population density, using three of these measures.[2] This composite variable proved endogenous, suggesting that there is a feedback relationship between population density and war—a result consistent with the views of Turchin (2007) and Turchin and Korotayev (2006). The composite variable was replaced with an instrument created by regressing the composite variable on the exogenous independent variables and a set of variables related to climate and ecology developed by Hijmans et al. (2005).[3] It is this instrument (which we call *pdens*) that is used to produce all of our results reported in the Tables and Figures.

Nolan (2003) found no effect of population density on the frequency of warfare among simple horticultural societies and found evidence for a (almost significant) negative relationship for advanced horticultural societies. He proposed that these results may indicate "…the importance of an unmeasured variable in this analysis – features of the biophysical environment that affect subsistence and social organization. What is needed to address this possibility is an objective measure for the key dimensions of the environment comparable to that used for mode of subsistence…" (Nolan 2003:28). We create the environmental taxonomy variable Nolan suggests by merging the SCCS with major terrestrial habitat type data from a GIS shapefile created by Olson et al (2001). Twelve dummy variables (*mht.name*) were then created for these habitat types.

Otterbein's (1994) empirical work on the causes of war found no significant economic or ecological determinants. Instead, political structures seemed to have the most influence. We introduce a number of variables related to political structures, both as controls (to avoid omitted variable bias) and to establish whether political factors do indeed outweigh economic-ecological factors.

The number and quality of a society's neighbors obviously condition its probability of engaging in external war. Since a community will be less constrained in going to war if it is autonomous – that is, if it is not part of a larger polity – we include a variable for political autonomy (*v81*). And if a community is isolated from others, it will be less likely to engage in war—a pattern Younger (2008) observed in Polynesia. To capture isolation, we introduce two variables: *v1874* gives the number of other societies within a 100 mile radius; and *v787* measures the *in*frequency of contact with other societies.

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[2] The three variables are *v64*, *v156*, and *v1130*; the composite is the mean of the normalized values of the three variables. The proportion of their variation explained by the first principal component is 0.948; Cronbach's alpha is 0.972.

[3] The 23 variables related to climate and ecology are *bio.1-19*, *meanalt*, *sdalt*, *medianalt*, and *CValt*, found in the sccsA dataset in the zip folder accompanying this article. The R^2 for the regression creating the instrument is 0.839.

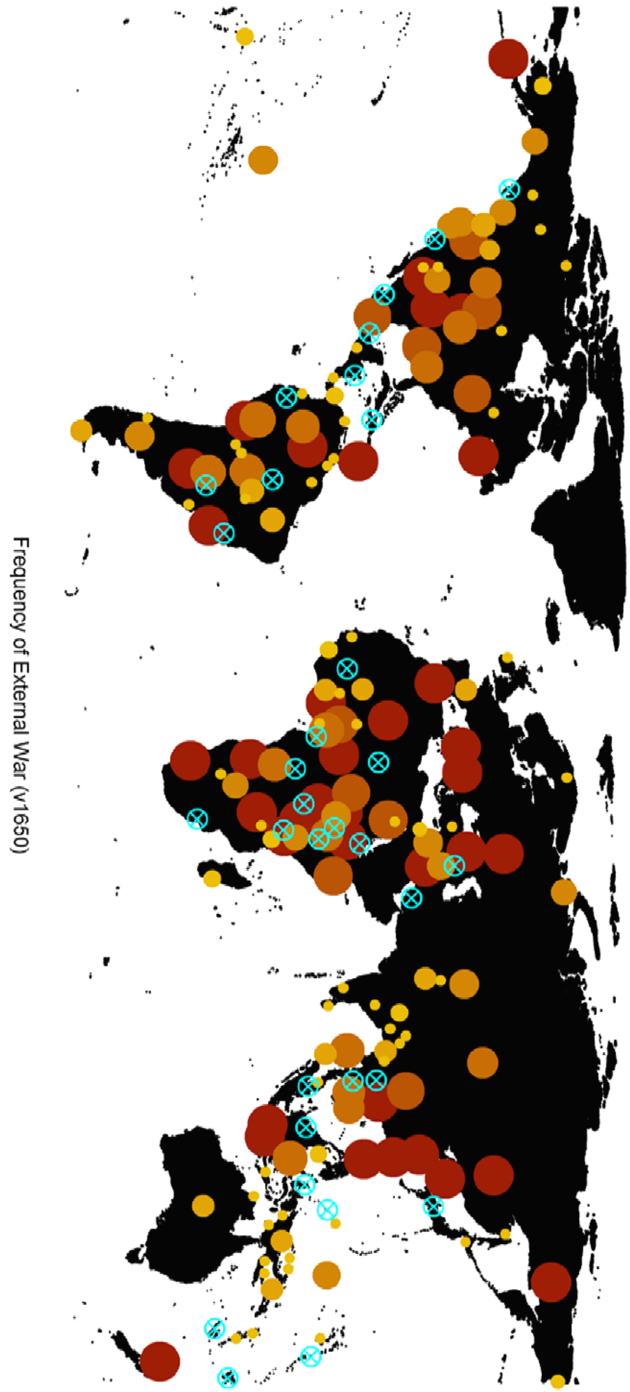

Figure 1: Each point represents a SCCS society. The larger and darker the circle, the more frequently the society engaged in external warfare. The circled Xs are the 32 societies with missing data for variable v1650, which were not used in this study.

Table 2: Variables Used.

Ordinal variables		n	mean	sd	max	min
v1650	Frequency of external warfare	154	8.1	6.66	17	1
v814	Importance of agriculture	186	36.47	26.34	99	0
v815	Importance of domes. anim	186	13.9	18.1	90	0
v816	Importance of fishing	186	15.97	18.73	90	0
v817	Importance of hunting	186	14.89	16.3	80	0
v818	Importance of gathering	186	11.26	13.66	75	0
v819	Importance of trade	186	7.63	10.34	65	0
v17	Money (media of exchange) and credit	183	2.61	1.55	5	1
v81	Political autonomy	184	3.67	1.52	6	1
v238	High gods	168	2.15	1.19	4	1
v826	Average female contribution to subsistence	183	32.87	16.55	79	0
v149	Writing and records	186	2.35	1.47	5	1
v787	(low) Contact with other societies	87	1.64	0.75	3	1
v757	Political and religious differentiation	83	2.08	0.8	3	1
v575	Unstable political power index	76	1.78	1.02	4	1
v236	Jurisdictional hierarchy of local community	186	2.89	0.6	4	2
v63	Community size	185	3.47	1.71	8	1
v1874	Atlas: Number of societies within 100 mile radius	183	2.53	3.69	25	0
v64	Population density	184	3.76	1.98	7	1
v156	Density of population	186	2.86	1.56	5	1
v1130	Population density	186	3.94	1.58	7	2
v153	Technological specialization	186	3.09	1.41	5	1
Categorical variables		*nobs*	*ncats*	*smCatN*	*bgCatN*	
v248	Sex differences in metal working	183	6	1	101	
v254	Age or occupational specialization in metal working	183	4	2	105	
v140	Metal	179	4	1	93	

Dummies

mht.name: WWF major habitat type	Freq	v93: Political power - most important source	Freq
Boreal forest/taigas	8	Direct subsistence production	90
Deserts and xeric shrublands	15	Warfare wealth	11
Flooded grasslands	1	Tribute or taxes	3
Mediterranean scrub	3	Slaves	13
Montane grasslands	4	Contributions of free citizens	20
Snow, ice, glaciers, and rock	2	Large land-holdings	12
Temperate broadleaf and mixed forests	13	Political office	14
Temperate coniferous forests	15	Foreign commerce	6
Temperate grasslands, savannas, and shrublands	8	Capitalistic enterprises	11
Trop. & subtrop. coniferous forests	2	Priestly services	3
Trop. & subtrop. dry broadleaf forests	12	NA	3
Trop. & subtrop. grasslands, savannas, and shrublands	32		
Trop. & subtrop. moist broadleaf forests	66		
Tundra	4		
Water	1		

Notes: mht.name is major terrestrial habitat type, from GIS shapefile, created by Olson et al (2001). The number of categories for each categorical variable is given by *ncats*; the number of observations in the category with fewest observations is given by *smCatN*; the number in the category with the most observations is *bgCatN*.

In his 2008 study of pre-contact Polynesia, Younger finds that warfare often was initiated by elites in order to enhance their own status and power (Younger 2008:931). To test if the methods by which individuals gain political power affect the frequency of warfare, we make use of SCCS variable *v93* – "political power: most important source." As shown in Table 2, *v93* categorizes each society by the power-obtaining strategy most often used by its elites. For example, in some societies, political power is obtained by large land holdings while in others it is gained by those who perform priestly services. It seems likely that warfare would be especially encouraged in those societies where "warfare wealth" or "slaves" are the predominant status-attaining strategy. We create dummy variables for each of these political power sources and include nine of them in our model.

Wealth accumulation provides the means for elites to enhance their status, and this status-enhancement strategy is both an alternative to the strategy of war and can be disrupted by war, making war less attractive to elites. SCCS variable *v17* was included as a scale for the use of money and credit.

Small communities are less likely to have powerful elites (Younger 2008:931; Boehm 1999), and are therefore less likely to be driven by elites to war. In fact, Younger's (2008:932) study of Polynesian war found that smaller communities were more peaceful. We therefore include a scale for community size (*v63*). Elites will also be less able to drive a society to external war when their power is less secure; variable *v575* was included as an "unstable political power index."

If local political structures are complex, elite power may be fragmented, and it may be difficult for all relevant actors to agree upon a course of action, which would make war less frequent. For this reason, *v236*, a measure of the number of levels in the jurisdictional hierarchy of the local community, is included. Similarly, we introduce variable *v757*, which measures whether political authority is simultaneously religious authority, reasoning that more heterogeneous elites are less likely to find common cause in external war.

Military historians speak of the three "C's" in the analysis of war: causes, conduct, and consequences (Otterbein 1999:802). Our analysis focuses on the causes of war, but features of a society facilitating its conduct will also serve to make a society more likely to go to war, and in this way the feature can be seen as a cause. For example, when females contribute a great deal to subsistence, the opportunity cost of sending a man to war is lower, and the choice of war therefore is less costly. For this reason, we include variable *v826*, "average female contribution to subsistence."

Certain kinds of technology facilitate the conduct of war. For example, the development of metal weapons makes warfare more practicable and increases its incidence (Nolan 2003). Thus, we create the variable *metal* as the composite for four (somewhat contradictory) SCCS variables concerning the use of metal tools and weapons.[4] Similarly, Nolan (2003:21) notes that limited communications and transportation technology "were the only real constraints" horticulturalists faced in using war to control more land and subject peoples. We employ here *v149*, which measures the degree to which a society utilizes writing and records.

A prior study by Brown and Eff (2010) found the frequency of external warfare and the presence of moralizing gods to be inversely related; suggesting that morality

[4] The four dummy variables are: (v248<9); (v254<9); (v153>=4); (v140>0). Their mean gives the variable *metal*. Cronbach's alpha for the four dummies is 0.9614. The first principal component of the four dummies explains 0.8963 of their total variation.

reinforced by supernatural forces may serve to constrain warlike behavior. We investigate this by including SCCS variable *v238* in our model.

Table 3: Variables used in unrestricted model: imputed and normalized.

varb	SCCS	label	mean	sd	min	max
v814(s)	v814	Importance of agriculture	0.000	1.000	-1.349	1.921
v815(s)	v815	Importance of domes. anim	0.000	1.000	-0.765	4.177
v816(s)	v816	Importance of fishing	0.000	1.000	-0.852	3.880
v817(s)	v817	Importance of hunting	0.000	1.000	-0.936	3.952
v818(s)	v818	Importance of gathering	0.000	1.000	-0.870	4.778
v819(s)	v819	Importance of trade	0.000	1.000	-0.745	5.246
pdens(1) (s)	*composite*	Population density	0.000	0.997	-1.970	1.845
v17(s)	v17	Money (media of exchange) and credit	0.000	0.999	-0.977	1.614
v81(s)	v81	Political autonomy	0.000	0.998	-1.803	1.550
v238(s)	v238	High gods	0.000	0.991	-0.939	1.631
v826(s)	v826	Average female contribution to subsistence	0.000	0.995	-1.950	2.888
v149(s)	v149	Writing and records	0.000	1.000	-0.985	1.773
v787(s)	v787	(low) Contact with other societies	0.000	0.908	-0.969	1.836
v757(s)	v757	Political and religious differentiation	0.000	0.875	-1.269	1.213
v575(s)	v575	Unstable political power index	0.000	0.842	-0.855	2.076
v236(s)	v236	Jurisdictional hierarchy of local community	0.000	1.000	-1.526	1.855
metal(2) (s)	*composite*	Presence of metal technology	0.000	1.000	-0.981	1.131
v63(s)	v63	Community size	0.000	1.000	-1.431	2.640
v1874(s)	v1874	Number of societies within 100 miles	0.000	0.996	-0.666	5.871
v93	*v93*	*Political power - most important source*				
v93.SubsProd	v93==0	Direct subsistence production	0.494	0.502	0.000	1.000
v93.WarWealth	v93==1	Warfare wealth	0.065	0.247	0.000	1.000
v93.Slaves	v93==3	Slaves	0.067	0.248	0.000	1.000
v93.FreeContrib	v93==4	Contributions of free citizens	0.097	0.297	0.000	1.000
v93.LargeLand	v93==5	Large land-holdings	0.071	0.258	0.000	1.000
v93.PoliOffice	v93==6	Political office	0.084	0.274	0.000	1.000
v93.ForgnCommerce	v93==7	Foreign commerce	0.030	0.166	0.000	1.000
v93.CapitalistEnt	v93==8	Capitalistic enterprises	0.058	0.235	0.000	1.000
v93.PriestlyServ	v93==9	Priestly services	0.020	0.139	0.000	1.000
mht.name(3)		*WWF major habitat type*				
mht.Taiga		Boreal forest/taigas	0.052	0.223	0.000	1.000
mht.Xeric		Deserts and xeric shrublands	0.091	0.288	0.000	1.000
mht.Maquis		Mediterranean scrub	0.013	0.114	0.000	1.000
mht.MountGrass		Montane grasslands	0.019	0.139	0.000	1.000
mht.SnowIceRock		Snow,ice,glaciers,and rock	0.013	0.114	0.000	1.000
mht.TempBroadLeaf		Temperate broadleaf and mixed forests	0.078	0.269	0.000	1.000
mht.TempConif		Temperate coniferous forests	0.084	0.279	0.000	1.000
mht.TempGrass		Temperate grasslands,savannas,shrublands	0.052	0.223	0.000	1.000
mht.TropSubDryBroadLeaf		Trop. & subtrop. dry broadleaf forests	0.071	0.258	0.000	1.000
mht.TropSubGrass		Trop. & subtrop. grasslands,savannas,shrublands	0.182	0.387	0.000	1.000
mht.TropSubWetBroadLeaf		Trop. & subtrop. moist broadleaf forests	0.299	0.459	0.000	1.000
mht.Tundra		Tundra	0.026	0.160	0.000	1.000
v814pdens	v814*pdens	Importance of agriculture:Population density	0.684	0.827	-1.328	2.658
v815pdens	v815*pdens	Importance of domes. anim:Population density	0.093	0.848	-3.603	1.507
v816pdens	v816*pdens	Importance of fishing:Population density	-0.277	0.900	-3.500	2.498
v817pdens	v817*pdens	Importance of hunting:Population density	-0.671	1.119	-6.274	0.933
v818pdens	v818*pdens	Importance of gathering:Population density	-0.504	1.183	-8.522	0.973
v819pdens	v819*pdens	Importance of trade:Population density	0.314	1.008	-1.827	7.424
v819.2	v819^2	Importance of trade – squared	0.994	2.725	0.031	27.520
v236.2	v236^2	Jurisdictional hierarchy of local community -- squared	0.994	1.340	0.027	3.442
v81.3	v81^3	Political autonomy -- cubed	-0.187	2.336	-5.860	3.725
v814.2	v814^2	Importance of agriculture -- squared	0.994	0.765	0.000	3.691

Notes: Statistics describe the mean value across the 10 imputed data sets for the 154 societies for which the dependent variable (v1650: Frequency of External War) is non-missing. (s) variable is normalized. (1) *pdens* is created as the mean of the normalized SCCS variables v64, v156, v1130. (2) *metal* is the mean of the following dummy variables: (v248<9), (v254<9), (v153>=4), (v140>0). (3) mht.name is major terrestrial habitat type, from GIS shapefile, created by Olson et al (2001).

Some of the relationships between the frequency of external war and our independent variables could be non-linear. After some exploratory data analysis, we included four higher-order terms to model for possible polynomial effects: the square of the importance of trade (*v819.2*); the square of the importance of agriculture (*v814.2*); the square of the number of levels in the local jurisdictional hierarchy (*v236.2*); and the cube of political autonomy (*v81.3*).

Table 3 describes the variables used in the unrestricted model and gives their summary statistics post imputation and normalization.

Model

Because of missing data and Galton's problem, estimation bias is often a problem when using the SCCS. To avoid this bias, we follow the methodology developed by Dow (2007), Dow and Eff (2008, 2009a, 2009b), Eff and Dow (2008, 2009), and Eff (2008), basing our R scripts on those used in Eff and Dow (2009) and Brown and Eff (2010). Multiple imputation was used to deal with the problem of missing data. This was done with the help of the R package *mice* developed by Van Buuren and Oudshoorn (2009). While listwise deletion is the most common method for dealing with missing data, it must be noted that the SCCS contains only a small number of societies (186). Hence, the issue of missing data is especially severe and listwise deletion can lead to sample sizes that are too small to use. The issue of Galton's problem is addressed by using a composite weight matrix which includes geographic, linguistic, and religious proximity. Geographic and religious proximity capture the most important sources of horizontal cultural transmission, while linguistic proximity captures vertical cultural transmission.

The model takes the form: $y = \rho \mathbf{W} y + \beta \mathbf{X} + \varepsilon$, where y is the dependent variable (frequency of external warfare), $\mathbf{W}$ is the composite weight matrix, $\mathbf{W}y$ is the network-lagged dependent variable, $\mathbf{X}$ is the matrix of independent variables, ρ is the scalar coefficient for the spatially-lagged dependent variable, β is the vector of estimated coefficients for the independent variables, and ε is the vector of error terms. Since $\mathbf{W}y$ is endogenous, the model must be estimated using two-stage least squares, as described by Dow (2007).

IV. Estimation and Results

Using the R package *mice* (Van Buuren and Oudshoorn 2009), the data described in the previous section, and the auxiliary data described in Eff and Dow (2009), we create 10 imputed data sets. Our next step is to find the optimal composite weight matrix. We find $\mathbf{W}$ by estimating several models containing all candidate independent variables, as well as the single cultural transmission term $\mathbf{W}y$, where $\mathbf{W}$ is a linear combination of the geographic distance, linguistic proximity, and religion matrices: $\mathbf{W} = \omega_D \mathbf{W}_D + \omega_L \mathbf{W}_L + \omega_R \mathbf{W}_R$. Each of the models differs in ω_D, ω_L, and ω_R, which take on different values but where $\omega_D + \omega_L + \omega_R = 1$ always holds.[5] In our case, the optimal weight matrix, and thus the one used in our models, is the one that takes on the highest model R^2. This weight matrix has parameter values: $\omega_D = 0.52$, $\omega_L = 0.01$, and $\omega_R = 0.47$, suggesting that vertical

[5] Each of the matrices $\mathbf{W}_D$, $\mathbf{W}_L$, and $\mathbf{W}_R$ is row-normalized, so that the rows sum to one. By setting the sum of the weights equal to one, the composite matrix will also be row-normalized.

cultural transmission (descent from ancestral populations) is negligible as a channel for warfare, and that horizontal transmission—through geographic diffusion or the channel of religion—is all-important.

Table 4: Unrestricted Model.

varb	label	coef	p-value	VIF	
(Intercept)	Intercept	0.24885	0.738	NA	
Wy	Network lag term	0.58337	0.035	2.1	**
v814	Importance of agriculture	1.19560	0.435	822.9	
v815	Importance of domes. anim	0.83184	0.443	411.8	
v816	Importance of fishing	0.90822	0.424	452.6	
v817	Importance of hunting	0.65157	0.51	343.9	
v818	Importance of gathering	0.39901	0.617	222.8	
v819	Importance of trade	0.29875	0.625	131.3	
pdens	Population density	-0.34869	0.086	13.7	*
v17	Money (media of exchange) and credit	0.13248	0.186	3.4	
v81	Political autonomy	0.44459	0.015	12.0	**
v238	High gods	-0.43206	0	2.0	***
v826	Average female contribution to subsistence	0.05954	0.389	1.6	
v149	Writing and records	0.17016	0.09	3.4	*
v787	(low) Contact with other societies	-0.16017	0.038	1.8	**
v757	Political and religious differentiation	0.13852	0.095	1.6	*
v575	Unstable political power index	0.12103	0.131	1.8	
v236	Jurisdictional hierarchy of local community	-0.16309	0.017	1.6	**
metal	Presence of metal technology	0.32026	0.002	3.7	***
v63	Community size	-0.02978	0.772	3.5	
v1874	Number of societies within 100 miles	-0.03271	0.652	1.8	
v93	*Political power- most important source*				
v93.SubsProd	Direct subsistence production	-0.05599	0.923	25.2	
v93.WarWealth	Warfare wealth	0.94348	0.126	7.4	
v93.Slaves	Slaves	-0.32198	0.589	6.7	
v93.FreeContrib	Contributions of free citizens	-0.25369	0.67	9.9	
v93.LargeLand	Large land-holdings	-0.03990	0.949	8.1	
v93.PoliOffice	Political office	-0.14194	0.823	9.0	
v93.ForgnCommerce	Foreign commerce	-0.09378	0.901	4.2	
v93.CapitalistEnt	Capitalistic enterprises	-0.94041	0.149	7.4	
v93.PriestlyServ	Priestly services	0.12028	0.87	3.2	
mht.name	*WWF major habitat type*				
mht.Taiga	Boreal forest/taigas	-1.08795	0.071	6.3	*
mht.Xeric	Deserts and xeric shrublands	0.08647	0.871	8.2	
mht.Maquis	Mediterranean scrub	0.80151	0.295	2.6	
mht.MountGrass	Montane grasslands	0.57924	0.378	2.9	
mht.SnowIceRock	Snow, ice, glaciers, and rock	-0.03308	0.965	2.6	
mht.TempBroadLeaf	Temperate broadleaf and mixed forests	0.92839	0.098	7.6	*
mht.TempConif	Temperate coniferous forests	-0.48360	0.397	8.6	
mht.TempGrass	Temperate grasslands, savannas, shrublands	0.36261	0.54	6.1	
mht.TropSubDryBroadLeaf	Trop. & subtrop. dry broadleaf forests	-0.21173	0.717	7.5	
mht.TropSubGrass	Trop. & subtrop. grasslands, savannas, shrublands	0.45470	0.395	14.7	
mht.TropSubWetBroadLeaf	Trop. & subtrop. moist broadleaf forests	0.08937	0.863	19.3	
mht.Tundra	Tundra	-0.23504	0.721	3.8	
v814pdens	Importance of agriculture:Population density	-4.24671	0.029	871.7	**
v815pdens	Importance of domes. anim:Population density	-2.96865	0.029	447.3	**
v816pdens	Importance of fishing:Population density	-3.14604	0.027	551.1	**
v817pdens	Importance of hunting:Population density	-2.62587	0.031	623.6	**
v818pdens	Importance of gathering:Population density	-2.23592	0.026	471.7	**
v819pdens	Importance of trade:Population density	-1.71396	0.034	222.4	**
v819.2	Importance of trade – squared	-0.00086	0.983	4.0	
v236.2	Jurisdictional hierarchy of local comm. –squared	-0.14015	0.003	1.4	***
v81.3	Political autonomy – cubed	-0.15424	0.037	10.5	**
v814.2	Importance of agriculture – squared	-0.19266	0.095	2.6	*

Notes: The dependent variable is normalized frequency of external war (v1650). R^2 = 0.717; N=154; number of imputations=10; standard errors and R^2 adjusted for two-stage least squares. The variable *pdens* was originally endogenous, instrumental variable used above (in interaction terms as well). "***" p-value ≤0.01, "**" p-value ≤0.05, "*" p-value ≤0.10. Composite matrix weights: distance=0.52, language=0.01, religion=0.47.

Table 5: Restricted Model.

variable	label	coef	p-value	VIF	stdcoef	R2p	Hausman p-value
(Intercept)	Intercept	0.37445	0.000 ***				
Wy	Network lag term	0.69292	0.002 ***	1.5	0.195	0.0649	0.567
pdens	Population density	-0.42464	0.000 ***	3.4	-0.425	0.0246	0.590
v238	High gods	-0.38328	0.000 ***	1.4	-0.383	0.0511	0.186
v149	Writing and records	0.21237	0.005 ***	2	0.212	0.0305	0.635
v787	(low) Contact with other societies	-0.17588	0.011 **	1.5	-0.176	0.0511	0.325
metal	Presence of metal technology	0.35642	0.000 ***	2.5	0.356	0.0649	0.380
v93.WarWealth	Warfare wealth	1.08734	0.000 ***	1.2	0.269	0.0668	0.661
v93.CapitalistEnt	Capitalistic enterprises	-0.72245	0.005 ***	1.3	-0.170	0.0324	0.267
mht.Taiga	Boreal forest/taigas	-1.13971	0.000 ***	1.8	-0.254	0.0226	0.086
mht.TempBroadLeaf	Temperate broadleaf and mixed forests	0.91849	0.000 ***	1.2	0.247	0.0560	0.194
mht.TempConif	Temperate coniferous forests	-0.46898	0.032 **	1.4	-0.131	0.0118	0.119
v814pdens	Importance of agriculture:Population density	-4.01889	0.014 **	648.9	-3.337	0.0098	0.531
v815pdens	Importance of domes. anim:Population density	-2.80426	0.014 **	332	-2.384	0.0049	0.560
v816pdens	Importance of fishing:Population density	-3.03627	0.011 **	407.8	-2.740	0.0049	0.559
v817pdens	Importance of hunting:Population density	-2.47450	0.016 **	467.5	-2.775	0.0049	0.553
v818pdens	Importance of gathering:Population density	-2.02308	0.016 **	347.9	-2.397	0.0059	0.481
v819pdens	Importance of trade:Population density	-1.67099	0.014 **	165.1	-1.688	0.0059	0.442
v236	Jurisdictional hierarchy of local community	-0.17479	0.003 ***	1.2	-0.175	0.0147	0.351
v236.2	Jurisdictional hierarchy of local community -- squared	-0.15410	0.000 ***	1.2	-0.206	0.0413	0.442
v81	Political autonomy	0.37136	0.020 **	9.1	0.371	0.0334	0.970
v81.3	Political autonomy -- cubed	-0.13719	0.039 **	8.7	-0.321	0.0190	0.813
v814	Importance of agriculture	0.14794	0.072 *	2.4	0.148	0.0059	0.678
v814.2	Importance of agriculture -- squared	-0.21464	0.019 **	1.8	-0.164	0.0147	0.741

diagnostic test	p-value
Wald test. H0: appropriate variables dropped	0.688
Breusch-Pagan test. H0: residuals homoskedastic	0.598
Shapiro-Wilkes test. H0: residuals normal	1.000
LM test. H0: Spatial lag (language) not needed	0.130

Notes: The dependent variable is frequency of external war (v1650). R^2 = 0.648; N=154; number of imputations=10; standard errors and R^2 adjusted for two-stage least squares. The variable *pdens* was originally endogenous, instrumental variable used above (in interaction terms as well). "***" p-value ≤0.01, "**" p-value ≤0.05, "*" p-value ≤0.10. Composite matrix weights: distance=0.52, language=0.01, religion=0.47. R^{2p} is the R^2 partitioned to each independent variable (Chevan and Sutherland 1991; Grömping 2006).

This optimal weight matrix is used to estimate an unrestricted model. Table 4 shows the results of this unrestricted model along with the estimated coefficients, p-values, and variance inflation factors. Using this model as our starting point, we drop insignificant variables and use a Wald test to judge the appropriateness of our restricted model.

After several iterations, we end up with a final restricted model, shown in Table 5. The coefficients of the independent variables are all significant. Table 5 shows two ways of assessing the relative importance of each independent variable: standardized coefficients and hierarchically partitioned R^2 (Chevan and Sutherland 1991; Grömping 2006). Standardized coefficients give the number of standard deviations the dependent variable changes for a one standard deviation increase in the independent variable. The partitioned R^2s show each variable's contribution to the model's R^2. From this, we can see that the network lag term (***Wy***), *metal*, and *v93.WarWealth* explain the most variation in the frequency of war, with both *v238* (High Gods) and *v787* (Contact with other societies) close behind.

As ecological-evolutionary theorists have suggested, we have specified our model to show complex relationships between subsistence type, population density, and the frequency of warfare. We have also used polynomial specifications for a few other independent variables. It is difficult to comprehend interaction and polynomial relationships by simply viewing a table of estimated coefficients, and we have therefore plotted the estimated effects for these complex relationships in Figures 2 through 5 (described at length in the following section).

The results of the diagnostics are all satisfactory. The Wald test shows that the appropriate independent variables were dropped (Wooldridge 2006:587). The Breusch-Pagan test shows that heteroskedasticity is not a problem (Wooldridge 2006:280). The LM test for spatial lag shows that linguistic proximity was not needed (Anselin 1988; Bivand et. al. 2009). The Shapiro-Wilk test shows that the residuals follow a normal distribution (Shapiro and Wilk 1965). The Hausman test (Wooldridge 2006:532-533) is performed on all of the independent variables in the final model. The results show that at the 0.05 size of test, none of the variables are endogenous.

V. Discussion

For any model $y=f(x)$, the *marginal effect* of x on y is the change in y caused by a one unit increase in x (i.e., it is the first derivative $\delta y/\delta x$). Thus, for an estimated linear regression model $y_i = \hat{b}_0 + \hat{b}_1 * x_i + \hat{b}_2 * z_i + e_i$, the marginal effect of x on y is the scalar regression coefficient $\hat{b}_1$. For this linear model the *effect* of x on y is given by $\delta y/\delta x * x$ (i.e., marginal effect times data value, or $\hat{b}_1 * x$), which is not a scalar, but a vector with the same length as the vector x, and which plotted (with effect on the ordinate and x on the abscissa) is a straight line through the origin with slope $\hat{b}_1$. For a linear model, knowing just the marginal effect is sufficient, since it provides full information about the total effect (a straight line is fully identified when one knows its slope and intercept).

However, for a model with interaction or polynomial terms, marginal effects will be vectors with unique values for each observation, not scalars, and effects will not be straight lines. Little can be learned about these relations by simply examining the regression coefficients, but they can be easily discerned by plotting, as we do in Figures 2 through 5.

Figure 2 plots the effects and marginal effects for each of the six subsistence modes (*v814-v819*). For each subsistence mode, the top plot shows the marginal effect on the ordinate, and the importance of the subsistence mode on the abscissa; the bottom plot has the total effect on the ordinate. The size of the plot points represents population density (larger size implies higher population density). The specific formulas are shown in Table 6. The plot that most directly tests Nolan's first hypothesis—that more productive subsistence technology leads to more frequent war—is the marginal effect for the importance of agriculture (*v814*). Note (from the formula) that the marginal effect declines as the importance of agriculture increases ($\delta^2 y_i/\delta v814_i^2 < 0$). The smoothed values (the dotted line in the plot) show that the marginal effect is initially usually positive (increases in agriculture lead to increases in the frequency of external war), but becomes negative (increases in agriculture reduce the frequency of external war). The plot for the total effect shows that societies relying either very little or very much on agriculture for their subsistence are the most peaceful, while those for which agriculture is of medium importance are more warlike.

Table 6: Formulas for effects shown in Figure 2.

Total Effect	Marginal Effect
effect of v814= -4.0189*pdens*v814 + 0.1479*v814 - 0.2146*v814^2	dy/dv814= -4.0189*pdens + 0.1479 - 0.2146*2*v814
effect of v815= -2.8043*pdens*v815	dy/dv815= -2.8043*pdens
effect of v816= -3.0363*pdens*v816	dy/dv816= -3.0363*pdens
effect of v817= -2.4745*pdens*v817	dy/dv817= -2.4745*pdens
effect of v818= -2.0231*pdens*v818	dy/dv818= -2.0231*pdens
effect of v819= -1.671*pdens*v819	dy/dv819= -1.671*pdens

Notes: all parameter values come from the restricted model in Table 5; data values for each society are the mean of the 10 imputed data sets.

Note that the marginal effect declines as population density increases ($\delta^2 y_i/\delta v814_i \delta pdens_i$ <0), so that low population density societies have a higher marginal effect for any level of *v814*. This leads to the result that among societies with *low* importance of agriculture (who have a positive marginal effect), those with *higher* population densities are more likely to engage in external war. On the other hand, among societies with *high* importance of agriculture (who have a negative marginal effect), those with *lower* population densities are more likely to engage in external war.

For societies not relying primarily on agriculture, Nolan's (2003:26-27) findings coincide with our results, in that an increase in the reliance on agriculture leads to more war, and that increase in war will be more pronounced for societies with higher population densities. But the results also indicate that the frequency of war declines as societies increasingly rely on agriculture—a clear contradiction of Nolan's first hypothesis.

The results for the other five subsistence modes also contradict Nolan's first hypothesis: the marginal effects for dependence on domestic animals, fishing, hunting, and gathering become increasingly positive as dependence increases, while the marginal effects for trade become increasingly negative. Trade, like agriculture, seems characteristic of societies with accumulated wealth—wealth which would be worth attacking, worth defending, and could be used to support armies—suggesting theoretically that trade, like agriculture, should lead to a greater incidence of war. However, high reliance on trade and agriculture both *reduce* the incidence of war, while high reliance on domestic animals, fishing, hunting, and gathering all *increase* its incidence. Thus, our model contradicts Nolan's first hypothesis.

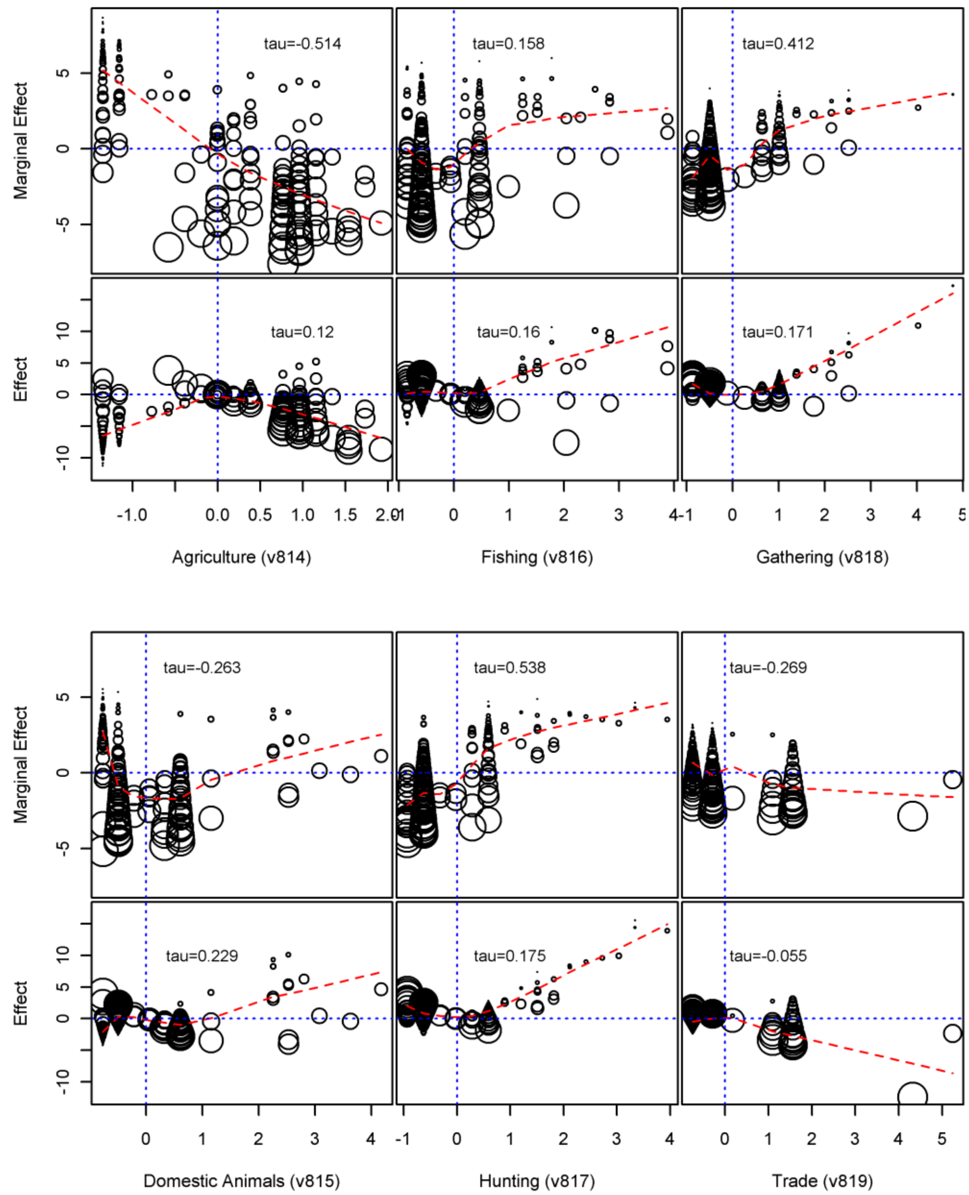

Figure 2: Effect on frequency of external war (*v1650*) of importance of six subsistence modes (*v814*-*v819*). For each mode, the top panel presents the marginal effect, and the bottom panel the total effect. Size of plotted points represents population density (*pdens*). The dashed line is the lowess smoother (Cleveland 1979). Kendall's tau is given for the relationship between the abscissa and ordinate values for each plot.

Nolan's second hypothesis is that higher population densities lead to greater frequency of war. Following Nolan (2003:24), we specified the model so that the effect of population density is conditioned by subsistence type, as defined by variables *v814*-*v819*. From the estimated coefficients in Table 5 we calculate the marginal effect as

$\delta y_i/\delta pdens_i$ =-0.4246 -4.0189$*v814_i$ -2.8043$*v815_i$ -3.0363$*v816_i$ -2.4745$*v817_i$ -2.0231$*v818_i$ -1.671$*v819_i$. The top panel of Figure 3 plots these marginal effects (ordinate) against population density (abscissa); the plot symbol represents the subsistence category most important for that particular society. All marginal effects are negative, showing that increases in population density lead to lower frequency of external war for all societies—a clear contradiction of Nolan's second hypothesis.

The bottom panel in Figure 3 plots the total effect ($\delta y_i/\delta pdens_i * pdens_i$) on the ordinate and *pdens* on the abscissa. Since *pdens* is standardized, the total effect will be positive for societies with below-mean population density, and negative for societies with above-mean population density. The resulting plot is nearly linear—fitting a negatively sloped straight line with an R^2 of 0.796.

Our model's negative relationship between population density and the frequency of war is consistent with Younger's (2008) findings but not those of Nolan (2003) or Keeley (1996). We believe that the positive association between population density and war found in previous studies is a result of omitted variable bias. That is, failure to include all relevant control variables will lead to biased coefficient estimates. Obviously, any study relying on bivariate methods (such as contingency tables) fails to include the relevant controls. We show in the appendix how omitted variable bias could, in our particular case, lead to a wide range of values for the association between population density and war. Leaving out important variables that are both highly correlated with population density and positively associated with war—variables such as the use of metal or the existence of writing and record-keeping—causes our measure for population density to capture variation that belongs to these other variables, and gives the false result that population density is positively associated with war.

The exact source of the negative relationship between population density and war is unclear. But we speculate that it may be due to the reluctance of others to attack high population density communities or to the reluctance of high population density communities to attack others. The former is plausible since high population density communities would have improved land and structures worth defending, and would have the potential to field large, well-equipped forces for effective defense. The latter because relatively complex high population density communities may find war a costly disruption, both to their economy and to the ambitions of their elites, who are likely to have non-war strategies (ecclesiastical, commercial, agrarian, etc.) for obtaining and keeping status.

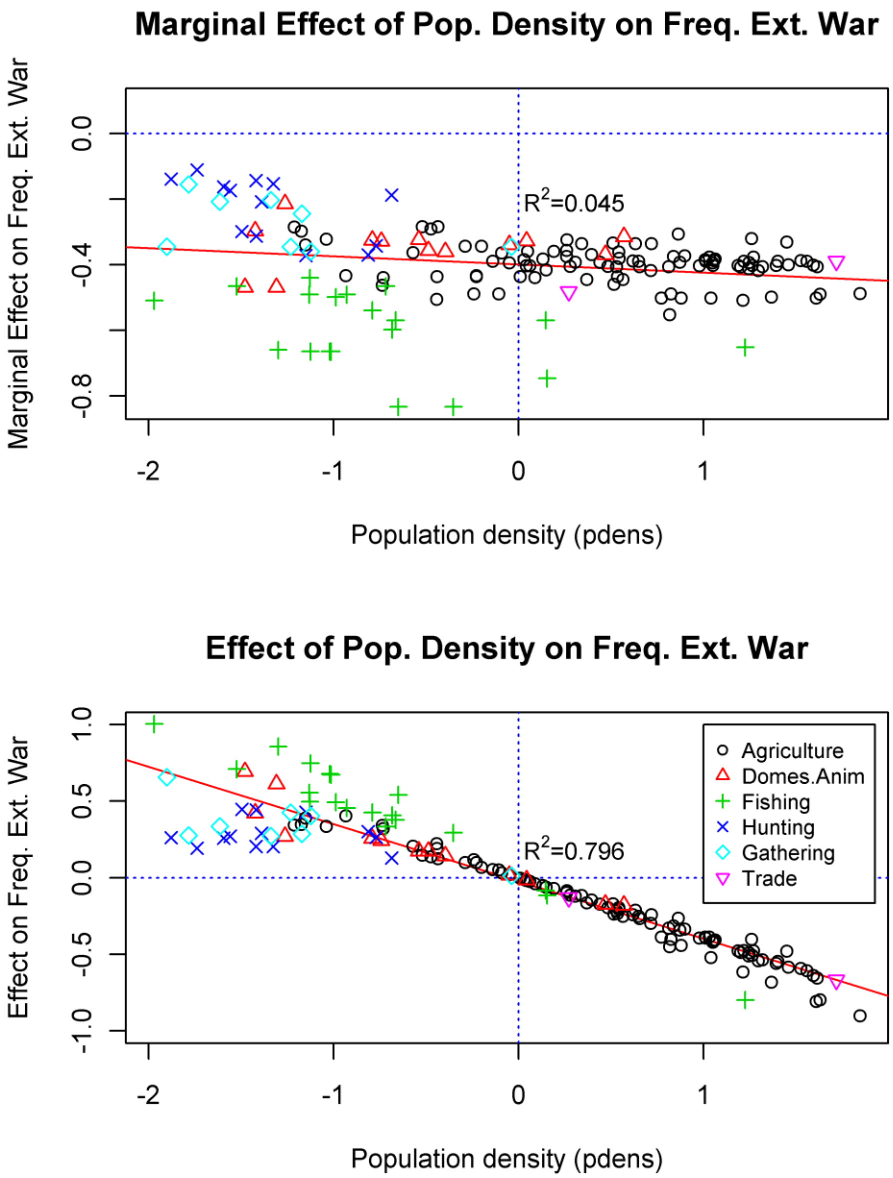

Figure 3: The top panel shows the marginal effect of population density (*pdens*) on frequency of external war (*v1650*): $\delta y_i/\delta pdens_i$ = -0.4246 -4.0189*$v814_i$ -2.8043*$v815_i$ -3.0363*$v816_i$ -2.4745*$v817_i$ -2.0231*$v818_i$ -1.671*$v819_i$. The bottom panel shows the total effect, which is $\delta y_i/\delta pdens_i {*} pdens_i$. The solid lines show the linear fit (with R^2); the symbols show the largest subsistence source for each plotted society (legend in top panel). Note that the marginal effects are negative for all societies.

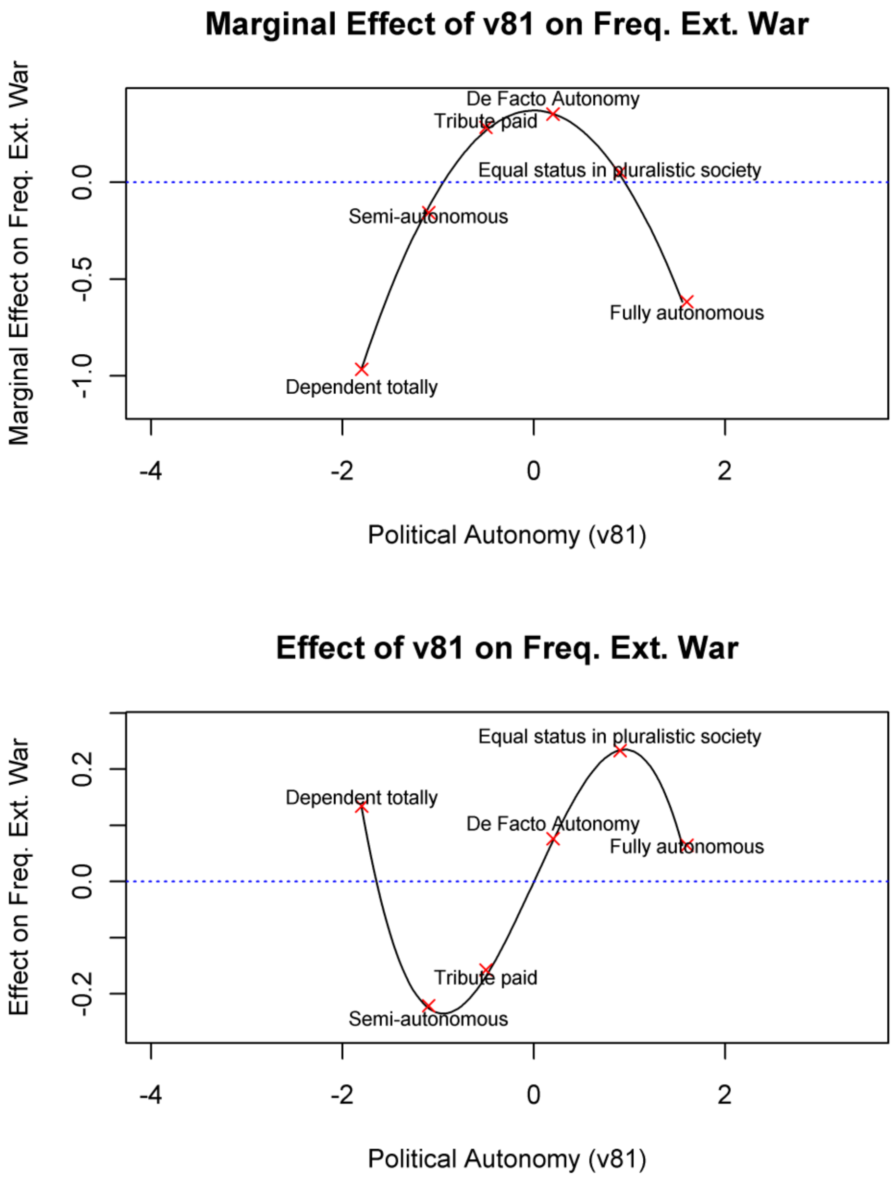

Figure 4: Effect of political autonomy (*v81*) on frequency of external war (*v1650*). Top panel is the marginal effect$_i$= 0.3714 -3*0.1372*$v81_i^2$. Bottom panel is the total effect$_i$= 0.3714*$v81_i$ -0.1372*$v81_i^3$.

We had speculated that communities with little political autonomy (*v81*) would be less likely to go to war, since any antagonism toward an external community would require the approval of the larger polity before actual war could develop. The estimated coefficients reveal a more complex pattern, as shown in Figure 4: both totally dependent and fully autonomous communities have a higher propensity to go to war than do communities that are semi-autonomous. It seems likely that the semi-autonomous are constrained by the larger polity from freely engaging in war, but are also too loosely controlled for the larger polity to draw them into irrelevant wars. On the other hand, totally dependent communities can be forced into wars by the larger polity, while the fully autonomous can enter any war that they choose. Most warlike of all are communities which have equal status to other communities in a pluralistic society. Such equal status may be the consequence of an often-exercised willingness to fight other communities.

We see a similar effect for the number of hierarchical levels within a community (*v236*). The theoretical minimum for the number of levels is two (family plus band); *v236* considers up to a maximum of four levels. As Figure 5 shows, communities with this maximum number of levels are much less likely to engage in external war than are other communities. Decisions to engage in external war may be more difficult when larger numbers of political actors must agree, as would be the case in larger, more complex, communities. As an example, one might consider the Mae Enga, of the New Guinea highlands, who deliberate the war decision in large meetings, where all fighters have the chance to speak (Meggitt 1977:76-80).

From the above, one can see that features of communities with a low propensity to engage in war include: high population densities (*pdens*); relatively complex community-level political structures (*v236*); and ties to other communities that constrain the free exercise of war (*v81*). These features reflect a more complex social and material order. Chronic war is the enemy of order, since its object is to destroy the crops, structures, institutions, and lives of a people. One would expect a community with a long history of peace to have evolved a complex social and material life, able to sustain high population densities. Thus, the features identified by our model may be a *cause* of low levels of war, as we hypothesize, but can also be a *consequence*. Our results provide some insight into causality, in the form of the endogeneity tests. Since these show that no independent variables are endogenous, our estimated model in Table 5 can therefore be interpreted as representing solely the causes of external war, not consequences.

Three of the 12 major habitat dummies survived to the final model (Figure 6). Relative to all other habitat types, societies found within temperate coniferous forests or boreal forests/taigas have lower incidences of external warfare. Conversely, societies who make their homes in temperate broadleaf and mixed forests experience higher incidences of warfare. These results confirm Nolan’s (2003) suggestion that there are features of biophysical environments that affect the frequency of war. Though the exact paths of that effect are not clear, they are independent of the confounding effects of subsistence and cultural transmission, which are controlled for in our model.

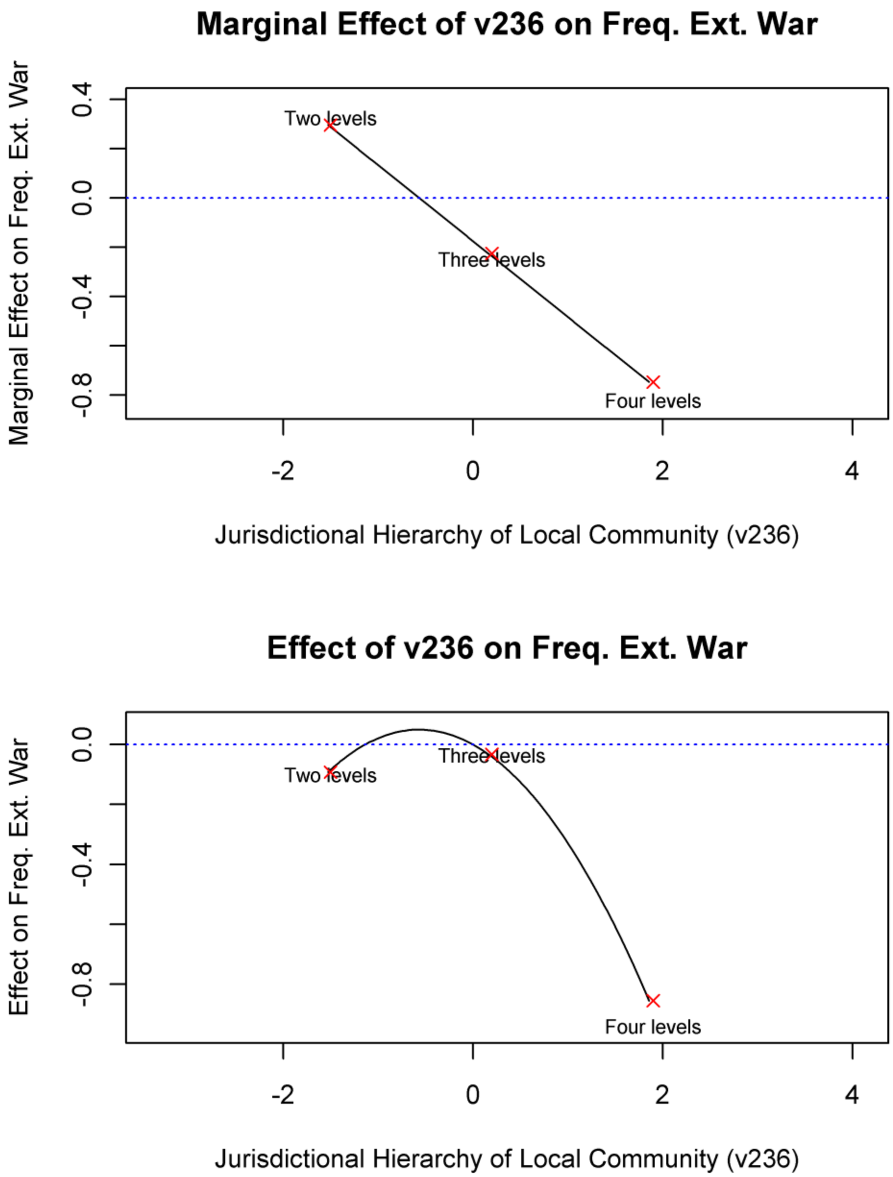

Figure 5: Effect on frequency of external war (*v1650*) of jurisdictional hierarchy of local community (*v236*). Top panel shows the marginal effect$_i$= -0.1748 -2*0.1541*$v236_i$. Bottom panel shows the total effect$_i$= -0.1748*$v236_i$ -0.1541*$v236_i^2$.

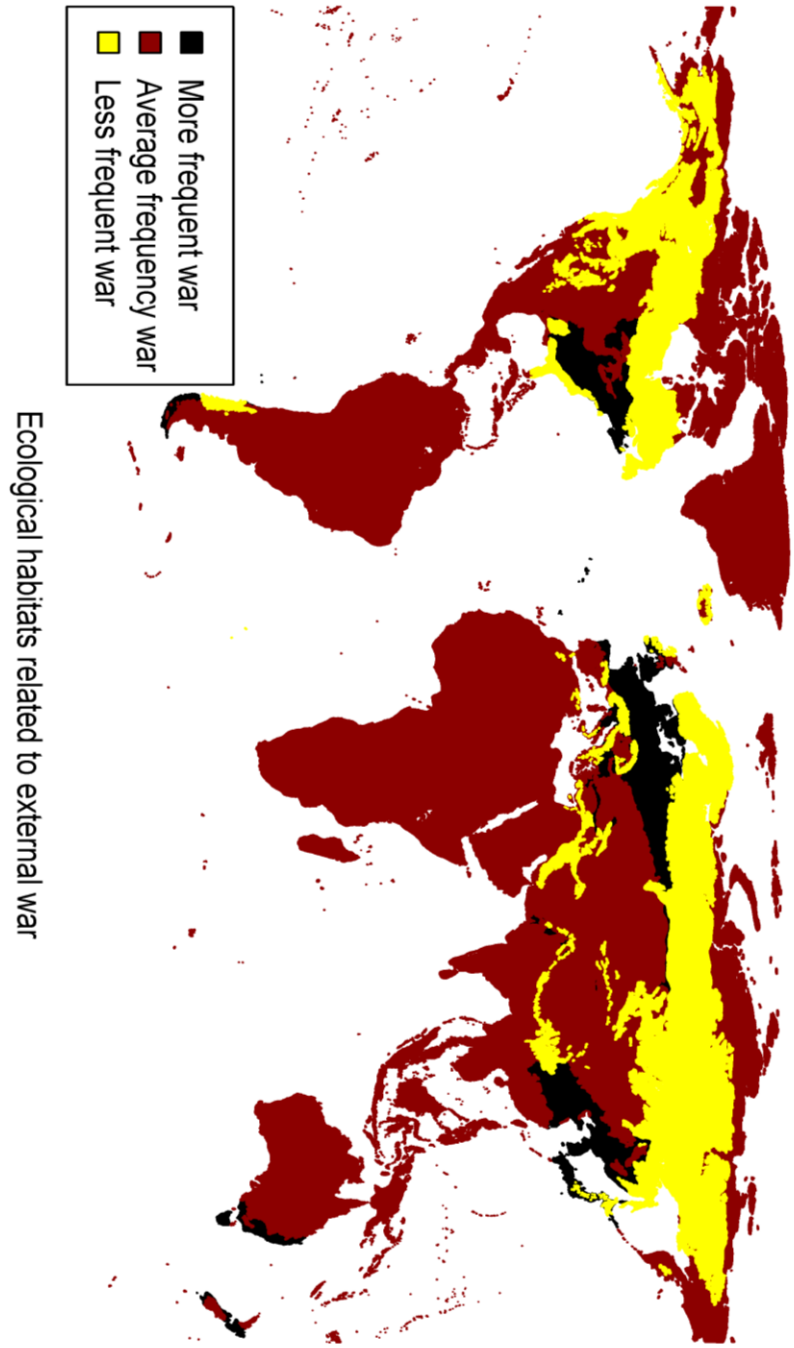

Figure 6: The lightest areas are those major habitat types (*Boreal forest/taigas*; *Temperate coniferous forests*) which the restricted model (Table 5) shows have lower frequency of external war. The darkest area is the *Temperate broadleaf and mixed forests* habitat, which has a higher propensity for external war.

Two of the 'most common source of political power' dummies appear in the final model. Unsurprisingly, *v93.WarWealth* has a positive coefficient. That is, societies in which the most common method of political advancement is through the wealth gained from warfare go to war more often. More interesting is the negative coefficient of *v93.CapitalistEnt*, indicating that capitalism provides nonviolent means to increase elite status.

As expected, societies with technologies that facilitate war—metal and writing—practice war more often; those with beliefs in moralizing gods practice war less often; and isolated societies are more peaceful. Surprisingly, neither community size (*v63*) nor the elite accumulation of slaves (*v93.Slaves*) had any effect on the frequency of war.

The partitioned R^2 given for each variable in the restricted model (column R^{2p} in Table 5) provides a ready means to evaluate the relative influence of groups of variables. Since R^{2p} sums to the total R^2, one can add the R^{2p} of a group of variables to obtain a measure of how much that group contributes to the model. Table 7 presents some aggregated groups.

Table 7: Partitioned R^2 by group.

Group	Summed R^{2p}	PrpTotal	Variables
All subsistence variables	0.0569	0.0886	v815pdens + v816pdens + v817pdens + v818pdens + v819pdens + v814 + v814pdens + v814.2
Agriculture	0.0304	0.0474	v814 + v814pdens + v814.2
Population density	0.0609	0.0949	v815pdens + v816pdens + v817pdens + v818pdens + v819pdens + v814pdens + pdens
Ecological dummies	0.0904	0.1408	mht.TempConif + mht.Taiga + mht.TempBroadLeaf
All ecological-evolutionary	0.1719	0.2678	v815pdens + v816pdens + v817pdens + v818pdens + v819pdens + v814 + v814.2 + v814pdens + mht.TempConif + mht.Taiga + pdens + mht.TempBroadLeaf
Facilitating technology	0.0954	0.1486	metal + v149
Ecological-evolutionary + technology	0.2673	0.4164	v815pdens + v816pdens + v817pdens + v818pdens + v819pdens + v814 + v814pdens + mht.TempConif + v814.2 + mht.Taiga + pdens + v149 + mht.TempBroadLeaf + metal
Elite strategies	0.0992	0.1545	v93.CapitalistEnt + v93.WarWealth
Political organization	0.1084	0.1688	v236 + v81.3 + v81 + v236.2
Political organization + elite strategies	0.2076	0.3234	v236 + v81.3 + v93.CapitalistEnt + v81 + v236.2 + v93.WarWealth
High gods	0.0511	0.0796	v238
Neighbors	0.1160	0.1807	Wy + v787

Notes: The variables and R^{2p} are from the restricted model of Table 5. R^{2p} is summed for each of the variables shown, to give the final R^2 due to the group as a whole. "PrpTotal" gives the proportion of the final R^2 (0.648) explained by the group of variables.

The general thesis of the ecological-evolutionary theorists is that ecology, subsistence type, and population density are the dominant determinants of the frequency with which a society goes to war. Table 7 shows that ecology, subsistence type, and population density together account for only about 17 percent of the variation in the frequency of external war. If one broadens the set of variables to include technology facilitating war (i.e., one combines all "materialist" variables), the broader set accounts for about 27 percent of the variation in the dependent variable. Thus, only when quite broadly defined does the general thesis of the ecological-evolutionary theorists find strong support in our results.

Otterbein (1970: Preface) has argued that sociopolitical variables have much more influence than economic or ecological variables in determining the frequency and nature of war. Variables reflecting political organization account for about 11 percent of the variation in the frequency of external war; variables reflecting the strategies by which elites gain status account for another 10 percent. Add to this the five percent accounted for by the degree to which the supernatural supports morality, and the resulting 26 percent of variation in frequency of external war accounted for by sociopolitical factors is about the same as the 27 percent accounted for by the broadly defined ecological-evolutionary variables.

Some believe that the frequency of war may simply be a function of who a society happens to have as neighbors: Keely (1996:127-128) suggests that hostile neighbors may be the most important determinant of whether a society is warlike, and Younger (2008:930) finds that more isolated societies are more peaceful. We include two variables that provide some measure of the effect of neighbors, and together they account for about 12 percent of the variation in the frequency of external war. The first of these confirms Younger's view that more isolated societies are more peaceful. The second—our network lag term—shows the effect of cultural transmission. The network lag term's optimal composite weight matrix indicates that societies will tend to engage in war at much the same frequencies as their geographical neighbors and their co-religionists. Table 5 contains two pieces of evidence suggesting that a society will not be much influenced by the frequency with which their ancestors went to war: the near-zero value of the composite weight for linguistic phylogeny, and the high p-value for the LM test for spatial lag based on linguistic phylogeny. In other words, there is evidence here that vertical transmission does not account for the frequency of external war.

VI. Summary and Conclusion

We re-examine Patrick Nolan's (2003) empirical work on the causes of war. We criticize his methods, which consist of bivariate or tri-variate tabular analyses, for sacrificing variation, for ignoring confounding variables, for failing to show the relative importance of the analyzed effects, for ignoring Galton's problem, and for ignoring the problem of missing data. Our approach is to build a multivariate model, which uses multiple imputation to handle the problem of missing data, and uses a network lag term to handle Galton's problem.

Our results reinforce Nolan's conclusions on a few points, notably the positive association between metal technology and war. And while this relationship is important, it is hardly decisive—accounting for about 6.5 percent of the variation in the frequency of external war. When we evaluate the total importance of all factors related to ecology, subsistence, population density, and technology, we find that together they explain about 27 percent of the variation in the frequency of external war. This is comparable to the 26 percent explained by a broad set of sociopolitical factors. Thus our results suggest that those who argue for ecological-evolutionary theory, such as Nolan, are about as correct as those who argue that sociopolitical factors are the main determinants of war, such as Otterbein (1970). This serves as an example of the superiority of multivariate methods: by including all of the most likely determinants of war, one can gain a sense of their relative importance.

For the first of the two specific hypotheses advanced by Nolan—more productive subsistence leads to more frequent war—we find only qualified support. Taking the proportion of subsistence derived from agriculture as a measure of productivity, we find the relationship to be quadratic. As Nolan would predict, increases in agriculture's importance leads to increases in the frequency of external war, but for *non-agricultural* societies only. For societies primarily relying on agriculture, we find a result opposite to that predicted by Nolan: increases in agriculture's importance *lower* the frequency of external war.

Our results explicitly contradict Nolan's second hypothesis: that higher population densities lead to higher frequency of war. We find a strictly negative relationship, in which high population densities discourage war. In the appendix we show that omitted variable bias is the probable reason that other studies failed to find a negative relationship. This highlights again the necessity of multivariate models in cross-cultural research—only by considering all important confounding factors can a model be free of omitted variable bias.

Finally, we feel encouraged that our results support an optimistic view of peace among human societies. The propensity to engage in war is not vertically transmitted, is not a behavior that a society is locked into by the practices of its ancestors, but rather appears to be a product of current conditions. And many of the features of contemporary societies appear to be those which favor peace: high population densities; moderately restricted political autonomy; more complex political structures; widespread belief in moralizing gods; and the prevalence of capitalism as a means for elites to gain status. If peace is our goal, perhaps we are heading in the right direction.

Appendix: Omitted variable bias

Many readers may find it difficult to accept that the effect of increasing population density is to decrease the frequency of war. Previous literature (e.g., Nolan 2003; Keeley 1996) has found the opposite effect (i.e., a positive correlation between population density and war), and indeed the Pearson correlation between *v1650* (frequency of external war) and *pdens* (our measure of population density) returns a very small positive value of 0.0191. But these positive effects are due to the failure to control for other determinants of the frequency of war; in other words, they are the product of omitted variable bias.

Estimated coefficients will be biased when the set of independent variables omits one or more significant determinants of the dependent variable. Thus, if the true model is $y = \mathbf{X}b+\mathbf{Z}c+\epsilon$ (where **X** and **Z** are matrices of variables), but the estimated model is $y = \mathbf{X}\hat{b} + e$, then the estimated coefficients $\hat{b}$ will be biased *unless* the omitted variables **Z** are orthogonal to the included variables **X** (Kennedy 2003:107-108). While this might be true at times, in practice most variables are collinear, and when multicollinearity is high, omitted variables will cause serious bias.

Pairwise analysis of variables, such as correlation coefficients or contingency tables, will always suffer from the problem of omitted variable bias. It is only within a multivariate model framework that the important independent variables can be included and omitted variable bias mitigated. Previous studies finding that population density is positively associated with the frequency of war all failed to address the problem of omitted variables. We illustrate that in this appendix by estimating a very simple (and incomplete) model of the effect of population density on frequency of external war, and then showing how the inclusion of even one additional independent variable can lead to large changes in the expected effect of population density.

Our simple model consists of the portion of our unrestricted model containing terms related to population density:

$$y_i = b_0 + (b_{pdens} + \Sigma_j\, b_j\, x_{ij})*pdens_i + e_i \qquad \text{(A.1)}$$

where y_i is the frequency of external war, $pdens_i$ is population density, the x_{ij} consist of the variables *v814* through *v819* (subsistence shares of agriculture, domestic animals, fishing, hunting, gathering, and trade), e_i is an error term and the b_j and b_{pdens} are scalar parameters. We estimate this model[6] and calculate the fitted effect of *pdens*:

$$\hat{y}_i = (\hat{b}_{pdens} + \Sigma_j\, \hat{b}_j\, x_{ij})*pdens_i \qquad \text{(A.2)}$$

The Pearson correlation coefficient of $\hat{y}_i$ against $pdens_i$ is 0.084, which shows that as population density rises, external war is more frequent. We now add an additional independent variable z_i:

$$y_i = b_0 + (b_{pdens} + \Sigma_j\, b_j\, x_{ij})*pdens_i + \alpha\, z_i + e_i \qquad \text{(A.3)}$$

[6] Since this is for illustrative purposes only, we use one of our ten imputed data sets for all estimations.

And using the new estimated coefficients $\hat{b}$, recalculate $\hat{y}_i$ using equation A.2. Note that the coefficient α and the variable value z_i are not used in calculating $\hat{y}_i$ –changes in the fitted value are solely due to changes in the estimated coefficients $\hat{b}$ caused by the introduction of z_i.

Table A.1 shows the Pearson correlation coefficient of $\hat{y}_i$ against $pdens_i$ for each of the models estimated with equation A.3; the variables z_i are shown in the leftmost column. Adding a single independent variable (*metal*) can turn the correlation from weakly positive to strongly negative. On the other hand, a few other independent variables can strengthen the positive correlation.

Figure A.1 presents scatter plots for fitted values $\hat{y}$ against *pdens*. The red line is the lowess smoother (Cleveland 1979). The histograms give the distributions of marginal effects $\delta\hat{y}/\delta pdens = (\hat{b}_{pdens} + \Sigma_j \hat{b}_j x_j)$. Each row differs by the independent variables included in the model used to estimate the $\hat{b}$. The first model includes only the population density variables used to calculate $\hat{y}$; note the positive correlation (0.084) between $\hat{y}$ and *pdens*. The second row estimates the coefficients $\hat{b}$ in a model that includes one additional independent variable (*v93.CapitalistEnt)*—keep in mind that the coefficient for that additional variable is **not** used to estimate $\hat{y}$, but the presence of that additional independent variable causes the coefficients $\hat{b}$ to change, so that $\hat{y}$ is changed. Note that the positive correlation between $\hat{y}$ and *pdens* is now strengthened (0.263). The third row replaces *v93.CapitalistEnt* with a different independent variable (*metal*)—the correlation between $\hat{y}$ and *pdens* is now negative (-0.641). Finally, the last row shows not the effect from one additional variable, but from the full restricted model (Table 5), where we tried to introduce all relevant independent variables, and where omitted variable bias should be negligible—the correlation between $\hat{y}$ and *pdens* is now even more strongly negative (-0.894).

The marginal effects give the change in the frequency of external war for a unit increase in population density. The histograms in Figure A.1 show that the marginal effects are sometimes positive and sometimes negative for each model except the full model (reported in the lower panel of Figure 3), where they are always negative.

It's not hard to explain these results. Population density is highly collinear with some of these omitted variables: the use of metal, the existence of capitalist enterprises as a means to gain status, and the use of writing. When these variables are omitted, population density captures some of the variation that belongs to them, so that the effect of population density is conflated with the effect of these other variables. For example, the use of metal increases the frequency of war, so that omitting the variable *metal* allows the variable *pdens* to proxy metal use, and makes it appear that population density increases the frequency of war.

Table A.1: Correlation between *pdens* and fitted effect of *pdens* when additional variables added to model; v814-v819 as subsistence measures.

Variable added	Correlation between *pdens* and fitted effect of *pdens*
metal	-0.6410
v149	-0.3388
v814	-0.2075
mht.Taiga	-0.1749
mht.TempBroadLeaf	-0.0740
v814.2	-0.0434
Wy	-0.0209
v787	-0.0207
v81	0.0573
mht.TempConif	0.0604
v81.3	0.0840
--No additional variable--	0.0844
v236.2	0.0894
v238	0.1265
v236	0.2163
v93.WarWealth	0.2411
v93.CapitalistEnt	0.2630

Notes: The fitted effect of *pdens* = $\hat{y} = (\hat{b}_{pdens} + \Sigma_j \hat{b}_j x_j)*pdens$, where the x_j are *v814* through *v819*. The correlation between $\hat{y}$ and *pdens* is given for a range of models, each of which takes the form $y_i = b_0 + (b_{pdens} + \Sigma_j b_j x_{ij})*pdens_i + \alpha z_i + e_i$, where the additional variable z is named in the left column of the table. Note that the estimated coefficient α and the variable z are **not** used to estimate $\hat{y}$; their effect on $\hat{y}$ is entirely due to the changes to $\hat{b}$ caused by the inclusion of an additional variable.

These results are not simply an artifact of the subsistence variables we chose to interact with population density. To illustrate this, we repeat the above examples using a slightly different specification, where our subsistence terms are dummy variables for the subsistence categories in *v858* (see Table 1 above). Our simple model is:

$$y_i = b_0 + (b_{pdens} + \Sigma_j b_j d_{ij})*pdens_i + e_i \quad \text{(A.4)}$$

where y_i is the frequency of external war, $pdens_i$ is population density, the d_j are dummy variables for the categories of *v858*, e_i is an error term and the b_j and b_{pdens} are scalar parameters. We estimate this model and calculate the fitted effect of *pdens*:

$$\hat{y}_i = (\hat{b}_{pdens} + \Sigma_j \hat{b}_j d_{ij})*pdens_i \quad \text{(A.5)}$$

The Pearson correlation coefficient of $\hat{y}_i$ against $pdens_i$ is 0.0563. We now add an additional independent variable z_i:

$$y_i = b_0 + (b_{pdens} + \Sigma_j b_j d_{ij})*pdens_i + \alpha z_i + e_i \quad \text{(A.6)}$$

And using the new estimated coefficients $\hat{b}$, recalculate $\hat{y}_i$ using equation A.5. Table A.2 shows the Pearson correlation coefficient of $\hat{y}_i$ against $pdens_i$ for each of the models in equation A.6; the variables z_i are shown in the leftmost column.

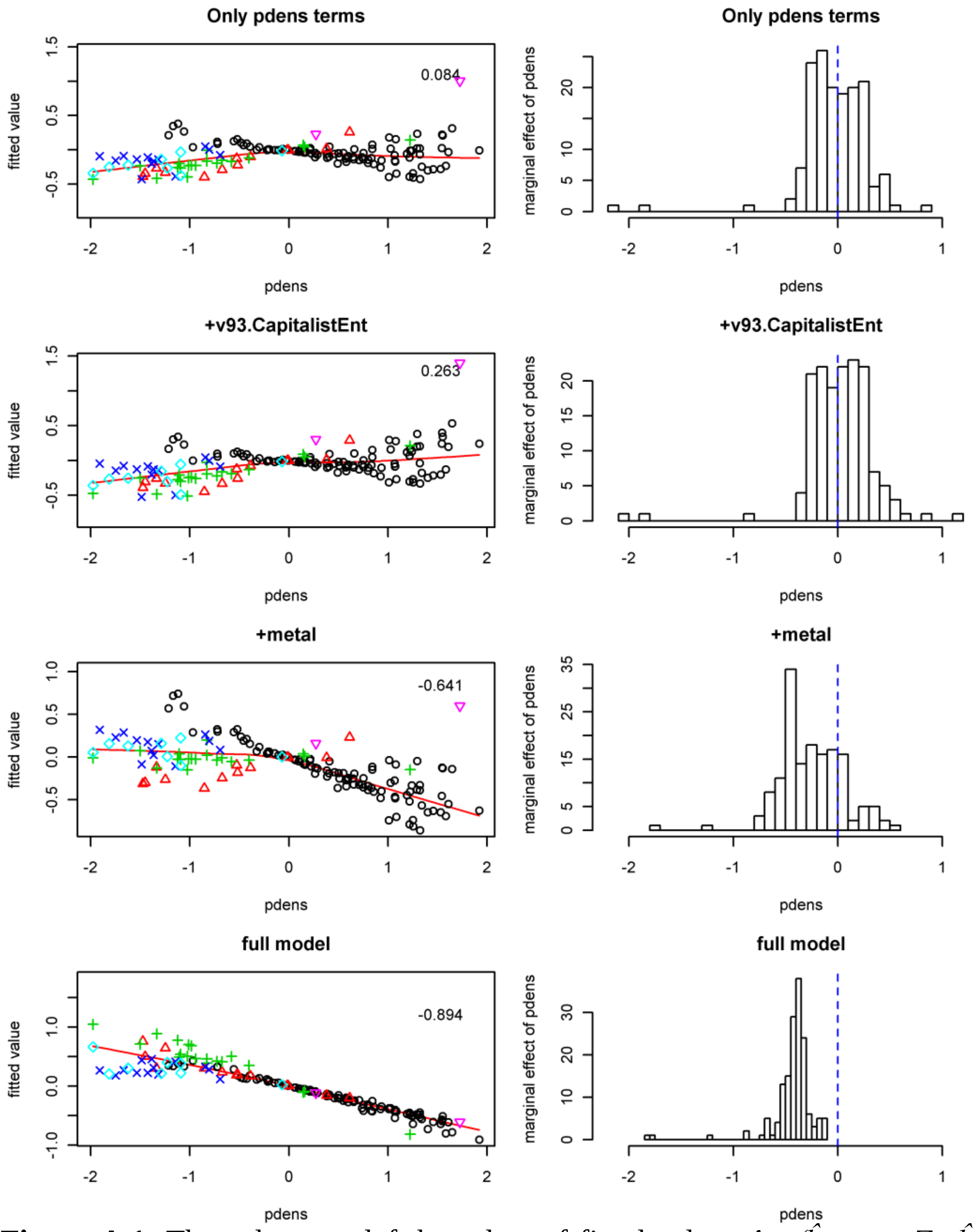

Figure A.1: The column at left has plots of fitted values $\hat{y} = (\hat{b}_{pdens} + \Sigma_j \hat{b}_j x_j)*pdens$ against *pdens*, where the x_j are *v814* through *v819*. The number in each plot is the Pearson correlation coefficient between $\hat{y}$ and *pdens*. The histograms give the distributions of marginal effects $\delta\hat{y}/\delta pdens = (\hat{b}_{pdens} + \Sigma_j \hat{b}_j x_j)$. Each row differs by the independent variables included in the model used to estimate the $\hat{b}$. The red line is the lowess smoother (Cleveland 1979). The predominant subsistence mode is given by the symbols (see legend in top panel of Figure 3).

Note the strong similarities between Tables A.1 and A.2—both tables show that adding a single independent variable can lead to a very large difference in the Pearson correlation coefficients.

Finally, Figure A.2 plots the values for three of the rows in Table A.2: where no additional variable is added; where *metal* is added; and where *V93.CapitalistEnt* is added. There is no full model, since no full model was developed using the categories of *v858*.

These results illustrate that the true empirical relationship between population density and the frequency of war can only be uncovered by fully and carefully specified multivariate models, which contain all of the most important factors determining the frequency of war.

Table A.2: Correlation between *pdens* and fitted effect of *pdens* when additional variables added to model; *v858* as subsistence measure.

Variable added	Correlation between *pdens* and fitted effect of *pdens*
metal	-0.5056
v149	-0.2176
mht.Taiga	-0.0566
mht.TempBroadLeaf	-0.0483
v814	-0.0421
v814.2	-0.0371
Wy	-0.0136
v787	-0.0075
mht.TempConif	0.0285
v81	0.0420
v236.2	0.0544
--*No additional variable*--	0.0563
v81.3	0.0567
v238	0.0977
v236	0.1285
v93.WarWealth	0.1694
v93.CapitalistEnt	0.1856

Notes: The fitted effect of *pdens* = $\hat{y} = (\hat{b}_{pdens} + \Sigma_j \hat{b}_j d_j)*pdens$, where the d_j are dummy variables for the categories of *v858*. The correlation between $\hat{y}$ and *pdens* is given for a range of models, each of which takes the form $y_i = b_0 + (b_{pdens} + \Sigma_j b_j d_{ij})*pdens_i + \alpha z_i + e_i$, where the additional variable z is named in the left column of the table. Note that the estimated coefficient α and the variable z are **not** used to estimate $\hat{y}$; their effect on $\hat{y}$ is entirely due to the changes to $\hat{b}$ caused by the inclusion of an additional variable.

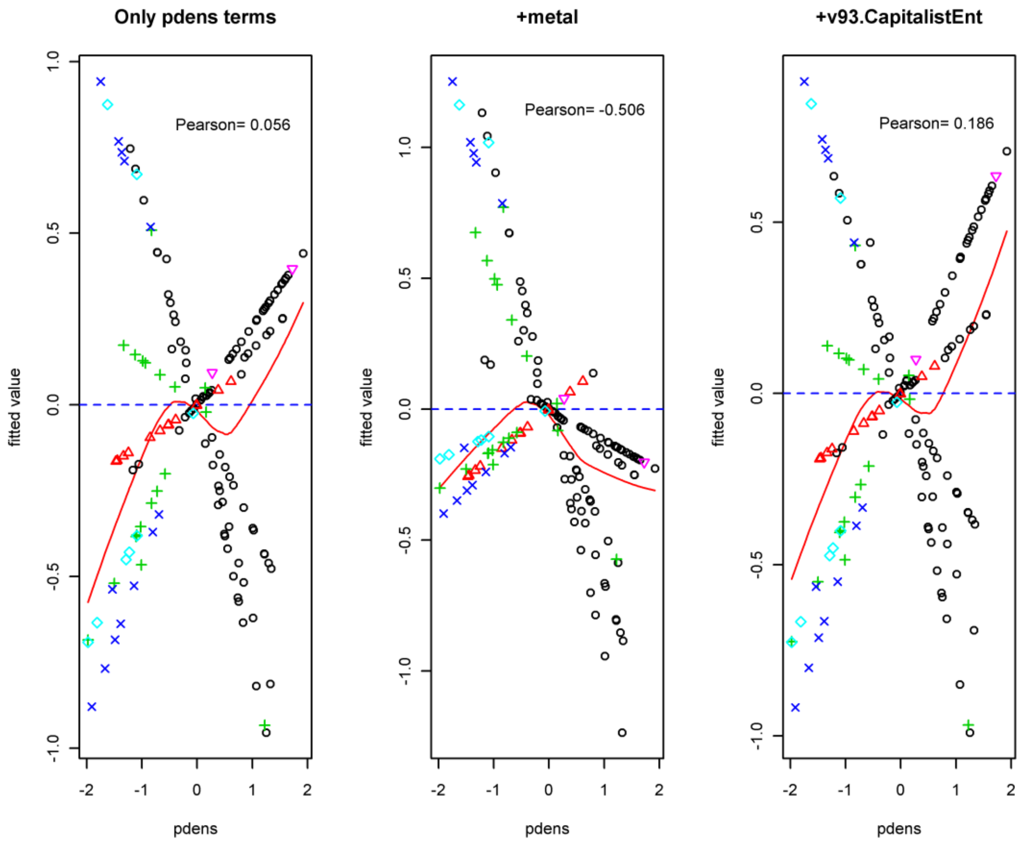

Figure A.2: Each chart plots fitted values $\hat{y} = (\hat{b}_{pdens} + \Sigma_j \hat{b}_j d_j) * pdens$ against *pdens*, where the d_j are dummy variables for the categories of *v858* (category 1 is dropped). Each chart differs by the independent variables included in the model used to estimate the $\hat{b}$. The first model includes only the population density variables used to calculate $\hat{y}$; note the positive correlation (0.056) between $\hat{y}$ and *pdens*. The second chart estimates the coefficients $\hat{b}$ in a model that includes one additional independent variable (*metal)*—the coefficient for that additional variable is **not** used to estimate $\hat{y}$, but the presence of that additional independent variable causes the coefficients $\hat{b}$ to change, so that $\hat{y}$ is changed. Note that the positive correlation between $\hat{y}$ and *pdens* has now become negative (-0.506). The third chart replaces *metal* with a different independent variable (*v93.CapitalistEnt*)—the correlation between $\hat{y}$ and *pdens* is now positive (0.186). The red line is the lowess smoother (Cleveland 1979). The predominant subsistence mode is given by the symbols (see legend in top panel of Figure 3).

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