Historical Disease Prevalence, Cultural Values, and Global Innovation

Daniel L. Bennett
Research Professor
Baugh Center for Entrepreneurship & Free Enterprise
Baylor University
One Bear Place #98011
Waco, TX 76798
bennettecon@gmail.com
(312) 835-9492

Boris Nikolaev
Assistant Professor
Department of Entrepreneurship
Baylor University
One Bear Place #98011
Waco, TX 76798
borisnikolaev@gmail.com
(813) 401-9756

Abstract

The historical prevalence of infectious diseases has had an enduring effect on innovation around the world. Building on the Parasite Stress Theory of Values, we propose a framework suggestive that the impact of historical disease pathogens on contemporary innovation is transmitted through the development of cultural values as an evolutionary psychological immune system response to ecological conditions. Economic and social interaction between groups was greater [limited] in countries with low [high] pathogen levels, resulting in the development of individualistic [collectivistic] values, which in turn encouraged [impeded] innovation. We provide supportive empirical evidence for a sample of 83 countries.

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INTRODUCTION

Scholars are increasingly interested in understanding how neurobiological factors influence innovative outcomes (Shane & Nicolaou, 2015). A nascent body of scholarship, for example, provides exciting insights on the importance of genetics (Chávez-Eakle, 2007; Nicolaou et al., 2008; Zhang et al., 2009), physiology (Nicolaou, Patel, & Wolfe, 2017; Unger et al., 2015; White et al., 2006; Wolfe & Patel, 2017) and neurodevelopment (Sol et al., 2005; Wiklund et al., 2016; Wiklund et al., 2017) for innovative behavior. It is unlikely, however, that innovative behavior is explained solely by human biology (Nofal et al., 2018). Instead, cultural contexts shape and are shaped by psychological and neurobiological processes that unfold over time (Kim & Sasaki, 2014) and are likely to work together to influence human behavior, including people's innovative tendencies (Kaufman et al., 2011). At present, research on these interlocking processes is relatively limited, and some psycho-biological mechanisms, especially those examining how cultural, neural, and biological factors interact with each other, are yet to be empirically studied in the context of innovation (Nofal et al., 2018). Our research contributes to this emerging biological perspective in several ways.

First, we contribute to the literature on the causes of innovation by suggesting that cross-country differences in innovation outputs such as knowledge creation and diffusion have their deep origins in the historical disease prevalence, an exogenous environmental factor (Faulkner et al., 2004; Park et al., 2007). Specifically, building on the Parasite Stress Theory of Values (PSTV), we propose that people living in regions with a greater prevalence of infectious diseases were less likely to interact with out-group members as a psychological adaptation to limit exposure to pathogens. While ancestral decisions to avoid interactions with out-group members may have been optimal in terms of minimizing exposure to potentially fatal diseases (Fincher & Thornhill, 2012; Thornhill & Fincher, 2014), such evolutionary responses to the ecological

environment also served as a critical innovation juncture. In regions marked by high levels of disease pathogens, minimal interactions between groups limited the extent of mutually-beneficial economic and social interactions, thus hindering the division of labor, specialization, and gains from trade possible in broader markets (Smith, 1776). As a result of path dependency, countries with high historical levels of disease pathogens are less innovative today than those that were historically exposed to lower levels of pathogenic stress.

Second, we explore to what extent the relationship between pathogenic stress in the past and contemporaneous innovation is driven by the development of cultural values associated with the dimension of individualism-collectivism. Specifically, drawing on the PSTV, we propose that the relationship between the historical disease prevalence and contemporaneous innovation is to a great extent mediated by psychological factors manifested in a nation's cultural values associated with individualism-collectivism. As a psychological immune system adaptation to potentially life-threatening ecological conditions, people living in regions with a high prevalence of disease pathogens were more likely to develop collectivist cultural values associated with ethnocentric and philopatric tendencies such as neophobia, xenophobia, and nepotism (Hofstede, 2001; Thornhill & Fincher, 2014). Ethnocentric and philopatric values generated local and family-based production, xenophobic tendencies reduced intergroup and between-region economic and social interactions, and neophobic attitudes rewarded conformity and obedience towards traditional ideas and discouraged new ways of thinking. In turn, such collectivistic values were more likely to impede the creative activity needed for economic and social innovations to develop and depressed the advancement of progressive technologies and innovation-facilitating institutions (Chiao & Blizinsky, 2009; Fincher et al., 2008; Thornhill & Fincher, 2014).

Finally, while there is a body of literature linking individualistic culture to innovation (Rinne et al., 2012; Shane, 1992, 1993; Taylor & Wilson, 2012), most of the previous studies are correlational. Our theory, meanwhile, relies on a causal mechanism that has its origins in evolutionary theory and is based on a rich literature in behavioral psychology and biology that has identified the instrument (historical disease prevalence) *a priori*. This is important because cultural values, just like economic and political institutions, "impose norms on individual behavior and structure incentives in human interaction and exchange" (Nikolaev et al., 2017), which can influence how societies invest in the development and implementation of new ideas and technologies. Thus, our identification strategy allows us to present some of the first *causal* estimates of the relationship between the cultural values of individualism-collectivism and national innovation outputs, measured by the output sub-index from the Global Innovation Index (GII). The GII captures knowledge creation, impact, and diffusion, as well as intangible assets, creative goods and services, and online creativity. In additional robustness tests, we also explore specific cultural mechanisms related to out-group trust, affective and intellectual autonomy, and examine the possible effect of shifting cultural values over time.

CONCEPTUAL FOUNDATIONS

The Parasite Stress Theory of Values

The PSTV describes an evolutionary process linking the historical disease prevalence in a region to the development of individualistic/collectivistic cultural attitudes, beliefs, and values (Thornhill & Fincher, 2014). Humans have adapted to defend against infectious diseases, a major source of morbidity and mortality, in two main ways: (1) adaptations of the classical (physiological) immune system (e.g., biochemical, cellular, and tissue systems), and (2) adaptations of the behavioral (psychological) immune system (Schaller & Duncan, 2007;

Thornhill & Fincher, 2014). A growing body of biological and evolutionary psychology literature provides evidence that adaptations of the psychological immune system, which consist of "ancestrally adaptive feelings, attitudes, and values about and behaviors toward out-group and in-group members"[1] (Fincher & Thornhill, 2012, p. 62), have played a significant role in the natural selection of cultural values in human evolutionary history (Fumagalli et al., 2011; McNeill, 1998; Volk & Atkinson, 2013; Wolfe et al., 2007).

Specifically, out-group members may carry novel parasites for which local immunity has not yet developed, or they may lack the knowledge of local parasite infection norms and customs related to, for example, hygiene and food preparation (Fincher & Thornhill, 2008; Fincher et al., 2008). To avoid exposure to contagious diseases, people living in regions with high levels of pathogenic stress developed various forms of prejudice towards out-group members, including philopatry, xenophobia, neophobia, and ethnocentrism (Fincher et al., 2008; Thornhill et al., 2009), leading to the emergence of collectivist cultural values (Thornhill and Fincher, 2014). Meanwhile, groups of people living in regions with low levels of pathogenic stress were less concerned with contracting infectious diseases from out-group members and were, therefore, more open to economic and social interactions with outsiders, leading to the emergence of individualistic cultural values associated with social tolerance, trust of out-group members, and openness to novel ideas.

A large number of studies provide support for the PSTV. For example, experimental studies suggest that when people perceive to be exposed to pathogens, they are more likely to display

[1] An in-group is defined as a group of genetically or immunologically similar individuals (Fincher et al., 2008) who share common norms (e.g., culinary, linguistic, moral, sexual, nepotistic, etc.) that portray their in-group affiliation (Fincher & Thornhill, 2012). The behavioral (psychological) immune system is defined as human adaptations that defend against parasites and comprise (1) anti-parasite psychology and behavior and (2) psychology and behavior that manages infectious diseases when they occur (Fincher & Thornhill, 2012, p.62).

behaviors associated with ethnocentrism (Navarrete & Fessler, 2006) xenophobia (Faulkner et al., 2004), and, more generally, avoidance of others (Mortensen et al., 2010). For example, when people are primed with a disease contagion threat, they tend to be less agreeable, less open to new experiences, and more introverted (Mortensen et al., 2010). Additional evidence shows that parents are more likely to raise their children with collectivist values in societies with a high degree of pathogenic stress (Cashdan & Steele, 2013). High prevalence of pathogenic stress has also been linked to cultural practices associated with in-group favoritism or positive bias towards family members, friends and close associates (Fincher & Thornhill, 2012; van Leeuwen et al., 2012) and conformity (Murray et al., 2011), values that are common in collectivist cultures.

The Individualism-Collectivism Cleavage

We focus on the individualism-collectivism cleavage because the PSTV suggests that behavioral adaptations to the disease environment influence values along this cultural dimension (Thornhill & Fincher, 2014). Individualistic societies are those "in which the ties between individuals are loose: everyone is expected to look after himself or herself and his or her immediate family." Meanwhile, collectivistic societies are those "in which people from birth onwards are integrated into strong, cohesive in-groups, which throughout people's lifetime continue to protect them in exchange for unquestioning loyalty" (Hofstede, 1991, p. 51). As a result, individualistic societies tend to value individual freedom, opportunity, personal achievement, advancements, and recognition, while collectivistic cultures place a higher value on harmony, cooperation, and relations with superiors (Gorodnichenko & Roland, 2011b, 2012; Hofstede, 1980; Shane, 1992). Several studies have also suggested that the multifaceted value system of individualism and collectivism is the main dimension of cultural variation across

societies (Greenfield, 2000; Heine, 2016; Markus & Kitayama, 1991; Thornhill & Fincher, 2014; Triandis, 1995).

Innovation

We are interested in both incremental and radical technological changes that potentially facilitate creative destruction and long-run technological advancement (Ettlie et al., 1984; Schumpeter, 1942). Therefore, we follow the Oslo Manual developed by the European Communities and the Organization for Economic Co-operation and Development and the Global Innovation Index (2018, p. 56) in defining innovation as "the implementation of a new or significantly improved product (good or service), a new process, a new marketing method, or a new organization method in business practices, workplace organization, or external relations." This broad conceptualization treats innovation as a discovery-based process (Shane & Venkataraman, 2000) and accounts for a comprehensive set of incremental and radical innovations.

THEORY & HYPOTHESES DEVELOPMENT

Disease Pathogens & Innovation

Individuals living in regions with low parasite stress faced lower risks of infectious disease contagion. They were, therefore, more likely to engage in mutually-beneficial economic and social interactions with individuals from out-groups. This is because the potential economic benefits exceeded the potential cost of infectious disease contagion (Fincher & Thornhill, 2012). The exchange of goods and services between groups is a positive-sum economic activity that leads to mutually beneficial gains by providing individuals with access to greater diversity and lower cost of goods and services. As the market for goods and services expands, a greater division of labor and specialization develops. This, in turn, leads to productivity-enhancing

innovations that further drive down the costs of production and improves the quality of goods and services available, creating a virtuous cycle of innovation (Smith, 1776).

Cooperative economic and social activity between individuals living in different regions also facilitates the exchange of new ideas and technology, leading to knowledge spillovers that can further encourage innovation (Audretsch & Keilbach, 2007), and innovation-supporting infrastructure (Audretsch et al., 2015; Bennett, 2019a; Van De Ven, 1993; Woolley, 2014) and institutions (Fagerberg & Srholec, 2008; North, 1990). In turn, lower transaction costs of exchanging goods, services, and ideas between regions further facilitate the adoption and diffusion of new knowledge and technologies. Meanwhile, individuals living in regions with high parasite stress faced higher risks of infectious disease contagion and were, therefore, less likely to engage in economic and social interactions with individuals from out-groups, which stifled mutually-beneficial trade, knowledge diffusion, and subsequent innovation.

Ancestral responses to parasitic stress (e.g., decisions to interact with out-groups) were similar in neighboring regions with comparable geo-climatic conditions, suggesting that the effects of infectious disease stress on innovation were localized. The evolutionary decision to avoid interaction with out-group members meant that individuals living in regions with a high prevalence of infectious diseases had limited exposure to new ideas and technologies, which led to a path-dependent lock-in to earlier adopted technologies (Liebowitz & Margolis, 1995). Such evolutionary-induced aversion to new ideas and technologies was likely perpetuated over time, leading to a long-lasting adverse effect on a region's innovative potential. As such, we expect countries with high levels of historical disease prevalence to be less innovative today. Appendix Figure 1 supports this view by showing a strong negative correlation between disease prevalence and contemporary innovation outputs. Therefore, we propose the following hypothesis:

H1: *Countries with greater historical disease prevalence are less innovative today.*

Individualism-Collectivism and Innovation

A large number of studies theorize that individualistic cultures should be more innovative than collectivist ones. Leaps in innovation require people who are venturesome, open to new ideas, and willing to challenge the status quo (Rogers, 1995). Because entrepreneurs often take substantial personal risks associated with market entry and innovation (Shane et al., 1995), they also expect to be rewarded individually if they succeed (Hayton et al., 2002). Personal rewards and recognition of achievements are more culturally acceptable in individualistic societies (Shane, 1992). Because individualistic cultures promote self-expression and independent thinking, people are more likely to develop positive attitudes towards the creation and adoption of innovations (Alesina & Giuliano, 2010). Individualistic cultural beliefs also better facilitate anonymous exchange than collectivist cultural beliefs, leading to a broader market for goods and services, a greater division of labor and specialization, and hence, more productivity-enhancing innovations (Greif, 1994).

Other studies, however, have argued that the relationship between individualism-collectivism and innovation is more nuanced. Shane (1995), for instance, suggests that individualism influences the type of innovation strategy and not necessarily the sheer volume of innovation activity. Morris et al. (1993) and Effrat (2014) suggest that too much individualism may stifle innovation and that the appropriate functional relationship is curvilinear. Similarly, Gorodnichenko and Roland (2017) argue that the greater emphasis placed on conformity and the internalization of group interests in collectivist societies potentially enables lower cost collective action and static productive efficiency gains. Collectivistic cultures may also foster commitment and sacrifice among employees, which

can facilitate the development of new business ideas (Gelfand, Lim, & Raver, 2004). However, as Zhao et al. (2012) point out, collectivistic values are only likely to play a positive role in developing countries because new ventures in highly developed countries can draw on several alternative resources (e.g., angel investors, credit markets, etc.) that can facilitate launching their businesses.

Collectivist cultures tend to be "segregated" with each person interacting primarily with in-group members (same region, ethnicity, and extended family). In such cultures, in-group members are highly involved in cooperation with other in-group members, but a defining feature is non-cooperation between different in-groups. In contrast, individualistic cultures are "integrated" with economic and social interaction occurring among people from different groups in society (Greif, 1994). In such cultures, social interactions and exchanges with non-relatives are paramount. The theoretical implication is that individualist cultures, unlike segregated collectivist societies, are more likely to promote within- and between-region economic transactions and diffusion of technology and innovations. Bounded, localized social networks, which characterize collectivist cultures, on the other hand, retard knowledge creation and diffusion. Previous studies, for example, show that regions with individualistic values are more likely to adopt and diffuse new medical and agricultural technologies (Thornhill & Fincher, 2014).

Because individualistic cultures provide greater incentives for innovative behavior and encourage anonymous economic and social interactions (Gorodnichenko & Roland, 2011b, 2017), and considering the preponderance of empirical evidence (Rinne et al., 2012; Shane, 1992, 1993; Stephan & Uhlaner, 2010; Taylor & Wilson, 2012), we propose the following hypothesis:

H2: *Countries with individualistic (collectivistic) values are more (less) innovative.*

Disease Prevalence, Individualism-Collectivism, and Innovation

Behavioral adaptations such as negative attitudes toward out-group members were an optimal evolutionary response to local infectious disease conditions. Such adaptations also served as a critical juncture in the development of regional cultural values, reflecting the collective knowledge (Hayek, 1960) of how to best avoid infectious diseases at the time as a manifestation of decision-making heuristics (Nunn, 2012). The adaptation of beliefs, norms, and values is path-dependent (North, 1994) such that the psychological immune system adaptations get culturally transmitted over time via social learning and passed down across generations (Hofstede, 1980). In turn, the ontogenesis of contemporary cultural values has been linked to historical disease prevalence (Fincher & Thornhill, 2012; Thornhill & Fincher, 2014).

In this respect, one of the key implications of the PTSV, an *a priori* theory supported by a growing body of cross-cultural and experimental research, is that contemporary cultural values associated with the individualism-collectivism cleavage are deeply rooted in the historical disease prevalence (Thornhill & Fincher, 2014). The preponderance of evidence suggests that regions and countries with a historically low prevalence of infectious disease were more likely to develop individualistic value systems, characterized by greater openness to economic and social interactions with outsiders and cultural values associated with inclusiveness, tolerance, out-group trust, as well as greater respect for individual liberties. Behavioral preference for extraversion, curiosity, and openness to unfamiliar and new ideas, however, is associated with a higher risk of contracting new diseases. Thus, in contrast, countries with historically high levels of infectious diseases were more likely to develop collectivist value systems, characterized by less openness to economic and social interactions with outsiders and cultural values associated with exclusion, intolerance, mistrust of outsiders, as well as greater emphasis on conformity and less respect for

individual liberties (Fincher et al., 2008; Murray et al., 2011; Navarrete, Fessler, & Eng, 2007; Thornhill et al., 2009). Regions with high parasitic stress, for example, were more likely to naturally select behaviors such as xenophobia, ethnocentrism, introversion, and neophobia, which comprise the value dimension of collectivism-individualism. (Schaller & Murray, 2008; Thornhill & Fincher, 2014). Such behaviors, in turn, not only reduced economic transactions between groups and across regions, but also rewarded conformity, obedience toward traditional order, and discouraged novelty and the adoption of new technologies and knowledge.

Taken together, the theoretical and empirical evidence above implies that the historical disease prevalence robustly predicts the development of cultural values associated with the individualism-collectivism cleavage. In turn, cultural values related to individualism-collectivism have been demonstrated empirically to correlate strongly with various innovative outputs. Indeed, Appendix Figure 2 shows that countries with a lower historical disease prevalence are more individualistic today, and Appendix Figure 3 shows that more individualistic countries have higher levels of innovation. Therefore, we propose the following hypothesis:

> **H3:** *Individualism (collectivism) mediates the relationship between disease pathogens and global innovation such that low disease prevalence leads to the development of more individualistic cultural values, which, in turn, encourage higher levels of innovation.*

DATA & METHODOLOGY

Table 1 provides descriptions, sources, and summary statistics for all variables. Table 2 provides a correlation matrix for the main variables used in our analysis.

[TABLE 1 & 2 HERE]

Historical Disease Prevalence

We follow a large cross-cultural literature (e.g., Gorodnichenko & Roland, 2017; Nikolaev et al., 2017; Nikolaev & Salahodjaev, 2017; Thornhill & Fincher, 2014) and use the index

developed by Murray and Schaller (2010) that assesses the intensity of the historical disease prevalence for more than 155 countries. The index is based on the severity of nine diseases that are destructive to human survival and reproductive health (i.e., leishmania, trypanosomes, leprosy, schistosomes, filariae, tuberculosis, malaria, dengue, and typhus). To create the index, the authors use historical epidemiological atlases of infectious diseases and other epidemiological information dating back to the early 20th century, providing a deep-rooted measure of the historical disease prevalence.

The pathogen scores for each one of these diseases (coded on either three- or four-point scale)[2] were then standardized by converting them to z-scores. The composite disease prevalence index was estimated as the average of the individual disease z-scores. Positive values for each country indicate above-average disease prevalence, while negative values denote that disease prevalence is below the mean. The nine-item index had high internal validity (Cronbach alpha = .84). The index was also strongly correlated (R=0.9) with the disease prevalence index developed by Gangestad and Buss (1993), who used a similar rating procedure to estimate the overall historical prevalence of seven diseases in 29 countries. In addition, the index was highly correlated with a measure of contemporary parasite prevalence using recent epidemiological data (Fincher & Thornhill, 2008) and revealed that pathogenic stress is concentrated in the tropics compared to more temperate regions, which is consistent with a significant amount of evidence (Epstein, 1999; Murray & Schaller, 2010).

[2] For example, the 4-point coding scheme employed was: 0 = completely absent or never reported, 1 = rarely reported, 2 = sporadically or moderately reported, 3 = present at severe levels or epidemic levels at least once.

Innovation Outputs

To measure innovation, we use the output score from the Global Innovation Index (GII) (Dutta et al., 2018). The GII was initially developed in 2007 to capture better the richness of innovation in society than traditional measures of innovation used by researchers (e.g., level of R&D expenditures; number of research articles published; patents filed/granted). The innovative outputs sub-index is comprised of two main pillars—(1) knowledge and technology outputs; and (2) creative outputs—capturing various outputs of innovative activities within an economy. In turn, each of the two pillars consists of several sub-pillars. Specifically, the knowledge and technology outputs pillar is comprised of three sub-pillars: (1a) knowledge creation, (1b) knowledge impact, and (1c) knowledge diffusion. The creative outputs pillar is also comprised of three sub-pillars: (2a) intangible assets; (2b) creative goods & services, and (2c) online creativity. In total, 27 individual indicators were used to create the innovation outputs index. Appendix Table A1 describes the composition of the innovation outputs index.

Data for the indicators are obtained from a large number of public international bodies and private organizations. Most of the indicators are normalized by either population or GDP as a means to enable cross-country comparability. Because the GII is comprised of a large number of indicators from various sources, data is not available for all indicators for all countries. We use the 2018 GII dataset, which is based on observational data from 2016 and provides coverage for 126 economies that represent over 90 percent of the global population and economic output.

Individualism-Collectivism

Following an extensive literature in cross-cultural innovation and research on the PSTV, we focus on the Individualism-Collectivism index created by Hofstede (1980) as our primary measure of cultural values. This approach is consistent with the predictions of the PSTV,

according to which collectivism (in contrast to individualism) "functions as a defense against infectious diseases, and thus is more likely to be evoked in cultures that have a greater prevalence of parasites" (Thornhill & Fincher, 2014, p. 112). The Individualism-Collectivism index, which is derived from factor analysis, is available for more than 100 countries and ranges from 0 (most collectivistic) to 100 (most individualistic). Appendix Table A2 describes differences in cultural values between individualistic and collectivistic countries. We use the most recent version of the international values survey module, which consists of twenty-four values questions rated on a scale of 1 (most important) to 5 (least important) and was updated in 2013 based on replications and extensions of earlier studies.. The data were initially collected through a global survey of 100,000 IBM employees in 1967 and 1973. Subsequent waves of the survey and replication studies have included, in addition to IBM employees, several additional subgroups, including airline pilots, students, civil service managers, and "up-market" consumers and elites (Hofstede, 2010).

Control Variables

We control for a variety of factors that previous studies have found to influence country-level innovation. First, we control for property rights institutions (Aidis et al., 2012; McMullen et al., 2008; Nikolaev et al., 2018) using the property rights sub-index from the Index of Economic Freedom (Heritage Foundation, 2019). The index is measured on a scale of 0-100, with higher scores reflecting greater legal protection of private property rights. We also control for a country's level of economic development using the natural log of GDP per capita, adjusted for purchasing power parity (Anokhin & Wincent, 2012; Gorodnichenko & Roland, 2011a). Additionally, we include a set of control variables that are commonly held constant in the comparative economic development literature. This consists of a set of legal origins dummies

that reflect the historical roots of a nation's legal system (French, English, German, and Scandinavian), the shares of a nation's population belonging to the major world religions, ethnolinguistic fractionalization (i.e., probability that two people selected at random from a country's population belong to the same ethnic group), and a measure of democracy to account for the potential influence of political institutions. The measure of democracy is an average of civil rights and political freedoms and is measured on a scale from 0 (least political freedom) to 7 (most political freedom) (Abramowitz, 2018). Our final sample consists of up to 83 countries. Appendix Table A3 provides a list of all countries in our sample and their scores for individualism (independent variable), disease prevalence (instrumental variable), and innovation output (dependent variable).

Methodology

We analyzed the data using several different statistical methods. First, we used the Ordinary Least Squares (OLS) estimator (Wooldridge, 2010) to examine the direct impact of disease prevalence on innovation. The OLS regressions also served as a falsification test that allowed us to examine the validity of our instrumental variable. To test the potential mediating effect of culture on the relationship between disease prevalence and innovation, we used the Two-Stage Least Squares (2SLS) estimator (Wooldridge, 2010). The 2SLS estimator provides a means to overcome potential endogeneity issues (we discuss the validity of our approach in the next section). Additionally, we report heteroskedastic-robust standard errors (White, 1980), clustered at the regional level. Specifically, we clustered the standard errors (Cameron & Miller, 2015) around the six major regions of the world (i.e., Asia-Pacific, Europe, Middle East/North Africa, North America, South and Central America/Caribbean, Sub-Saharan Africa) that share common geo-climatic environments that potentially influence the prevalence of infectious diseases

(Burton et al., 1996) and, hence, the cultural transmission process at the heart of our theory and empirical strategy (Kuppens & Pollet, 2014; Pollet et al., 2014). Regional clustering of the heteroskedastic-robust standard errors, in conjunction with our employment of the 2SLS estimator, allows us to account for the hierarchical nature of our data attributable to the potential ecological and cultural interdependencies among countries within a region (Dow, 2007). We utilized the statistical software Stata 15 for all of the analyses.

EMPIRICAL RESULTS

Disease pathogens and innovation

Table 3 presents the results from OLS regressions of innovation on historical disease prevalence. Model 1 is a simple regression that does not hold any other variables constant. The results suggest that disease prevalence exerts a strong negative, and highly statistically significant effect on innovation. The R^2 value is 0.43, suggesting that historical disease prevalence alone explains close to half of the variation in innovation across countries today. Model 2 controls for legal origins. Model 3 adds variables that account for population diversity such as the religious composition of a country's population and ethnolinguistic fractionalization. Models 4 and 5 further introduce controls for property rights institutions and economic development.[3] Disease prevalence remains negatively and highly significantly ($p<0.001$) correlated with innovation in all models, providing support for H1. The -7.67 coefficient in model 5 suggests that a standard deviation increase in disease pathogens is associated with a 0.40 standard deviation decrease in innovation outputs, ceteris paribus. Finally, in model 6, we also

[3] Because cultural values are potentially endogenous with economic development and institutions (Alesina & Giuliano, 2015; Gorodnichenko & Roland, 2017; Nikolaev & Salahodjaev, 2017), we isolate the variation in institutions and development net of cultural values by using the residuals from OLS regressions of economic development and institutions on cultural values. The residuals capture the portion of institutions and development that is not correlated with culture. The results do not change, however, if we use the non-residual values of institutions and development.

introduce our measure of cultural values, individualism-collectivism. The estimated coefficient on disease prevalence loses its significance, and its magnitude becomes almost negligible. At the same time, we find that the predicted coefficient on individualism-collectivism is highly statistically and economically significant, with a standard deviation increase in individualism associated with an increase in innovation outputs of 0.62 standard deviations.

[TABLE 3 HERE]

Several additional results from Table 2 are worth mentioning. First, the variables in our most complete model (column 6) jointly explain over 75 percent of the variation in innovation outputs across countries. Second, countries with German and Scandinavian legal origins are more innovative. Third, countries with a larger share of Muslims and Protestants are less innovative.

Overall, these results provide support for H2. However, we should be careful in interpreting these findings as causal for several reasons. First, countries with high levels of innovation likely have higher levels of economic growth and development, which may promote the development of individualistic values over time (Ball, 2001). There could also be omitted variables that are correlated with both individualism and innovation, introducing additional bias to the estimates. This can be mitigated if we have a valid instrumental variable that is strongly correlated with individualistic cultural values but has no direct effect on innovation outputs. Therefore, model 6 also serves as a falsification test that provides evidence for the validity of our instrumental variable (disease prevalence). Specifically, one of the most critical assumptions of our 2SLS model is that our disease prevalence impacts innovation only through the channel of culture, holding other factors constant. If disease prevalence were a significant predictor of innovation when controlling for culture (model 6), then this would imply that our instrument (disease prevalence) can potentially impact innovation through some other (unobserved) channel besides

culture. This would suggest that we have not solved the endogeneity problem and that our estimates are likely biased. However, because disease prevalence loses its significance once we control for individualism (model 6), this suggests that the variables in our model account for all possible channels through which disease prevalence may influence innovation.

Finally, a possible concern with our analysis so far is the degree of collinearity between the independent variables in our model. As collinearity increases, regression model estimates become unstable, and standard errors inflated. Although our clustering of the robust standard errors likely mitigates this possibility, we nonetheless calculated the variance inflation factor (VIF) for all independent variables of our most complete model (6) in Table 3 to check for potential multi-collinearity. The results, which are presented in Table 4, suggest that none of the variables in our model exceed VIF greater than 10 (or 1/VIF less than 0.1), which is considered to be the threshold for tolerance of multi-collinearity.

Overall, the results in Table 3 provide support for H1 and H2. That is, the historical disease prevalence is strongly and negatively correlated with innovation outputs today (H1), and cultural values associated with individualism are strongly and positively correlated with innovation outputs (H2). Next, we test whether the relationship between disease prevalence and innovation is mediated by the cultural channel of individualism-collectivism (H3) using 2SLS regression.

Disease Pathogens, Culture and Innovation

The PSTV suggests that people living in regions plagued by a high prevalence of diseases were more likely to develop cultural values associated with more collectivist societies. Our theory suggests that the strong association between disease pathogens and innovation is transmitted through the cultural channel (H3), as more individualistic cultures provide social and economic rewards that incentivize the pursuit of innovative ideas.

To test the theory that culture serves as a transmission mechanism from disease pathogens to innovation, we employ a 2SLS model in which innovation outputs is the dependent variable, individualism is the endogenous independent variable, and disease pathogens prevalence is the exogenous instrumental variable excluded from the second-stage of the analysis. In other words, we use the historical disease prevalence as an instrument for individualism, which then predicts innovation in the next stage. The exclusion restriction implied by our instrumental variable estimation is that, conditional on all other factors in our model, the historical disease prevalence does not affect innovation output today other than through the cultural channel of individualism. Our falsification test in Table 3 (model 6) provides support for this critical assumption.

We present the second-stage and first-stage estimates of our 2SLS analysis in panels A and B of Table 5, respectively. Model 1 shows a bivariate regression where only the instrumented individualism index is included on the right-hand side. Analogous to Table 3, subsequent models add controls for legal origins (model 2), religious affiliation and ethnocentric fractionalization (model 3), economic and political institutions (model 4), and economic development (model 5). Individualism remains highly statistically significant ($p<0.001$) in all models. The disease prevalence index is also a strong predictor of individualistic values in all first-stage models (panel B). These results are consistent with H3 and suggest that a standard deviation increase in disease pathogens is associated with a 0.44 to 0.53 standard deviation decrease in individualism. Collectively, the first-stage regressors explain more than 64 percent of the variation in individualism for our sample of 83 countries. Finally, at the bottom of Table 5, we report the IV F-statistic for instrument relevance. In the case of a single endogenous regression, which is our case, the t-value of the instrument should be greater than 3.2. Here, the rule of thumb is that the F-statistic of a joint test whether all excluded instruments are significant should be greater than

10. Otherwise, we have a weak instrument problem, which can produce biased results (Stock & Yogo, 2005). The F-statistic easily exceeds the critical value of 10 in all of our models, providing further confidence in the validity of our identification strategy.

[TABLE 5 HERE]

Overall, the results from our 2SLS analysis provide support for H2 and H3, suggesting that the effect of disease pathogens on innovation is transmitted through the cultural channel of individualism-collectivism. The magnitude of the effect is also economically significant. The coefficient estimates suggest that a standard deviation increase in individualism is associated with a 0.80 to 1.21 standard deviation increase in innovation outputs.

Alternative Measures of Individualism-Collectivism

Even though Hofstede's index of individualism-collectivism has been widely used in the cross-cultural and innovation literature, his model has also received criticism (Schwartz, 1994). Therefore, we performed robustness tests using several alternative measures of individualism-collectivism. This also enabled us to explore more specific cultural transmission mechanisms through which historical disease prevalence has impacted contemporary innovation. We report these additional results in Table 6.

First, according to the PSTV, people in individualist societies "are more trusting of [both] in-group and out-group members" (Thornhill & Fincher, 2014, p. 320). In turn, outgroup trust plays a significant role in cultivating and facilitating economic exchange, including the adoption and diffusion of novel ideas that can lead to experimentation and innovation. To explore the role of outgroup trust, we used data from the World Values Survey (WVS). Specifically, we measured the share of people in a country who responded that "*most people can be trusted*." Scores were averaged across all waves of the WVS (1981-2014) and ranged from .04 (Trinidad and Tobago)

to 0.69 (Norway). Previous studies suggest that this measure captures generalized trust behaviors effectively (Johnson & Mislin, 2012). The results from model 1 suggest that countries with high levels of disease prevalence were less likely to develop cultural values associated with outgroup trust, which, in turn, is a strong predictor of innovation outputs in the second stage.

Next, we used three measures from Schwartz's cultural orientation scale, which were derived from an extensive list of 57 single value items that asked respondents to indicate the importance of each value as "a guiding principle in my life" (Schwartz, 1994). Data were collected between 1998 and 2000 in 78 countries. Similar to Hoftede's Individualism-Collectivism scale, Schwartz differentiates cultures based on an autonomy-embeddedness dimension. Autonomous (individualistic) cultures view people as independent entities and encourage them to cultivate and express their own preferences, feelings, ideas, and abilities. Embedded (collectivist) societies, on the other hand, place value on the status quo, discouraging individual actions that may compromise traditional order. People in such societies find meaning by identifying with the group and striving toward shared values and goals. We use the autonomy-embeddedness index, as well as its two sub-indexes of affective autonomy and intellectual autonomy that measure the extent to which people are encouraged to seek personal enjoyment and pleasure by any means or pursue independent ideas and thoughts, respectively. Overall, the results are highly consistent with our main findings. More embedded (collectivist) societies are less likely to be innovative compared to more autonomous (individualistic) societies (model 2). We also found that pathogenic stress is negatively correlated with both affective autonomy (model 3) and intellectual autonomy (model 4), which, in turn, are strong predictors of innovation outputs.

Finally, it is possible that cultural values change over time and that the effect of culture on innovation erodes over time (Shane, 1993). Over the past 30 years, there has been a modest

worldwide shift towards individualism, although there is mixed evidence regarding whether this cultural shift has been absolute (Beugelsdijk, Maseland, & Van Hoorn, 2015) or relative (Taras, Steel, & Kirkman, 2012). To account for cultural change over time, we used an updated dataset of cultural scores along the individualism-collectivism dimension of Hofstede's cultural framework (Taras et al., 2012).[4] These results are reported in model 5 and are consistent with our main findings from Table 5.

[TABLE 6 HERE]

We also note that utilizing alternative measures of culture reduced our sample size from 83 countries to 37-63 countries, depending on the cultural measure employed. That our results were robust to various sample sizes and cultural measures provides further confidence in our findings, particularly given that cross-country empirical results can be highly sensitive to sample size and measurement selection (Bennett & Nikolaev, 2017).

DISCUSSION

Contributions

The emerging biological perspective in the entrepreneurship and innovation literature has focused mainly on human biology, largely overlooking the role that cultural contexts play in shaping, and being shaped by, interdependent evolutionary psychological and neurobiological processes that influence human behavior (Kaufman et al., 2011; Kim & Sasaki, 2014; Nofal et al., 2018). We contribute to this line of research by examining how a deeply-rooted environmental factor, the historical prevalence of infectious diseases, influenced contemporary levels of innovation. Specifically, we propose that the long-lasting effects of disease pathogens on innovation were transmitted through the development of cultural values as a behavioral

[4] In their meta-analysis, Taras et al. (2012) calculated individualism-collectivism scores for the 1980s, 1990s, and 2000s. We used the overall measure, which represents the average of these three time periods.

immune system adaption to potentially adverse ecological conditions. We theorize that countries with historically low levels of disease pathogens are more innovative today, in part because they developed—as an evolutionary response to minimize pathogenic contagions—individualistic cultural values that better incentivized innovation than collectivistic cultural values.

Our framework builds on a theory from biology and evolutionary psychology, the Parasite Stress Theory of Values (PSTV). The PSTV suggests that regions marked by high disease prevalence minimized the risk of contracting infectious diseases by avoiding interactions with out-group members, resulting in the development of collectivistic cultural values. Meanwhile, regions marked by low disease prevalence were more open to interactions with out-group members, resulting in the development of individualistic cultural values (Fincher & Thornhill, 2012; Thornhill & Fincher, 2014). While previous studies have employed the PSTV to established a link between disease prevalence and macro-level outcomes such as long-run economic growth (Gorodnichenko & Roland, 2011a, 2017), income inequality (Nikolaev et al., 2017), economic and political institutions (Gorodnichenko & Roland, 2015; Nikolaev & Salahodjaev, 2017; Thornhill & Fincher, 2014), and forest preservation (Cai et al., 2019), we extend this literature to the domain of innovation.

While our study suggests that both cultural values and innovation tendencies are deeply rooted in human biology, these dynamic processes are still on-going today. For example, with the spread of the coronavirus in recent months, there has been a rise in xenophobic attitudes toward Chinese people around the world (Bennett, 2020a). Similarly, in an attempt to contain the disease, the Chinese government has shut down production in several regions and limited interaction between citizens. Similarly, the Ebola outbreak in 2014-2016 evoked similar reactions toward Africans. Such responses (both at the individual and national level), driven by

the fear of contracting a highly infectious diseases without a cure, may be natural behavioral adaptations of the psychological immune system in response to potential biological threats. However, they can also have both short and long-term negative economic consequences.

The cross-cultural innovation literature suggests that individualistic societies tend to respect individual liberties, reward personal achievement with social status, and encourage economic and social integration, thereby providing a more supportive innovation environment than collectivistic societies, which tend to reward conformity and emphasize group interests over personal freedom (Greif, 1994; Shane, 1992, 1993). Numerous studies provide supportive empirical evidence linking individualism to innovation. However, most of these studies are correlational (Rinne et al., 2012; Shane, 1992, 1993; Taylor & Wilson, 2012). This is problematic because culture is widely regarded to be a highly endogenous variable. By connecting the PSTV to the cross-cultural innovation literature, we not only develop a causal theoretical framework linking historical disease conditions to contemporary innovation via the channel of cultural development, but we also propose an instrumental variable (historical disease prevalence) that allows us to identify an exogenous source of variation in contemporary cultural values and overcome the endogeneity problem so that we can estimate the causal effect of individualism on national innovation. Using a 2SLS model for a sample of 83 countries, we provide evidence that individualistic cultural values, which were shaped by low levels of historical disease prevalence, are a strong, positive, robust, and causal determinant of national innovation.

Practical Implications

Our theory and empirical evidence indicate that nations with more individualistic cultures, which were influenced by a historical disease environment marked by low prevalence of

diseases, are more innovative today than nations with collectivistic cultures. This is suggestive of an ecological-cultural path dependency that has had enduring effects on a nation's innovative potential over a long period. We want to stress, however, that our research should not be interpreted as supportive of cultural determinism implying that nations marked by historically high levels of disease that developed more collectivistic cultural values as a behavioral immune system response are permanently condemned to be technological laggards, with no role for policymakers and innovators to help shape a more innovative and prosperous future. Instead, we stress that readers consider several important caveats that provide valuable implications for those in a position to influence policy.

First, our research suggests that culture is only one of the many determinants of national innovation. The national innovation systems literature indicates that other factors comprising the innovation ecosystem (e.g., formal institutions, government policy, infrastructure, entrepreneurs and firms, and even luck) are also essential inputs in the innovation process (Freeman, 1995; Lundvall et al., 2002). For example, our empirical findings also suggest that property rights institutions are a strong positive predictor of national innovation. This is consistent with previous research that has identified property rights institutions as one of the most critical determinants of entrepreneurship and innovation (Aidis et al., 2012; Boudreaux & Nikolaev, 2019; McMullen et al., 2008; Nikolaev et al., 2018; Sweet & Eterovic Maggio, 2015). Although property rights institutions may have arisen as a formalization of norms and informal rules practiced by individualistic societies (Eesley et al., 2018; Nikolaev & Salahodjaev, 2017), formal institutions may be altered rapidly through the political process, whereas cultural values only change gradually over time (Bylund & McCaffrey, 2017; North, 1990). This suggests that, rather than attempting to change culture, improving property rights institutions may be a more tangible and

direct means for policymakers to encourage innovation and economic development (Acemoglu et al., 2001; Bennett et al., 2017).

Next, although culture tends to change slowly, there is evidence that cultural values along the individualism-collectivism cleavage have changed in recent decades for many countries (Taras et al., 2012). Hofstede's (1980) cultural value dimensions were designed to capture relative differences between countries and, as Beugelsdijk et al. (2015) point out, much of the measured change in culture over the past three decades has been absolute rather than relative. In other words, cultural differences between country pairs have remained relatively stable over time, although Taras et al. (2012) provide some evidence to the contrary. Even if most countries are undergoing a cultural shift towards the adoption of more individualistic values such that relative rankings between countries remain unchanged, our theory and empirical evidence suggest that this cultural change may still provide an impetus when it comes to the absolute change in innovation. One possibility for achieving this is to invest in improving health care systems around the world to prevent the spread of infectious diseases. This may be particularly impactful in developing countries. In such contexts, improvements in health can not only allow developing nations to detect and contain infectious diseases and potential epidemics, but also continue to foster cultural values that promote innovation and economic development. In turn, better health can lead to higher levels of human capital and economic opportunities, which can lift countries out of poverty and make them less reliant on foreign aid (Williamson, 2008).

In this respect, China and Vietnam provide illustrative examples of countries that, despite having historically high disease prevalence and collectivistic cultural values, have experienced rapid economic growth since beginning their transitions from centrally-planned to market economies in 1978 and 1986, respectively. Both countries have experienced a cultural shift

towards individualism in recent decades (Taras et al., 2012) and decentralized institutional reforms have gradually removed barriers to innovation and competition, resulting in productivity-enhancing innovations in both China (Chang & Wu, 2014; Coase & Wang, 2016; Lau et al., 2000) and Vietnam (Nguyen et al., 2015; Tran, 2018). China now ranks among the top decile of innovative countries for which data are available, contributing substantially to the recent global growth of intellectual property filings. Meanwhile, Vietnam has been identified as an innovation achiever by the Global Innovation Index, meaning that it outperforms on innovation relative to its level of development and produces greater innovative output than would be expected by its level of innovation infrastructure (Dutta et al., 2018).

Additionally, while it is impossible to alter the historical disease environment of a nation, some countries, particularly those located in or near tropical regions, remain plagued by high levels of infectious diseases (Epstein, 1999; Fincher et al., 2008). This inhibits individuals and firms from making productive investments in human and physical capital, restraining such disease-ridden nations of their potential to innovate and achieve economic development (Bennett et al., 2017; Carstensen & Gundlach, 2006). Controlling the spread of debilitating infectious diseases through improving the health care system should be a priority in such countries that can help unleash their innovative potential. However, this will likely require innovative approaches involving the international community and both the local public and private sectors (Archibugi & Bizzarri, 2004; Geoffard & Philipson, 1997).

Limitations and Future Research Guidance

Even though our analysis contributes to our understanding of the processes by which the historical disease prevalence shaped the path of innovation around the world, it is conceivable that the historical processes that we analyze are more important for certain types of innovation

than others. This is relevant because we use an aggregated measure of innovation, which is comprised of numerous underlying innovation indicators. In Appendix Table A4, we re-estimated our main 2SLS model (Table 5, model 5) to examine the effect of individualism-collectivism on the two sub-areas and three sub-pillars of the GII. These preliminary results suggest that the historical prevalence of pathogens is negatively correlated with individualism, which, in turn, has a strong and positive effect on all but one of the innovation outputs measures. Future research can build on our preliminary analysis to study which categories of innovation are more strongly linked to path dependency versus those that are more fluid and amenable to the influence of policymakers, entrepreneurs, and innovators.

Next, although our main results control for the effect of institutions and are robust to several alternative cultural measures, including the Taras et al. (2012) individualism measures that capture within-country variations over time, researchers increasingly recognize that culture and institutions co-evolve (Alesina & Giuliano, 2015; Nunn, 2012). Future research that examines the dynamic relationship between culture, institutions, and innovation—either through detailed country case studies or comparative analysis—would facilitate a better understanding of the complex and interdependent mechanisms underlying national innovation. One empirical challenge to exploring this dynamic relationship, particularly if using the GII dataset, is developing innovation metrics that are comparable across both countries and time, as the index methodology and the variable coverage are not constant over time.

Another limitation of our analysis is the observational/correlational nature of our data. While our estimation approach, 2SLS, is grounded in a rich literature in behavioral psychology and evolutionary biology that suggest the instrument *a priori*, our results should be interpreted with caution. Here, we are less worried about reverse causality because it is highly unlikely that

innovation levels today drive pathogenic stress in the past. It is possible, however, that our instrument—the historical prevalence in pathogens—is correlated with other omitted variables and cultural values that predict innovation levels today. Thus, while we include a large number of covariates and provide a number of additional tests with alternative cultural measures, our results should be interpreted as implying only *weak* causality.

Finally, our research focuses on the link between disease pathogens and innovation at the national level. However, significant variation in innovation and historical patterns of pathogenic stress exists within countries (Cooke et al., 1997; Fincher and Thornhill, 2014). Similarly, there could be variation in cultural values (e.g., Tung, 2008) and institutions (e.g., Bennett, 2019b, 2020b) across a country's subnational regions. In this regard, future research can explore the links between disease pathogens and innovation at the subnational level in order to establish validity for our framework in a within-country context.

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Table 1: Variable Descriptions, Sources, and Summary Statistics

Variable	Description	Source/Year	Mean	Std. Dev.	Min	Max
Innovation Output Index	Index measuring innovative outputs in two categories (1) knowledge & technology outputs, and (2) creative outputs. The index ranges from 0 (least innovative) to 100 (most innovative). Knowledge and technology outputs are measured with: (1a) knowledge creation (e.g., patents, utility models, scientific and technical articles, etc.), (1b) knowledge impact (e.g., growth rate per worker, new businesses, computer software spending, etc.), and (1c) knowledge diffusion (e.g., intellectual property receipts, high-tech net exports, FDI net outflows). Creative outputs are measured with: (2a) intangible assets (e.g., trademarks, industrial design, ICTs & business model creation, etc.); (2b) creative goods & services (e.g., cultural and creative services exports, national feature films, entertainment and media market, etc.), and (2c) online creativity (e.g., generic top-level domains, Wikipedia edits, mobile app creation).	Cornell University, INSEAD and WIPO (2018)/2016	32.18	12.72	8.3	67.13
Individualism	Index measuring the degree to which a society accepts and reinforces individualist or collectivist values. The index ranges from 0 (most collectivistic) and 100 (most individualistic). Appendix Table A2 describes key differences between individualistic and collectivistic societies. Data was originally collected in 1967 and 1973. The dataset was updated in 2013, partly based on replications and extensions of the original study.	Hofstede et al. (2010)/1967-2010	40.36	22.65	6	91
Disease Pathogens	Index measuring the historical prevalence of infectious diseases in a particular country. The index is based on the severity of nine diseases that are destructive to human survival and reproductive health (leishmania, trypanosomes, leprosy, schistosomes, filariae, tuberculosis, malaria, dengue, and typhus). The index is based on historical epidemiological atlases of infectious diseases and other epidemiological information dating back to the early 20th century. The pathogen scores for each one of these diseases (coded on either three- or four-point scales) were then standardized by converting them to z-scores. The composite pathogen prevalence index was estimated as the average of the individual disease z-scores. Positive values for each country indicate above average disease prevalence while negative values denote that pathogen prevalence is below the mean.	Murray and Schaller (2010)/early 20th century	-.04	.66	-1.31	1.16
Legal Origins - French	Dummy variable = 1 if legal origin French; 0 otherwise.	La Porta et al. (1999)	.36	.48	0	1
Legal Origins - German	Dummy variable = 1 if legal origin German; 0 otherwise.	La Porta et al. (1999)	.06	.24	0	1
Legal Origins - Scandinavian	Dummy variable = 1 if legal origin Scandinavian; 0 otherwise.	La Porta et al. (1999)	.06	.24	0	1
Percent Muslim	Share of population Muslim in 1980.	La Porta et al. (1999) /1980	16.74	30.97	0	99.4
Percent Catholic	Share of population Catholic in 1980.	La Porta et al. (1999) /1980	34.48	37.42	0	97.3

Variable	Description	Source/Year	Mean	Std. Dev.	Min	Max
Percent Protestant	Share of population Protestant in 1980.	La Porta et al. (1999) /1980	14.54	24.87	0	97.8
Ethnolinguistic Fractionalization	Index that captures the probability that two individuals, selected at random from a country's population, will belong to different ethnic groups. Data collected from various years over the period 1979-2001.	Alesina et al. (2003) / 1979-2001.	.39	.24	0	.86
Democracy	Index is created as an average of civil rights and political liberties.	Freedom House/ 2016	4.49	1.6	0	6
Property Rights	Sub-index of economic freedom which measures the degree to which a country's laws protect private property rights and the extent to which those laws are respected. The index is created by equally weighing the following five sub-factors: (1) physical property rights, (2) intellectual property rights, (3) strength of investor protection, (4) risk of expropriation, and (5) quality of land administration. The index is measured on a scale from 0 (least protection) to 100 (greatest protection).	Heritage Foundation / 2016	53.13	25.23	10	95
Economic Development	The logged value of GDP per capita in 2016, adjusted for purchasing power parity.	World Bank/ 2016	9.7	1.03	6.66	11.42
Outgroup Trust	Share of people in society who respond that "most people can be trusted." Scores are averaged across all waves of the WVS (1981-2014).	World Values Survey/1981-2014	.25	.14	.04	.70
Embeddedness (vs Autonomy)	Index that reflects the extent to which people find meaning through identifying with the group, participating in a shared way of life, and striving towards shared goals. In embedded societies high value is placed on the status quo and avoiding individual actions that might undermine traditional order. Values range from 0 (not at all important) to 6 (very important).	Schwartz (2008)/ 1998-2000	3.80	0.39	3.01	4.63
Affective Autonomy	Index of affective autonomy that reflects the extent to which people are encouraged to pursue pleasure and seek enjoyment by any means. Values range from 0 (not at all important) to 6 (very important).	Schwartz (2008)/ 1998-2000	3.43	0.51	2.13	4.39
Intellectual Autonomy	Index of affective autonomy that reflects the extent to which people are encouraged to pursue independent ideas and thoughts, whether theoretical or political. Values range from 0 (not at all important) to 6 (very important).	Schwartz (2008)/ 1998-2000	4.31	0.38	3.58	5.13
Individualism (Meta)	An updated Hofstede's Individualism-Collectivism scores for 49 countries based on the meta-analysis in Taras et al. (2012). Standardized values. Data collected from various studies in the 1980s, 1990s and early 2000s to develop measures for each decade. We use the average value over time for each country.	Taras et al. (2012) / 1980 - 2000	.04	.60	-1.39	1.13

Notes: Number of countries in our sample = 83. Year of publication for variable sources denoted in parentheses, with time of data observation noted after forward slash if different than year of publication.

Table 2: Correlation Matrix

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)
(1) Innovation Output	1.00																
(2) Individualism	0.67*	1.00															
(3) Disease Prevalence	-0.65*	-0.66*	1.00														
(4) Legal Origins: French	-0.27	-0.25	0.26	1.00													
(5) Legal Origins: German	0.37*	0.12	-0.17	-0.19	1.00												
(6) Legal Origins: Scand	0.33*	0.30*	-0.35*	-0.19	-0.06	1.00											
(7) Share Muslim	-0.35*	-0.30*	0.27	0.17	-0.14	-0.14	1.00										
(8) Share Catholic	0.04	0.04	-0.14	0.50*	0.01	-0.23	-0.42*	1.00									
(9) Share Protestant	0.32*	0.45*	-0.40*	-0.38*	0.07	0.78*	-0.27	-0.26	1.00								
(10) Ethno Fraction	-0.50*	-0.35*	0.36*	0.06	-0.24	-0.33*	0.23	-0.09	-0.12	1.00							
(11) Democracy	0.49*	0.55*	-0.53*	-0.04	0.21	0.24	-0.62*	0.42*	0.37*	-0.31*	1.00						
(12) Property Rights	0.75*	0.70*	-0.63*	-0.20	0.32*	0.38*	-0.37*	0.16	0.46*	-0.40*	0.71*	1.00					
(13) Econ Development	0.73*	0.54*	-0.71*	-0.09	0.23	0.25	-0.19	0.15	0.20	-0.48*	0.40*	0.69*	1.00				
(14) Outgroup Trust	0.59*	0.44*	-0.39*	-0.39*	0.19	0.53*	-0.08	-0.42*	0.52*	-0.37*	0.04	0.40*	0.45*	1.00			
(15) Embeddedness	-0.71*	-0.62*	0.63*	0.05	-0.35*	-0.33	0.58*	-0.32	-0.35*	0.59*	-0.66*	-0.72*	-0.74*	-0.43*	1.00		
(16) Affective Autonomy	0.70*	0.62*	-0.63*	-0.26	0.30	0.30	-0.51*	0.11	0.35*	-0.43*	0.55*	0.64*	0.70*	0.47*	-0.85*	1.00	
(17) Intellectual Autonomy	0.65*	0.53*	-0.60*	-0.03	0.31	0.36*	-0.45*	0.32	0.27	-0.56*	0.63*	0.62*	0.67*	0.31	-0.88*	0.74*	1.00
(18) Individualism (Meta)	0.54*	0.84*	-0.68*	-0.28	0.02	0.28	-0.35	0.07	0.52*	-0.06	0.57*	0.62*	0.57*	0.46	-0.60*	0.63*	0.50*

Note: * shows significance at the .01 level

Table 3: OLS Results - Disease Pathogens and Innovation Output

	(1)	(2)	(3)	(4)	(5)	(6)
	Dependent Variable = Innovation Output					
Disease Pathogen	-12.527***	-10.376**	-9.773***	-9.194***	-7.673***	-1.773
	(2.536)	(2.863)	(1.582)	(0.660)	(1.881)	(1.063)
Legal Origins - French		-1.244	0.194	0.033	-0.512	-0.380
		(3.920)	(2.714)	(2.506)	(2.370)	(0.742)
Legal Origins - German		15.072***	12.429***	9.433*	9.406*	9.466***
		(2.321)	(2.153)	(4.234)	(4.365)	(2.183)
Legal Origins - Scandinavian		7.942***	7.257	4.933	4.774	9.603
		(1.616)	(8.092)	(8.824)	(9.235)	(5.563)
Muslim Population Share			-0.087*	-0.072	-0.067	-0.082**
			(0.041)	(0.068)	(0.063)	(0.031)
Catholic Population Share			-0.049	-0.065	-0.064	-0.048
			(0.052)	(0.045)	(0.048)	(0.026)
Protestant Population Share			-0.062	-0.068	-0.051	-0.127
			(0.120)	(0.112)	(0.119)	(0.070)
Ethnolinguistic Fraction			-10.081**	-9.928*	-8.753*	-2.268
			(3.104)	(4.371)	(3.753)	(3.902)
Democracy				0.615	1.120	-0.694
				(2.030)	(1.693)	(1.305)
Property Rights				0.102	0.044	0.145**
				(0.098)	(0.064)	(0.055)
Economic Development					2.087	3.499**
					(1.796)	(1.241)
Individualism						0.352***
						(0.037)
Countries	83	83	83	83	83	83
R-squared	0.426	0.521	0.588	0.610	0.619	0.757

Notes: OLS regressions of innovation output on disease pathogens. See Table 1 for variable descriptions and sources. Robust errors clustered at the regional level (Asia-Pacific, Europe, Middle East/North Africa, North America, South and Central America/Caribbean, Sub-Saharan Africa) reported in parenthesis. Legal Origins - Great Britain used as a reference group. **** p<0.01, ** p<0.05, * p<0.1*

Table 4: Variance Inflation Factors

	VIF	1/VIF
Protestant Population Share	4.36	0.22
Legal Origins - Scandinavian	3.80	0.26
Democracy	3.66	0.27
Disease Pathogens	3.23	0.31
Individualism	2.81	0.35
Catholic Population Share	2.80	0.35
Property Rights	2.39	.42
Muslim Population Share	2.31	0.43
Economic Development	2.31	0.43
Legal Origins - French	2.21	0.45
Ethnolinguistic Fraction	1.72	0.58
Legal Origins - German	1.36	0.73
Mean VIF	2.75	

Note: VIF values for model 6 of Table 3.

Table 5: 2SLS Results - Disease Pathogens, Culture & Innovation

	(1)	(2)	(3)	(4)	(5)
Panel A: Second Stage			*Dependent Variable: Innovation Output*		
Individualism	0.551***	0.491***	0.543***	0.660***	0.455***
	(0.110)	(0.133)	(0.074)	(0.056)	(0.064)
Legal Origins - French		0.569	-0.555	0.977	-0.340
		(2.683)	(1.440)	(1.058)	(0.485)
Legal Origins - German		14.928***	16.540***	9.582***	9.484***
		(4.212)	(0.970)	(2.826)	(1.707)
Legal Origins - Scandinavian		4.521*	23.339***	14.248***	11.054***
		(2.692)	(5.484)	(2.729)	(3.915)
Muslim Population Share			-0.058***	-0.107***	-0.087***
			(0.010)	(0.021)	(0.021)
Catholic Population Share			-0.032**	-0.036	-0.044*
			(0.016)	(0.032)	(0.022)
Protestant Population Share			-0.280***	-0.232***	-0.149***
			(0.080)	(0.038)	(0.052)
Ethno Fractionalization			0.824	0.811	-0.320
			(4.012)	(4.099)	(3.489)
Democracy				-3.455***	-1.239
				(1.106)	(1.071)
Property Rights				0.366***	0.175***
				(0.060)	(0.059)
Economic Development					3.923***
					(0.925)
Panel B: First Stage			*Dependent Variable: Individualism*		
Disease Pathogens	-22.716***	-21.125***	-18.005***	-13.938***	-16.881***
	(2.718)	(3.389)	(2.298)	(1.669)	(2.267)
Legal Origins - French		-3.692	1.380	-1.432	-0.378
		(8.272)	(4.427)	(4.633)	(5.273)
Legal Origins - German		0.295	-7.573	-0.225	-0.172
		(5.518)	(6.194)	(9.043)	(8.774)
Legal Origins - Scandinavian		6.966	-29.628*	-14.123	-13.816
		(3.726)	(11.558)	(13.158)	(12.792)
Muslim Population Share			-0.053	0.053	0.043
			(0.061)	(0.110)	(0.113)
Catholic Population Share			-0.031	-0.044	-0.046
			(0.106)	(0.102)	(0.098)
Protestant Population Share			0.401**	0.249	0.217
			(0.115)	(0.177)	(0.165)
Ethno Fractionalization			-20.090**	-16.280**	-18.553**
			(7.273)	(5.528)	(4.739)
Democracy				6.170***	5.191***
				(1.237)	(1.043)
Property Rights				-0.401***	-0.288**
				(0.086)	(0.080)
Economic Development					-4.039
					(2.728)
Countries	83	83	83	83	83
IV F-Stat	69.87	38.86	61.36	69.75	55.44
R-squared	0.442	0.453	0.533	0.634	0.644

Notes: Panel A reports the second stage from the two-stage least squares estimations. Panel B reports the corresponding first stages. See Table 1 for description and sources of variables. "Legal Origins - Great Britain" is used as a reference group. Robust errors clustered at the regional level (Asia-Pacific, Europe, Middle East/North Africa, North America, South and Central America/Caribbean, Sub-Saharan Africa) reported in parenthesis. **** p<0.01, ** p<0.05, * p<0.1*

Table 6: Alternative Measures of Individualism

	(1)	(2)	(3)	(4)	(5)
Panel A: Second Stage	*Dependent Variable: Innovation Output*				
Outgroup Trust	98.429**				
	(40.751)				
Embeddedness		-24.356**			
		(10.967)			
Affective Autonomy			17.565***		
			(5.228)		
Intellectual Autonomy				28.130**	
				(12.704)	
Individualism (Meta)					20.007**
					(10.499)
Controls	YES	YES	YES	YES	YES
Panel B: First Stage	*Outgroup Trust*	*Embeddedness*	*Affective Autonomy*	*Intellectual Autonomy*	*Individualism Meta*
Disease Pathogens	-0.074*	0.220***	-0.305***	-0.191***	-0.261*
	(0.039)	(0.057)	(0.108)	(0.033)	(0.138)
Controls	YES	YES	YES	YES	YES
Countries	63	58	58	58	37
IV F-test	3.58	14.72	8.02	33.63	3.58
R-squared	0.573	0.754	0.586	0.696	0.606

Notes: Panel A reports the second stage from the two-stage least squares estimations. Panel B reports the corresponding first stages. All controls from model (5) in Table 5 are included. "Legal Origins - Great Britain" is used as a reference group. See Table 1 for description and sources of variables. Robust errors clustered at the regional level (Asia-Pacific, Europe, Middle East/North Africa, North America, South and Central America/Caribbean, Sub-Saharan Africa) reported in parenthesis. **** p<0.01, ** p<0.05, * p<0.1*

ONLINE SUPPLEMENTARY APPENDIX

TO

Historical Disease Prevalence, Cultural Values, and Global Innovation

Daniel L. Bennett
Research Professor
Baugh Center for Entrepreneurship & Free Enterprise
Baylor University
One Bear Place #98011
Waco, TX 76798
bennettecon@gmail.com
(312) 835-9492

Boris Nikolaev
Assistant Professor
Department of Entrepreneurship
Baylor University
One Bear Place #98011
Waco, TX 76798
borisnikolaev@gmail.com
(813) 401-9756

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Appendix A: Additional Tables

Table A1: Innovative Outputs Index

Knowledge & Technology Outputs Pillar	Creative Outputs Pillar
1. Knowledge Creation Sub-Pillar	*1. Intangible Assets Sub-Pillar*
1a. Patents applications filed by residents both at the national patent office and the international level through the PCT	1a. Trademark applications by residents at the national office
1b. Utility model applications filed by residents at the national office	1b. Industrial designs included in applications at a regional or national office
1c. Scientific and technical published articles in peer-reviewed journals	1c. Survey questions regarding the use of ICTs in business and organizational models
1d. Number of articles (H) that have received at least H citations	
2. Knowledge Impact Sub-Pillar	*2. Creative Goods & Services Sub-Pillar*
2a. Increases in labor productivity	2a. Cultural and creative service exports
2b. Entry density of new firms	2b. National feature film produced
2c. Spending on computer software	2c. Entertainment and media market
2d. Number of certificates of conformity with standard ISO 9001 on quality management systems issues	2d. Printing, publications, and other media market
2e. High and medium high-tech industrial output as share of total manufactures output	2e. Creative goods exports
3. Knowledge Diffusion Sub-Pillar	*3. Online Creativity Sub-Pillar*
3a. Intellectual property receipts as a percentage of total trade	3a. Generic domains, scaled by 15-69 year old population
3b. High-tech net exports as a percentage of total exports	3b. Country-code top level domains, scaled by 15-69 year old population
3c. Exports of ICT services as a share of total trade	3c. Average yearly edits to Wikipedia, scaled by 15-69 year old population
3d. Net outflows of FDI as a percentage of GDP	3d. Mobile app creation, scaled by GDP (bn PPP $)

Table A2: Key differences between individualistic and collectivistic societies

Collectivist	Individualist
General norms, family, school, and workplace	
• People are born into extended families or other in-groups which continue to protect them in exchange for loyalty	• Everyone grows up to look after him/ herself and his/her immediate (nuclear) family only
• Identity is based in the social network to which one belongs	• Identity is based in the individual
• Children learn to think in terms of 'we'	• Children learn to think in terms of 'I'
• Harmony should always be maintained and direct confrontations avoided	• Speaking one's mind is a characteristic of an honest person
• High-context communication	• Low-context communication
• Trespassing leads to shame and loss of face for self and group	• Trespassing leads to guilt and loss of self-respect
• Purpose of education is learning how to do	• Purpose of education is learning how to learn
• Diplomas provide entry to higher status groups	• Diplomas increase economic worth and/or self-respect
• Relationship employer-employee is perceived in moral terms, like a family link	• Relationship employer-employee is a contract supposed to be based on mutual advantage
• Hiring and promotion decisions take employees' in-group into account	• Hiring and promotion decisions are supposed to be based on skills and rules only
• Management is management of groups	• Management is management of individuals
• Relationship prevails over task	• Task prevails over relationship
Politics and ideas	
• Collective interests prevail over individual interests	• Individual interests prevail over collective interests
• Private life is invaded by group(s)	• Everyone has a right to privacy
• Opinions are predetermined by group membership	• Everyone is expected to have a private opinion
• Laws and rights differ by group	• Laws and rights are supposed to be the same for all
• Dominant role of the state in the economic system	• Restrained role of the state in the economic system
• Economy based on collective interests	• Economy based on individual interests
• Political power exercised by interest groups	• Political power exercised by voters
• Press controlled by the state	• Press freedom
• Imported economic theories largely irrelevant because unable to deal with collective and particular interests	• Native economic theories based on pursuit of individual self-interests
• Ideologies of equality prevail over ideologies of individual freedom	• Ideologies of individual freedom prevail over ideologies of equality
• Harmony and consensus in society are ultimate goals	• Self-actualization by every individual is an ultimate goal

Source: Hofstede, G. (1991). Cultures and organizations: Software of the mind. New York: McGraw Hill

Table A3: Country Sample and Individualism, Pathogens, and Innovation Scores

Country	Individualism	Pathogens	Innovation Outputs
Albania	20	-0.25	18.39
Australia	90	-0.25	38.30
Austria	55	-0.77	40.02
Bangladesh	20	0.62	16.01
Belgium	75	-1.00	41.47
Brazil	38	0.93	23.49
Bulgaria	30	-0.35	37.68
Burkina Faso	15	1.16	8.30
Canada	80	-1.31	40.28
Chile	23	-0.45	28.41
China	20	1.03	50.98
Colombia	13	0.27	22.52
Costa Rica	15	0.12	28.95
Croatia	33	-0.44	33.52
Czech Republic	58	-0.87	43.23
Denmark	74	-0.98	49.34
Ecuador	8	0.34	18.11
Egypt, Arab Rep.	25	0.44	21.62
El Salvador	19	0.30	15.17
Estonia	60	-0.62	45.39
Finland	63	-0.75	51.38
France	71	-0.46	45.40
Germany	67	-0.87	52.79
Ghana	15	1.16	16.63
Greece	35	0.08	28.75
Guatemala	6	0.42	18.35
Hungary	80	-1.00	40.95
Iceland	60	-1.19	44.26
India	48	0.94	27.83
Indonesia	14	0.63	22.47
Iran	41	-0.15	30.16
Ireland	70	-0.45	51.25
Israel	54	0.52	50.83
Italy	76	0.16	38.28
Jamaica	39	0.18	22.03
Japan	46	0.43	44.49
Kenya	25	0.95	25.30
Korea	18	-0.11	49.84
Kuwait	25	-0.34	29.36
Latvia	70	-0.62	35.27
Lebanon	40	0.36	18.70
Luxembourg	60	-1.11	52.87
Malawi	30	0.73	15.72
Malaysia	26	0.50	34.26

Malta	59	-0.41	45.84
Mexico	30	0.28	26.35
Morocco	46	0.59	23.50
Mozambique	15	0.83	15.71
Namibia	30	-0.09	16.44
Nepal	30	0.14	15.03
New Zealand	79	-0.98	39.17
Nigeria	30	1.16	14.89
Norway	69	-0.85	41.08
Pakistan	14	0.02	19.19
Panama	11	0.09	24.55
Peru	16	0.23	20.48
Philippines	32	0.50	23.98
Poland	60	-0.87	33.92
Portugal	27	0.47	37.82
Romania	30	-0.18	29.84
Russian Federation	39	-0.39	27.91
Saudi Arabia	25	0.04	21.81
Senegal	25	0.72	19.87
Serbia	25	-0.23	27.42
Singapore	20	0.31	45.43
Slovakia	52	-1.00	36.42
Slovenia	27	-0.87	39.82
South Africa	65	0.11	24.89
Spain	51	-0.05	40.20
Sri Lanka	35	0.64	21.06
Sweden	71	-0.98	56.94
Switzerland	68	-1.08	67.13
Tanzania	25	0.75	23.47
Thailand	20	0.64	31.51
Trinidad and Tobago	16	-0.03	16.08
Turkey	37	0.16	32.19
Ukraine	25	-0.40	36.59
United Arab Emirates	25	-0.45	28.36
United Kingdom	89	-1.01	52.37
United States	91	-0.89	51.81
Uruguay	36	0.39	26.77
Viet Nam	20	0.61	33.70
Zambia	35	0.64	12.77

Notes: Individualism (independent variable), disease pathogens (instrumental variable), and innovative output (dependent variable) measures for the countries in our sample. See Table 1 for variable information.

Table A4: Decomposing Innovation Outputs

	(1) Knowledge/Tech Outputs	(2) Knowledge Creation	(3) Knowledge Impact	(4) Knowledge Diffusion	(5) Creative Outputs	(6) Intangible Assets	(7) Creative Goods & Services	(8) Online Creativity
Individualism	0.462***	0.776***	0.327	0.284***	0.447***	0.250***	0.436***	0.852***
	(0.098)	(0.120)	(0.202)	(0.097)	(0.064)	(0.059)	(0.162)	(0.160)
Controls	YES	YES	YES	YES	YES	YES	YES	YES
Obs.	83	83	83	83	83	83	83	83
IV F-stat	55.44	55.44	55.44	55.44	55.44	55.44	55.44	55.44
R-squared	0.686	0.681	0.398	0.442	0.708	0.500	0.526	0.752

Notes: Estimates from second stage of the two-stage least squares estimations. All controls from model (5) in Table 5 are included. "Legal Origins - Great Britain" is used as a reference group. See Table 1 for description and sources of variables. Robust errors clustered at the regional level (Asia-Pacific, Europe, Middle East/North Africa, North America, South and Central America/Caribbean, Sub-Saharan Africa) reported in parenthesis. **** p<0.01, ** p<0.05, * p<0.1*

Appendix B: Figures

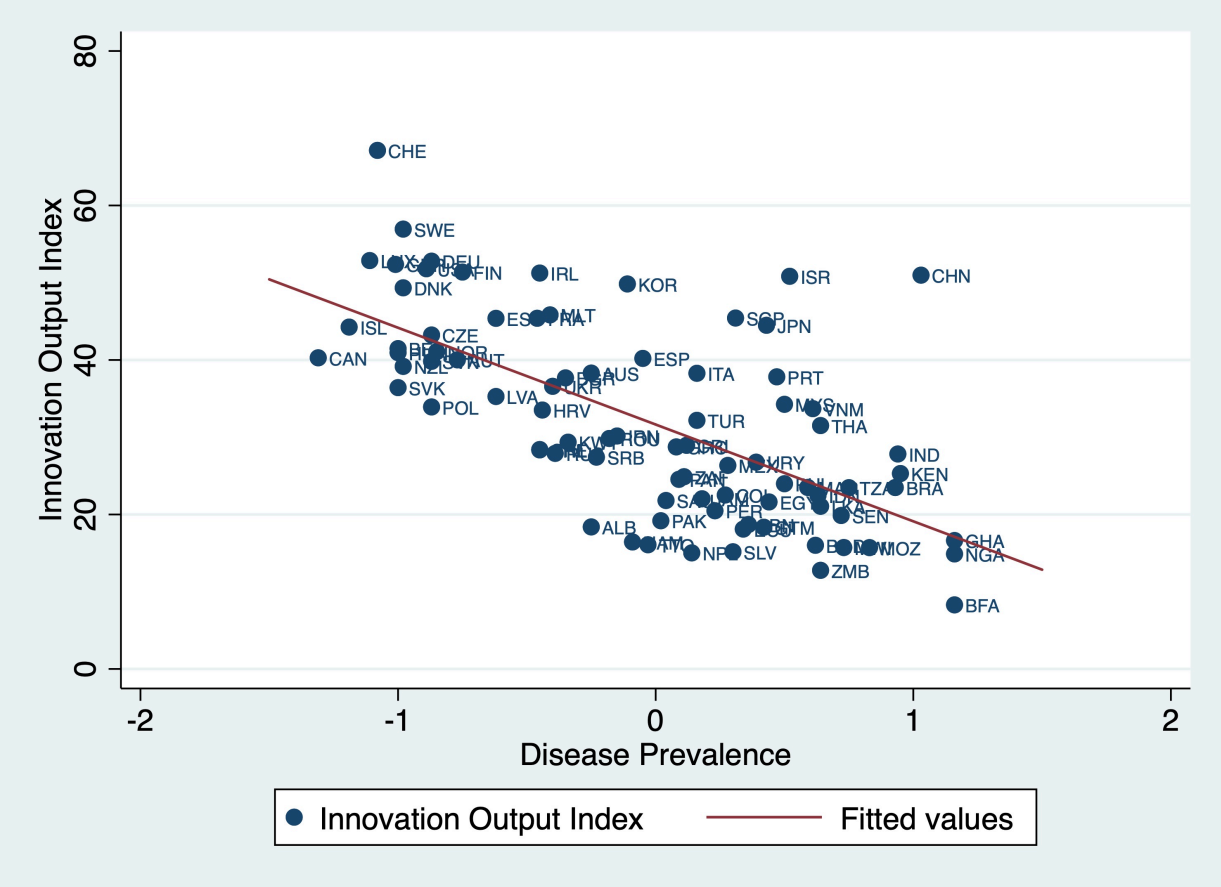

Figure 1: Innovation Output and Disease Pathogens

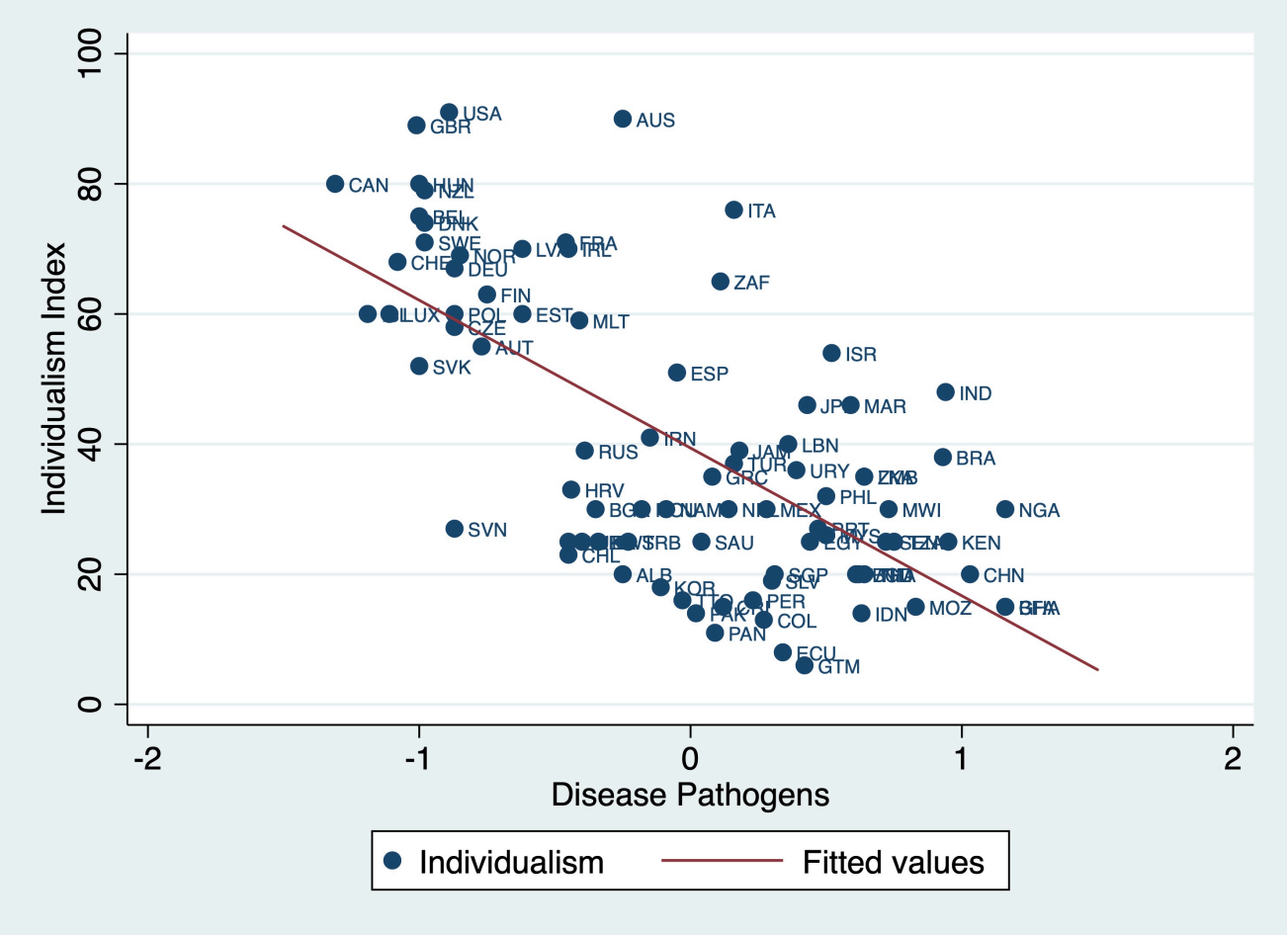

Figure 2: Individualism and Disease Pathogens

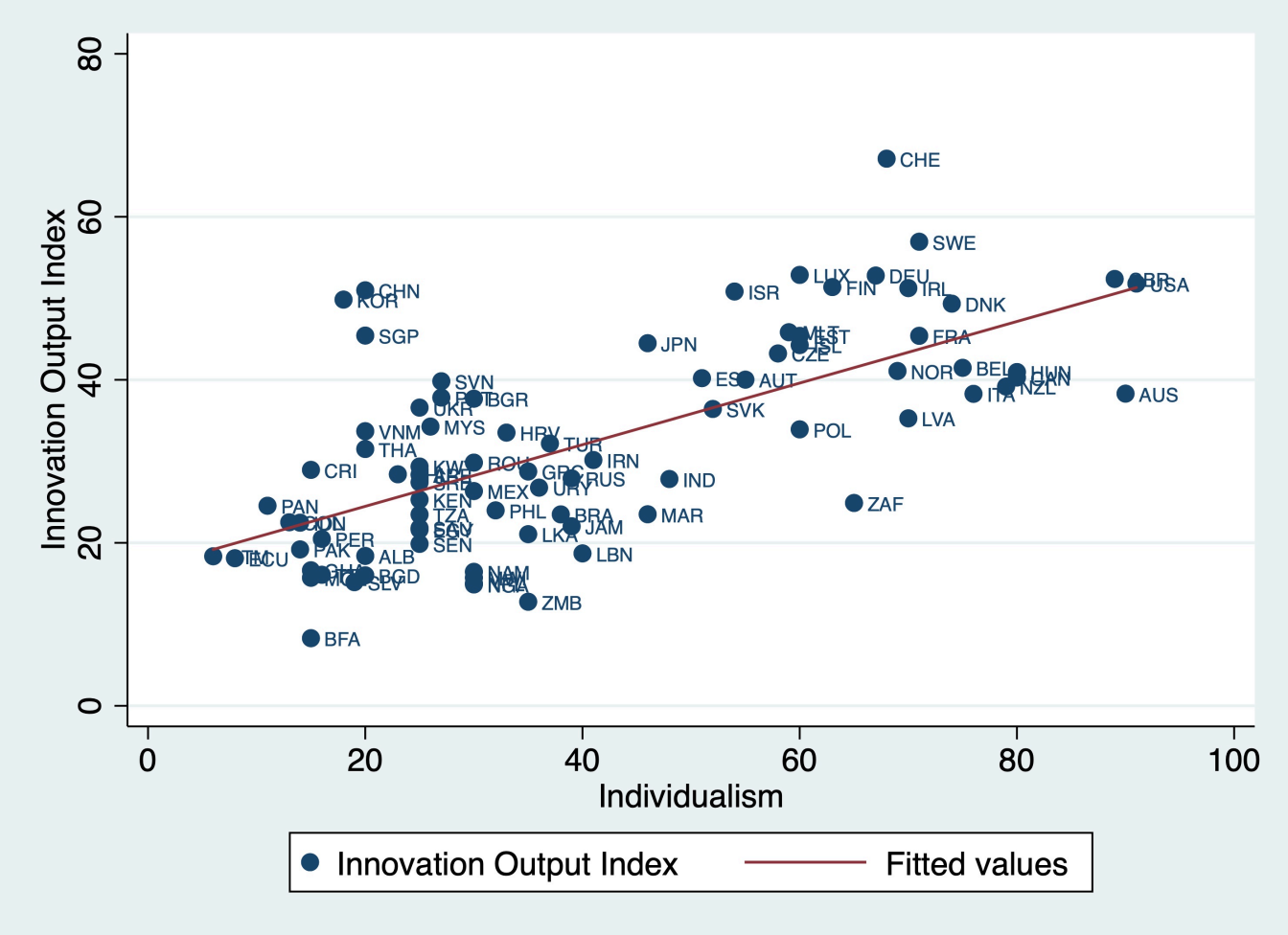

Figure 3: Innovation Output and Individualism