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Historical prevalence of infectious diseases and gender equality in 122 countries?

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Abstract

This study examines the effects of the historical prevalence of infectious diseases on contemporary gender equality. Previous studies reveal the persistence of the effects of historical diseases on innovation, through the channel of culture. Drawing on the Parasite-Stress Theory, we propose a framework which argues that historical prevalence of infectious disease reduces contemporary gender equality. Using Ordinary Least Squares (OLS) and Two Stage Least Squares (2SLS) in a cross-section with data from 122 countries between 2000 and 2021, we provide support for the underlying hypothesis. Past diseases reduce gender equality both directly and indirectly. The strongest indirect effects occur through innovation output. Gender equality analysis may take these findings into account and incorporate disease pathogens into the design of international social policy.

Keywords: infectious diseases; gender equality; economic development

JEL Classification: B15; B40; B54; I31; J24.

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1. Introduction

In recent decades, gender inequality has received particular attention from the research community. Although differences within societies in gender equality have been well documented, there is little discussion of the ecological causes of this problem. To the best of our knowledge, the study of Varnum and Grossmann (2017) is the only research which demonstrates that the reduction in gender inequality between 1951 and 2013 in the United States is a consequence of decreases in pathogen prevalence. Despite this clarification, no study to the best of our knowledge has addressed the persistence of historical infectious disease prevalence on gender inequality in a large sample by engaging the transmission channel.

In this paper, we contribute to the literature by establishing a reduced-form association between historical infectious disease prevalence and gender equality across countries. Our argument posits that populations faced with a permanent historical prevalence of diseases have developed a collectivist culture that is less open to criticism, entrepreneurship, new ideas, and challenges to the status quo. This failure has retarded innovation and fostered gender inequalities.

Our measure of "***historical prevalence of infectious diseases"*** is chosen under the inspiration of the vast cross-cultural literature developed by many authors such as Bennett and Nikolaev (2021), Bennett (2019), Bennett (2018), Nikolaev *et al*. (2017) and Fincher *et al*. (2013). The index used in this study is borrowed from Murray and Schaller (2010). This index assesses the intensity of historical disease prevalence for over 150 countries. The calculation of this index is based on the severity of nine diseases that are dangerous to human survival and reproductive health. These include: dengue, trypanosomes, schistosomes, leprosy, typhus, malaria, filariae, leishmanias, and tuberculosis. It also provides evidence for the parasitic stress theory of disease developed by Thornhill and Fincher (2014). The creation of the index was possible thanks to epidemiological information from the early 20th century and the archives of historical epidemiological atlases of infectious diseases. The combination of these two data sources allowed the authors to obtain a concrete measure of historical disease prevalence.

The measure of gender equality is the average value of the Sustainable Development Goal 5 indicator proposed by Sachs *et al*. (2021) between 2000 and 2021. This indicator is a combination of the following information: the demand for family planning met by modern methods, the ratio of women's average years of education to men's, the labor force participation rate of women compared to men, and the number of seats held by women in the national parliament.

Analysis of the effect of historical prevalence of infectious diseases on gender equality yields results that support a strong negative relationship between the two variables. We establish the robustness of this result in several ways. Potential omitted variable bias is accounted for by controlling for some contemporaneous and historical confounders. Correcting for endogeneity bias does not alter our results. In addition, we use alternative measures of gender equality and control for a range of contemporaneous influences, geographic controls, and continent fixed effects. The results survive these consistency checks. Given the influential findings of Bennett and Nikolaev (2021) that the path of innovation inequality is shaped by disease burden, we test whether the effect of innovation on gender equality operates through past illnesses. Analysis of this mechanism suggests that innovation is the primary mediator of the relationship between diseases of the past and gender equality. The high prevalence of epidemics reduces entrepreneurship, diversity, collaboration, research and development. It also reduces the extent to which companies and universities collaborate in research and development. In sum, an epidemic setting reduces the ability of individuals to innovate and delays the possibility of gender adjustment. While Varnum and Grossmann (2017) focus on the ecological explanation of gender inequality through the human capital component, our focus is on differences in innovation.

We explore how diseases of the past shape gender inequalities by considering several alternative mechanisms of innovation. In this article, we provide results on how an epidemiological framework affects women and men differently, and what the key long-term implications for gender equality might be. Innovation outcomes, entrepreneurship, capacity to innovate, and business-academic collaboration in development are elements to be considered in the epidemiological analysis of gender equality. Consideration of these channels is necessary because the relationship between the incidence of historical prevalence of infectious diseases and gender is potentially subject to omitted variable bias and even measurement error. Our results, however, do not provide strong evidence that past diseases capture the variation attributable to these factors. We recognize that innovation intensity is not necessarily the only or most important determinant of gender equality. Nonetheless, we believe the results improve our understanding of the underlying causes of comparative gender differences.

We do not claim that the level of development, agriculture, political regime, and diffusion of innovations and technologies do not play an important role in promoting gender equality. On the contrary, our hypothesis identifies these factors as important elements for the development of men and women. It proposes that innovation has effects or consequences of a previously unrecognized causal framework, and that it becomes important to identify it by highlighting the role of diseases of the past suffered by society.

The positioning of the study departs from the extant literature on gender equality which has largely focused on *inter alia*, the relevance of information and communication technology in promoting gender inclusion (Awel & Yitbarek, 2022), the linkage between gender inclusion and tax performance (Asongu *et al*., 2021), financial drivers of gender entrepreneurship (Ngono, 2021) and connections between mobile money, financial inclusion and gender gaps (Asongu & Odhiambo, 2018; Osabuohien & Karakara, 2018; Mndolwa & Alhassan, 2020; Kim, 2022).

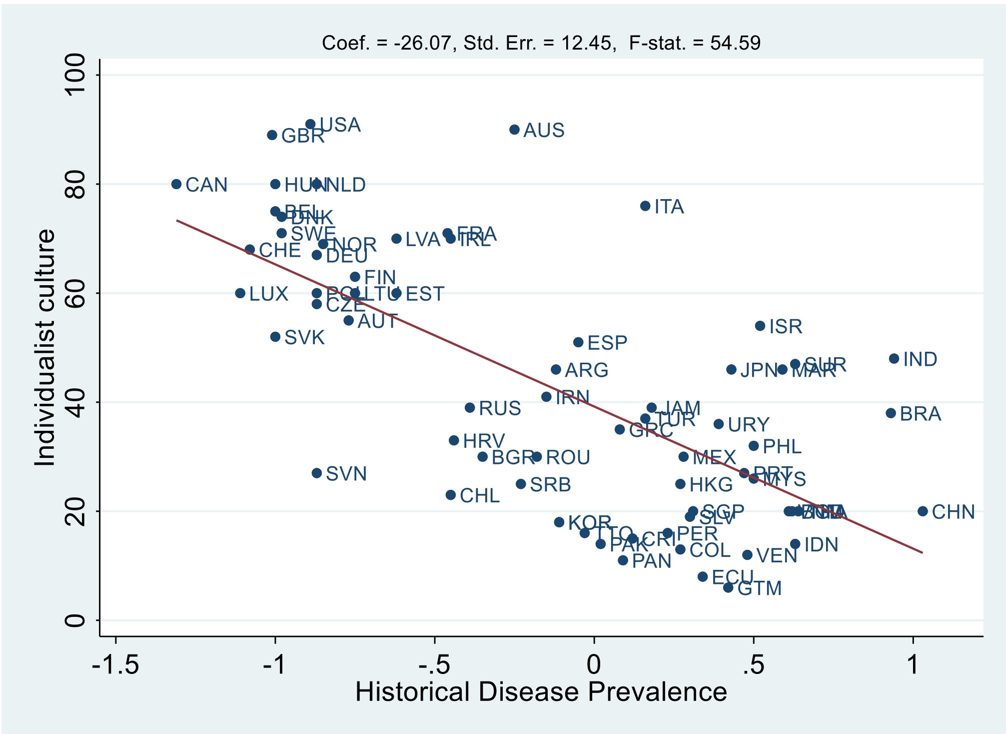
This paper proceeds as follows. Section 2 presents the conceptual framework, which is discussed in more detail. Section 3 describes the empirical approach, the data and their sources. Section 4 presents the baseline estimates and several robustness checks. Section 5 provides alternative mechanisms linking the historical prevalence of past illnesses to gender equality and Section 6 concludes.

2. Disease pathogen and gender equality: theoretical background

The importance of historical prevalence of infectious disease, and gender equality has garnered considerable attention on the parasite stress theory of economic development (Fincher *et al*., 2013; Murray et al., 2011, 2013; Murray & Schaller, 2010; Schaller & Murray, 2008; Thornhill & Fincher, 2014; Thornhill *et al*., 2009; Randy Thornhill & Fincher, 2011, 2014; Bennett & Nikolaev, 2021). In this theory, the link between these two variables can be drawn from many channels such as culture, innovation and political regime.

As far as the cultural channel is concerned, the inter-community disparity of the parasitic stress allows for distinction between individualistic and collectivist societies. In collectivist societies, the border between the group of belonging and the group of non-membership is important. One is suspicious of the members of the latter and refuses to come into contact with them. On the other hand, in individualistic societies, these constraints are not observed and the probability of contact between communities is very high (Gelfand *et al*., 2004; Sagiv & Schwartz, 1995; Oishi et al., 1954). As summarized by Thornhill and Fincher (2014), collectivist (conservative) societies favor in-group alliances while individualist (liberal) societies favor interaction with groups from other classes in society.

Figure 1 : Historical prevalence of infectious disease and individualist culture

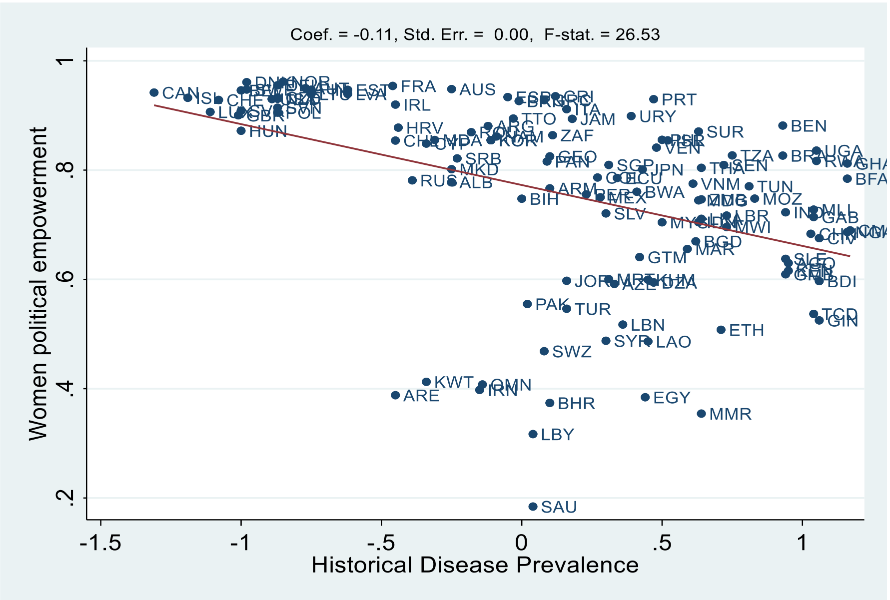


Source: authors' construction; ***Notes:*** The scatter plots in the above figure illustrate a negative relationship between Historical prevalence of infectious disease and individualist culture. Their correlation coefficient is -26.07. The total number of observations is 122.

According to the work of Thornhill and Fincher (2014), individualistic societies where everyone is expected to take care of themselves and their immediate family is associated to an environment with low prevalence of infectious diseases. These societies have the distinction of valuing class equality, personal achievement, opportunity, progress, knowledge, and individual freedoms. Collectivist societies, on the other hand, are formed in places where the rate of disease contamination is high. These societies integrate people from birth into strong, cohesive groups, which must ensure their safety throughout their lives in exchange for loyalty (Hofstede, 2011, p. 51). As a result, the greater value placed on harmony, cooperation, and a relationship with superiors in these societies often promotes the devaluation of the lower classes and the promotion of gender inequality. It is therefore argued that the higher (lower) the incidence of infectious diseases in a community, the more that society will tend towards a collectivist (individualist) ideology that will be favorable to gender equality (gender inequality). Figure 1 above shows a negative correlation between historical prevalence of infectious disease and individualist culture.

The parasitic stress of diseases also persists on gender equality through the autocracy versus democracy divide. Indeed, according to Thornhill *et al*. (2009), democratization which is primarily related to individualism, significantly involves the liberalization of values under ecological conditions of low disease stress. This makes the distribution of suffrage and political participation of women, as well as their rights and freedom in general, in such a community largely favored as demonstrated, for example, by the work of Wejnert (2005).

Figure 2: Historical prevalence of infectious disease and women's political empowerment

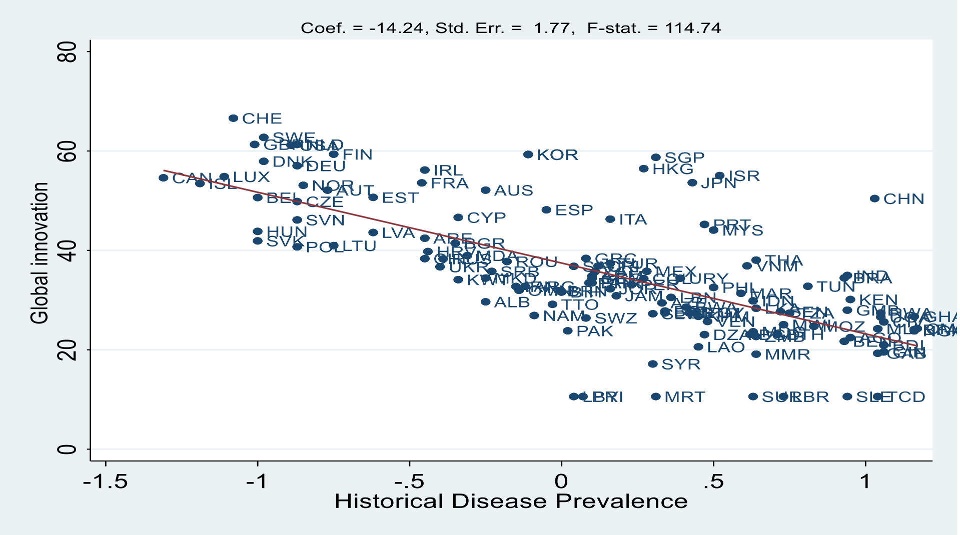


Source: authors' construction; ***Notes:*** The scatter plots in the above figure illustrate a negative relationship between Historical prevalence of infectious disease and women political empowerment.

In this environment, the relationship between women and men evolves in the direction of equity. This theoretical consideration has been supported by the empirical results of Inglehart and Norris (2003). On the other hand, the high incidence of infectious diseases encourages collectivism, which is sometimes an obstacle to gender equality. Gelfand *et al*. (2004) state that collectivism is negatively correlated with gender equality values. From the above, we can conclude that democracy, which is associated with the pursuit of gender equality values, is the consequence of an individualistic culture, which itself has its origins in an epidemic environment. In Figure 2 historical prevalence on infectious disease is negatively correlated with women political empowerment.
On the other hand, the autocratic ideology characterized by conservatism and gender differentiation and male superiority derives from collectivism which in reality is the consequence of an environment with high parasitic stress. Schaller and Murray (2008) following this logic show that parasitic stress positively affects cultural norms of sexual restraint, especially with regard to women. Thus, the difference in infectious disease risk observed worldwide, historically and currently, may favor democracy or autocracy which in turn determines gender equality.

Concerning the innovation channel, many studies show that innovation is positively associated with gender equality (Keisu, 2013; Saâd & Assoumou-Ella, 2019; Wrigley, 1992). Bennett and Nikolaev (2021) for example find that, a disease environment (dengue, trypanosomes, schistosomes, leprosy, typhus, malaria, filariae, leishmanias, and tuberculosis) had influential effects on the path of a culture in innovation development. The variation in associated morality rates caused society to either build an individualist or collectivist culture. According to some studies, the individualistic culture is more innovative than the collectivistic culture. Rogers (1995) demonstrates that the creation of innovation depends on people who are open to new ideas, bold and willing to put into perspective what is already established. This encourages independent thinking and self-expression which in turn promotes the adoption and creation of innovation (Alesina & Giuliano, 2010). The same scenario is not observable in collectivist societies. Innovation index in this study is measured by the indicator developed by Wipo (2021). The latter provides a more complete picture of innovation ecosystems around the world. It compiles, through weighting methods, the elements of the economy that enable and facilitate innovative activities (innovation inputs) and the outcome of innovative activities in the economy (innovation output). Its relation with historical prevalence of infectious disease in our sample is negative in Figure 3 below.

Figure 3: Historical prevalence of infectious disease and global innovation



Source: authors' construction; ***Notes:*** The scatter plots in the above figure illustrate a negative relationship between Historical prevalence of infectious disease and global innovation.

3. Methodology and data

3.1 Methodology

We hypothesize that historical prevalence of infectious disease and gender equality are negatively related a reduced-form link. To investigate the reduced-form link, the following specification is used:

$$\boldsymbol{Gender\ equality_i = \alpha + \beta.pathogens_i + \sigma.X_i + \varepsilon_i}$$

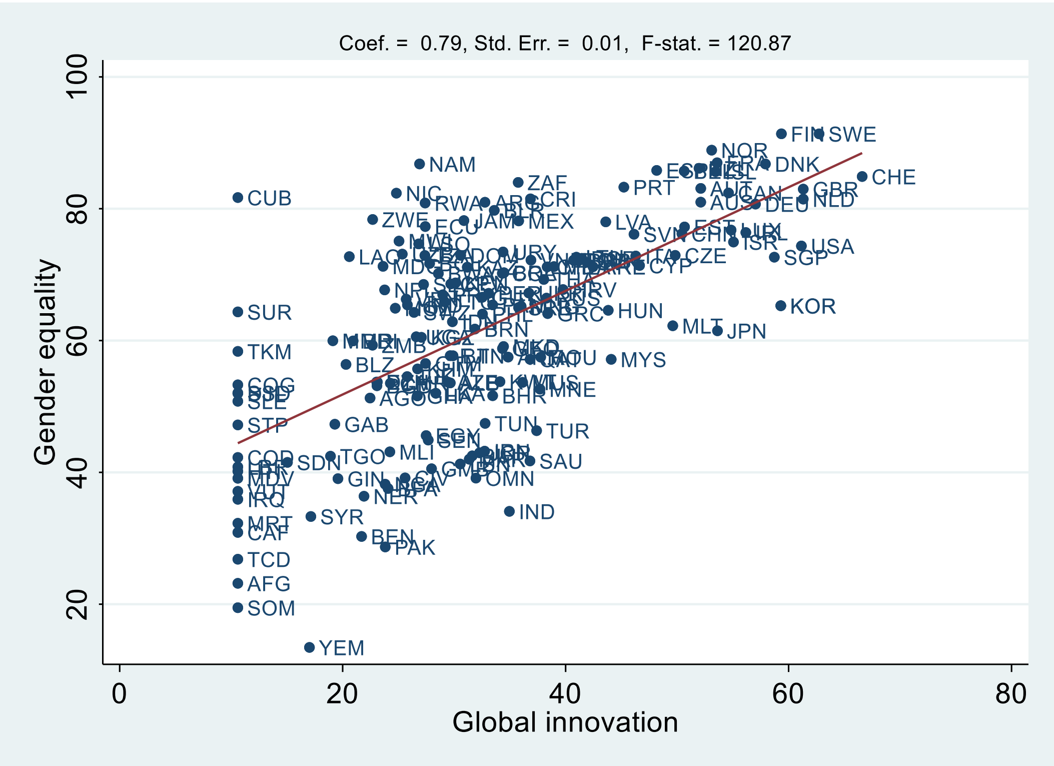
where $Gender\ equality_i$ is an indicator of the sexes ratio between men and women in country i; $\boldsymbol{pathogens_i}$ the historical prevalence of infectious disease in country i; $\boldsymbol{X_i}$ is a vector of control variables and ε_i is an unobserved error term. β is the coefficient of interest and is expected to carry a negative sign.

3.2 Data

In this section we discuss the key variables used. Appendix A provides a list of all variables used, the summary statistics and corresponding sources. Figure 4 shows a positive relationship between global innovation and gender equality for the sample countries. Their correlation coefficient is 0.79. Figure 5 and 6 give the geographical distribution of historical prevalence of infectious disease and gender equality across countries with a negative correlation. This suggests that the effect of historical prevalence of infectious disease on gender equality may potentially work through global innovation, an issue that we will explore further in Sections 5.1 and 5.2.

As stated above, the measure of gender equality is the average value of the indicator of the fifth SDG proposed by Sachs *et al*. (2021) between 2000 and 2021. This indicator is a combination of the following information: the demand for family planning met by modern methods, the ratio of women's average years of education to men's average years of education, the labor force participation rate of women compared to men and the number of seats held by women in the national parliament.

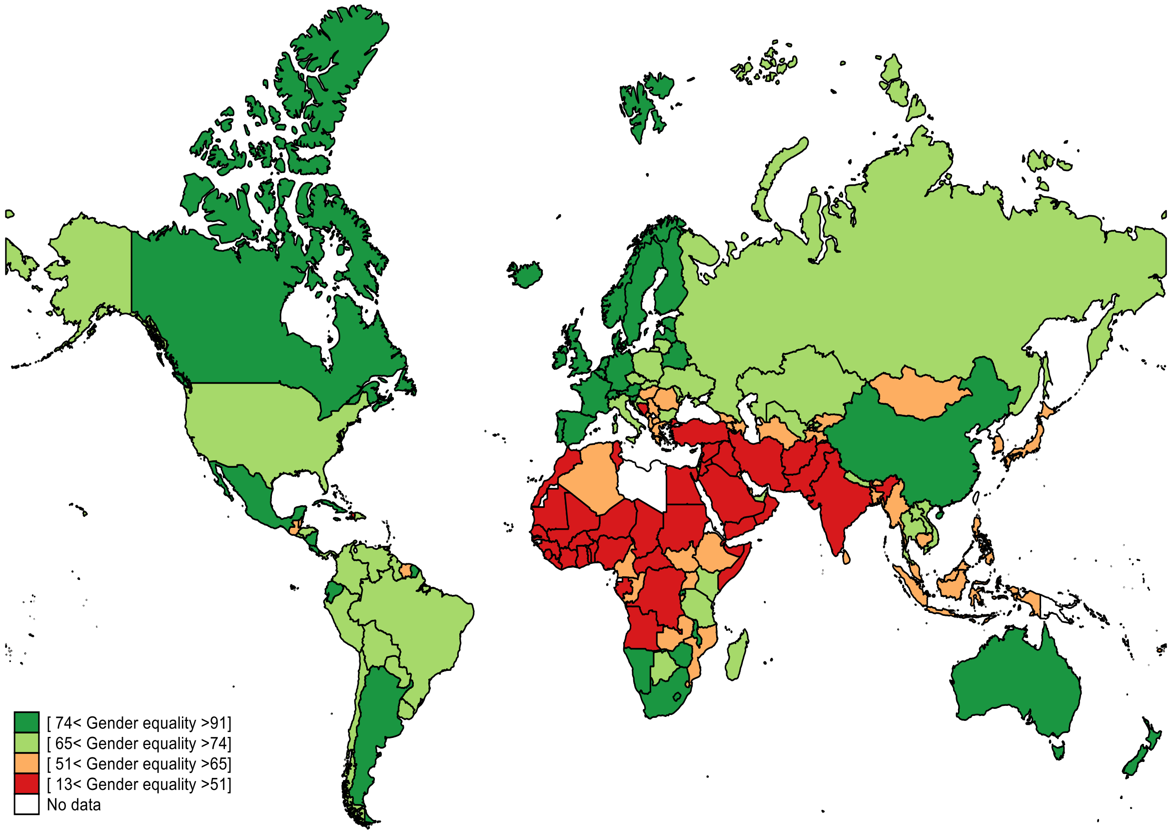
Figure 4. Global innovation and gender equality



Notes: The scatter plots in the above figure illustrate a positive relationship between global innovation and gender equality. Their correlation coefficient is 0.79. The total number of observations is 123.

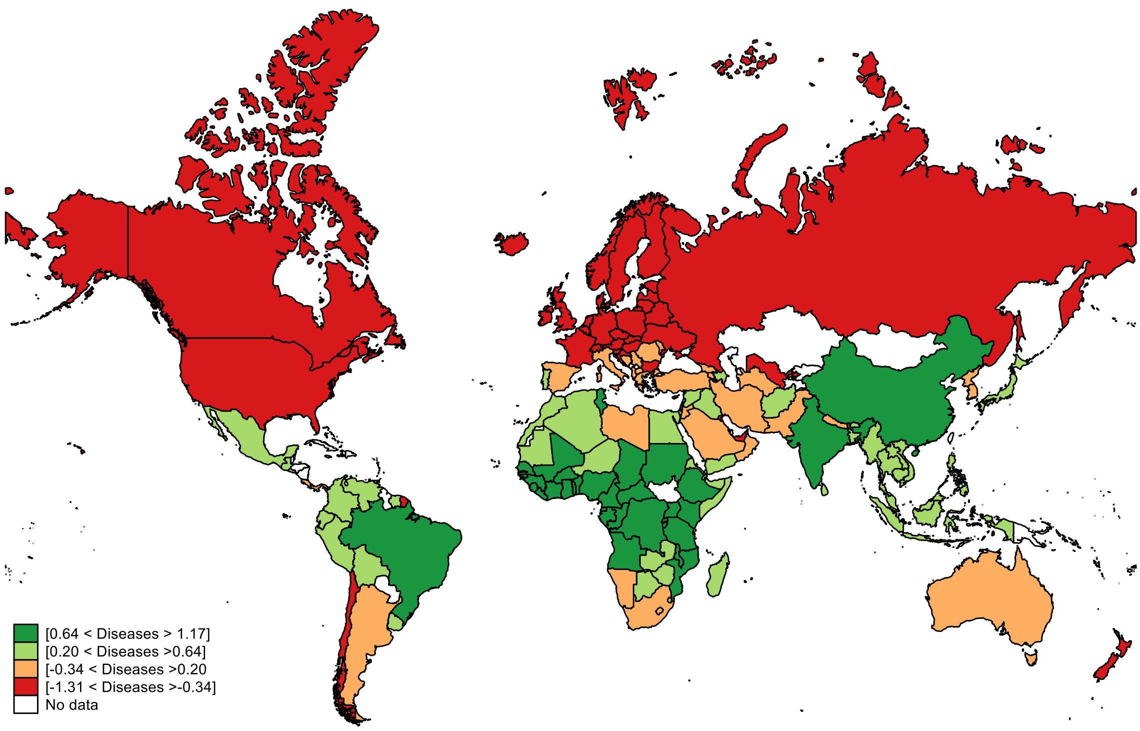
The data of this variable varies between 0 and 100, where a larger value signifies greater gender equality. Figure 5 depicts how the estimates of gender equality are distributed across the world.

Figure 5: Geographical distribution of gender equality across the world



Notes: green areas indicate better gender equality. The total number of observations is 174. The data are obtained from Sachs al. (2021).

Figure 6: Geographical distribution of historical prevalence of pathogens across the world



Notes : green areas indicate high prevalence of infectious disease. The total number of observations is 166. The data are obtained from Murray and Schaller (2010).

Historical prevalence of infectious disease is obtained from Murray and Schaller (2010). This index includes: dengue, trypanosomes, schistosomes, leprosy, typhus, malaria, filariae, leishmanias, and tuberculosis for 150 countries. Figure 6 above shows the distribution of this variable across the world. In this figure African, South American and Asian countries present high scores of historical prevalence of infectious disease.

4. Results and discussion

4.1. Main results

Our hypothesis is that historical prevalence of disease pathogen, via its effect on innovation, reduces gender equality. The OLS estimates in Table 1 support this hypothesis. The bivariate analysis in Column (1) shows that the coefficient of historical prevalence of disease pathogen is statistically significant at the 1% level and historical prevalence of disease pathogen alone can explain more than 30% of the total variation in gender equality. The historical prevalence of disease pathogen coefficients is precisely estimated, even after controlling for culture controls in Column (2), legal origin in Column (3), political characteristic in Column (4) and continental dummies in Column (5). When all control variables are included in Column (5), the effect of disease pathogen remains robust.

Table 1. The reduced-form effect of disease pathogens and gender equality

	(1)	(2)	(3)	(4)	(5)
Dependent variable: **Gender equality**	Basic specification	Add culture controls	Add legal origin	Add religion controls	Full specification with continent dummy
	OLS	OLS	OLS	OLS	OLS
Disease pathogen	**-13.584*****	**-9.023*****	**-7.822*****	**-7.611*****	**-6.480*****
	(1.504)	**(2.214)**	**(2.344)**	**(2.060)**	**(1.994)**
Individualist/collectivist		10.803***	9.955***	2.423	3.953
		(2.957)	(3.012)	(2.833)	(3.218)
German legal origin			2.400	-1.057	0.063
			(1.893)	(1.806)	(2.778)
French legal origin			-1.390	-0.699	-0.002
			(2.625)	(2.327)	(2.307)
Scandinavian legal origin			10.608***	3.892	3.995
			(2.408)	(4.876)	(5.347)
Catholic trust				0.068**	0.056
				(0.032)	(0.037)
Muslim trust				-0.198***	-0.207***
				(0.040)	(0.043)
Protestant trust				0.110	0.120*
				(0.067)	(0.072)
Democracy					0.113*
					(0.061)
America dummy					2.838
					(2.918)
Asia dummy					4.509*
					(2.687)
Other countries					-1.288
					(2.889)
Constant	65.518***	62.626***	62.805***	65.827***	64.631***
	(1.121)	(1.510)	(2.296)	(2.431)	(2.714)
Observations	123	123	120	113	108
R^2	0.32	0.37	0.38	0.65	0.68
Fisher	81.53	57.56	56.54	41.45	30.38

Notes: This table shows the correlation between disease pathogen in the past and gender equality. Consistent with our prediction, the results suggest that a higher level of historical prevalence of infectious disease is associated with lower score in gender equality. The results are robust to the inclusion of culture, legal origin, political controls and continental fixed effects. Robust standard errors are used and t-statistics are reported in the parentheses. *, ** and *** indicate significance at the 10%, 5% and 1% levels, respectively.

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Based on the estimates in Column (5), Canada experienced a lower prevalence of infectious disease similar to Switzerland (-1.08), the United Kingdom (-1.01), Belgium(-1), consistent with the data of Murray and Schaller (2010). The estimated gender equality score of these countries is high with respectively 84.89 ; 82.98 ; 85.72 in the data collected by Sachs *et al*. (2021). This result is also observed in countries with a high level of infectious diseases like Guinea (1.06); Burkina Faso (1.16) and Nigeria (1.16). The attendant countries present a poor performance in gender equality with 39.05; 37.55; 38.21 scores, respectively. Our initial results suggest that efforts to improve gender equality need to assess some fundamental determinants of this objective and pay attention to disease pathogens (Varnum &. Grossmann, 2017). Looking for the comparison made by the two groups of countries, it is clear that the difference between these countries can be made in innovation performance. The next section will show more.

4.2. Supplementary controls

In Table 2, we control for several other exogenous forces. Appendix C provides the results taking into account different components of gender equality. It is apparent that disease pathogens persist more in the ratio of education between men and women.

Table 2. Supplementary controls

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Disease pathogen	**-6.702****	**-4.350****	**-4.636****	**-6.783***	**-4.833****	**-4.619****	**-6.900****	**-8.073****
	(2.675)	**(2.023)**	**(2.246)**	**(3.846)**	**(2.044)**	**(2.146)**	**(3.440)**	**(3.541)**
Urbanization	0.335							
	(0.718)							
Agriculture	-0.097							
	(0.106)							
Education	0.524**							
	(0.262)							
High income		10.127***						
		(3.212)						
Country size			-1.915					
			(4.382)					
Fragility			-8.776***					
			(3.182)					
Island			3.230					
			(4.127)					
Landlocked				-3.116				
				(4.195)				
Tropical dummy				4.288				
				(5.359)				
Distance to equator				18.765				
				(19.434)				
Precolonial institution					17.946***			
					(6.692)			
State antiquity						1.329		
						(7.204)		
Technology 1500 BC							23.556***	
							(6.885)	
Population density in 1000 BC								-4.548
								(3.044)
Base line control	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Cultural controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Continent dummy	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Constant	60.737***	63.455***	64.840***	61.773***	45.310***	65.782***	47.567***	75.826***
	(7.266)	(2.696)	(2.810)	(11.172)	(7.805)	(4.165)	(6.622)	(7.639)
Observations	93	108	108	89	108	94	84	78
R^2	0.72	0.70	0.70	0.68	0.70	0.69	0.75	0.70
Fisher	24.00	25.11	28.50	23.53	26.03	23.18	22.72	19.41

Notes: This table shows supplementary controls of the effect of disease pathogen in the past on gender equality. Consistent with our prediction, the results suggest that the coefficients of disease pathogens remain significant in all cases. The results are robust to the inclusion of culture, legal origin, political controls and continental fixed effects. Robust standard errors are used and t-statistics are reported in the parentheses. *, ** and *** indicate significance at the 10%, 5% and 1% levels, respectively.

First, Beer (2009) highlights that gender equality is highly correlated with urbanization, agriculture, expenditure on education, income level and fragility. We control for this potential confounding effects in Columns (1), (2) and (3). Next, Bennett and Nikolaev (2021) consider geographic characteristics like landlockedness, tropical zone and distance to the Equator as the variables which are correlated with disease pathogens. These are considered in Column (4). Finally, Alesina et al. (2013) theoretically show that the gender ratio is closely linked to historical characteristics like historical technology adoption, pre-colonial institutions and population density. Accordingly, Columns (5), (6), (7) and (8) control for the underlying characteristics. Following the approach of Alesina *et al*. (2013), it is evident that the coefficients of disease pathogens remain significant in all cases.

5. Potential channels of influence and endogeneity

5.1. Innovation and women political empowerment channel

We hypothesize in this paper that a greater historical prevalence of infectious disease reduces the probability to develop innovation and this reduces the incentive to invest in gender equality. To test this hypothesis, we first control for the incidence of innovation in the regressions using innovation data provided by the World Intellectual Property Organization (WIPO), WIPO (2021). This variable is considered to be both a consequence of historical prevalence of infectious disease (Bennett & Nikolaev, 2021) and the determinant of gender equality (Keisu, 2013; Lauri, 2021; Smith-doerr & Smith-doerr, 2010). Historical prevalence of infectious disease may also be spuriously correlated with other contemporary variables such as women political empowerment that can indicate the evolution of gender equality, consistent with the parasite stress theory (Thornhill & Fincher, 2014). The results are reported in Table 3. The results in Column (1) show that disease pathogens continue to exert some direct effects on gender equality and the corresponding coefficient is highly significant at 1% level. In Column (2), the effect of innovation is more precisely estimated than the influence of disease pathogens, as shown by its relatively larger t-statistic. It is also relevant to note that the absolute value of the coefficient of disease pathogen and its significance falls dramatically when innovation is included. Taken together, the evidence suggests that although we cannot rule out some direct impact from disease pathogens on gender equality, a considerable amount of this influence occurs through innovation. This is not the same result with women's political empowerment in Column (5). Building on the work of Zelekha (2016) and Bennett and Nikolaev (2021), the aggregate innovation index of the latter should be considered as the main channel of transmission of the effect of the historical prevalence of infectious diseases on gender equality. The authors also state that in this case, the historical variable (disease pathogen) is a good instrument to control the effect of innovation on gender equality.

Table 3. Potential channels linking historical prevalence of disease to gender equality

	(1)	(2)	(3)	(4)	(5)	(6)
Dependent variable: gender equality	OLS	OLS	OLS	OLS	OLS	OLS
Disease pathogen	**-6.480***** **(1.994)**	**-2.685** **(2.044)**	**-2.163** **(1.908)**	**-6.058***** **(2.048)**	**-6.430***** **(2.045)**	**-2.892** **(2.021)**
Global innovation		0.532*** (0.131)				0.501*** (0.136)
Innovation output			0.525*** (0.107)			
Innovation input				0.137 (0.147)		
Women political empowerment					17.053* (9.017)	6.135 (9.314)
Constant	64.631*** (2.714)	45.388*** (5.473)	42.959*** (5.182)	63.807*** (2.753)	50.303*** (7.852)	41.375*** (8.633)
Observations	108	108	108	108	108	108
R^2	0.68	0.73	0.75	0.68	0.69	0.73
Fisher	30.38	28.17	31.31	29.39	27.67	26.40

Notes: This table shows the potential channels linking historical prevalence of disease to gender equality. Consistent with our prediction, the results suggest that the aggregate innovation index rather than women political empowerment should be considered as the main channel of transmission of the effect of the historical prevalence of infectious diseases on gender equality. The results are robust to the inclusion of culture, legal origin, political controls and continental fixed effects. Robust standard errors are used and t-statistics are reported in the parentheses. *, ** and *** indicate significance at the 10%, 5% and 1% levels, respectively.

Table 3 allows us to make several observations. We find in Columns (2) and (3) that the significance of past diseases disappears when we control for the overall innovation index and the products of innovation. In other words, the negative effect of past diseases on gender equality can be reduced by acting on innovation. In Table 4 below, to further check for a key channel of influence, we estimate the effects of disease pathogens on different measures of innovation and women political empowerment. These are the elements of the economy that enable and facilitate innovative activities (innovation inputs); the result of innovative activities within the economy (innovation output); the capacity to innovate and innovation linkage. For this purpose, each measure of innovation and women's political empowerment is regressed on the historical prevalence of infectious disease. To reduce omitted variables bias, we maintain the use baseline controls. The results reported in Table 4 reveal that disease pathogens negatively and significantly affect the contemporary components of innovation. Otherwise this effect is not significant on women's political empowerment.

Table 4. The effect of disease pathogens on innovation and women's political empowerment

	(1)	(2)	(3)	(4)	(5)
Method	OLS	OLS	OLS	OLS	OLS
	Global innovation	Innovation output	Innovation linkages	Capacity for innovation	Women political empowerment
Disease pathogen	**-6.550****	**-8.065****	**-6.248****	**-0.402*****	**0.043**
	(2.690)	**(3.398)**	**(2.936)**	**(0.152)**	**(0.036)**
Base line control	Yes	Yes	Yes	Yes	Yes
Geographic controls	Yes	Yes	Yes	Yes	Yes
Continent dummy	Yes	Yes	Yes	Yes	Yes
Constant	46.875***	50.518***	47.170***	4.256***	0.933***
	(3.323)	(3.711)	(5.156)	(0.222)	(0.050)
Observations	95	95	94	95	95
R^2	0.70	0.66	0.59	0.57	0.64
Fisher	51.27	40.60	28.95	47.41	10.89

Notes: This table shows the effects of disease pathogens on different measures of innovation and women political empowerment. The results that disease pathogens negatively and significantly affect the contemporary components of innovation. Robust standard errors are used and t-statistics are reported in the parentheses. *, ** and *** indicate significance at the 10%, 5% and 1% levels, respectively.

Table 5. Mediation analysis using structural equations modeling

Mediation variables	(1)	(2)
Dependent variable: Gender equality		
Mediator:	Global innovation index	women political empowerment
Step 1 (X -> M)	-0.724 ***	-0.426 ***
	(0.000)	(0.000)
Step 2 (M -> Y)	0.434***	0.161*
	(0.000)	(0.071)
Step 3 (X -> Y)	-0.112	-0.210
	(0.049)	(0.268)
Sobel test (of indirect effect)	-0.314 ***	-0.069*
	(0.000)	(0.085)
RIT	0.737	0.247
RID	2.796	0.327
Conclusion ZLC	**full mediation**	No mediation
Conclusion BK	**mediation is complete**	No mediation

Source: authors' construction; Notes: This table reports the partial results of structural equation modelling and distinguishes direct and indirect effects. P-values are in parentheses. * p < 0.10, ** p < 0.05, *** p < 0.01. RIT = (Indirect effect / Total effect). RID = (Indirect effect / Direct effect) ZLC: Zhao, Lynch and Chen (2010); BK: Baron and Kenny (1986).

To confirm the discussed mediation channels, we test the effectiveness of mediation using the approaches of Zhao *et al*. (2010) and Baron and Kenny (1986). The test results in Table 5 indicate that the null of no mediation is rejected at the 1% level of significance for innovation contrary for women political empowerment. The estimates also suggest that about 74% of the effect of disease pathogens on gender equality is channeled through innovation, suggesting that innovation is an important channel of influence.

5.2 Accounting for endogeneity

The previous results show that the main channel through which historical prevalence of infectious disease can influence gender equality is innovation. We therefore test whether the reduced-form effect of disease pathogens operates through innovation using an instrumental variable method in two stages. The results are reported in Table 6. We treat innovation as endogenous and instrument it using historical prevalence of infectious disease, conditional on the influence of each potential channel. If this occurs, innovation is likely to affect gender equality. The results indicate that the exogenous component of innovation exerts a strong positive effect on gender equality, and this effect is statistically significant at the 1% level. The p-value of under identification LM statistic is significant at the 1% level, suggesting that historical prevalence of infectious disease is a strong instrument. We run the estimation with a robust option using command “ivreg2” in Stata. The p-value of Anderson-Rubin test of endogenous regressors is significant at the 1% level. We conduct the weak instrument-robust inference using the approach of Anderson and Rubin (1949).

Table 6.Dealing with endogeneity

Panel A: 2nd-stage regressions	(1)
Dependent variable**: Gender equality**	
Innovation	**0.945***** **(0.093)**
Constant	29.895*** (3.888)
Panel B: 1st-stage regressions	
Dependent variable : **Innovation**	
Disease pathogen	**-14.241***** **(1.118)**
Constant	37.450*** (0.856)
Observations	123
R^2	0.41
Fisher	101.78***
Under identification LM statistic(p-value)	0.000
Anderson-Rubin chi-sq test of endogenous regressors (p-value)	0.048

According to Ang *et al*. (2018), this method which is robust to the presence of weak instruments, tests the significance of the endogenous regressor in the structural equation. The test rejects the null hypothesis that the coefficient of the endogenous regressor is equal to zero at the 5% level of significance, thus providing evidence that our endogenous regressor is relevant even in the presence of a weak instrument.

6. Concluding implication and future research directions

The literature on comparative development has attributed the determinants of gender equality to factors such as agriculture, urbanization, democracy, education, and culture. This paper departs from the literature by showing that historical prevalence of infectious disease plays a part in long-run gender equality. Disease pathogens according to parasite stress theory determine innovation, culture and political regime, which lead to the liberalization of values and promote equality between men and women. This reduced-form argument suggests that historical prevalence of infectious disease and gender equality are related. Our results provide considerable support for this notion. In fact, innovation is the main channel through which disease pathogens persist on gender ratio.

The main implication of this study is that innovation should be promoted as a means of fighting disease pathogens and by extension, promoting gender equality. It follows that countries that substantially invest in favoring an economic development culture that is supportive of innovation are also likely to benefit from comparatively less disease burden and gender equality.

Future studies can extend the findings in this study by assessing how other historical factors influence contemporary gender equality. Moreover, in order to provide findings with complementary implications, understanding how contemporary factors influence contemporary gender equality dynamics is also worthwhile for the achievement of SDG 5 focusing gender equality and women empowerment.

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Appendices

Appendix A: Descriptive Statistics

Descriptive Statistics

Variables	Obs	Mean	Std. Dev.	Min	Max	source
Gender equality	123	63.707	15.708	26.822	91.371	Sachs etal.(2021)
Diseases pathogens(historically)	123	.133	.656	-1.31	1.17	Murray and Schaller(2010)
German legal origin	121	.05	.218	0	1	Acemoglu et al.(2001)
culture	123	.211	.41	0	1	
French legal origin	120	.525	.501	0	1	Acemoglu et al.(2001)
Scandinavian legal origin	121	.041	.2	0	1	Acemoglu et al.(2001)
catholic trust	114	31.842	35.986	0	96.9	Acemoglu et al.(2001)
Muslim	114	23.034	35.265	0	99.4	Acemoglu et al.(2001)
Protestant trust	120	12.342	21.691	0	97.8	Acemoglu et al.(2001)
Democracy	116	-.051	14.42	-66	10	V-DEM(2021)
Innovation	123	35.789	12.966	10.6	66.6	WIPO(2021)
Innovation outputs	123	38.417	13.926	4.4	66.833	WIPO(2021)
Innovation inputs	123	10.701	8.68	.5	65.2	WIPO(2021)
Women political empowerment	120	.761	.168	.184	.962	V-DEM(2021)
urbanization	113	8.068	1.624	4.357	12.009	V-DEM(2021)
Agriculture	119	15.195	14.559	.116	75.362	WDI(2021)
Expenditure on education	113	14.314	4.332	6.293	24.938	WDI(2021)
high income	121	.296	.417	0	1	World Bank classification (2021)
Small country	120	.092	.29	0	1	World Bank classification (2021)
Fragile country	120	.108	.312	0	1	World Bank classification (2021)
Island	120	.033	.18	0	1	World Bank classification (2021)
Landlocked	105	.171	.379	0	1	Comin et al.(2010)
tropical	105	.476	.502	0	1	Comin et al.(2010)
Distance to equator	99	.294	.195	.003	.669	Comin et al.(2010)
Precolonial institution	122	.934	.17	0	1	Giuliano andNunn(2018)
State antiquity	105	.492	.236	.028	.964	Ang and Fredriksson(2018)
Technology adoption in 1500 BC	92	.647	.253	.157	.995	Comin et al.(2010)
Population density in 1000 BC	87	1.793	.701	1	3	Comin et al.(2010)
American dummy	123	.146	.355	0	1	Authors
Asian dummy	123	.252	.436	0	1	Authors
other continent dummy	123	.74	.441	0	1	Authors

Source: authors' construction

Appendix B: List of countries

Liste of countries				
Albania	Costa Rica	Israel	Netherlands	Syria
Algeria	Ivory cost	Italy	Nigeria	Tanzania
Angola	Croatia	Jamaica	Norway	Thailand
Argentina	Cyprus	Japan	Oman	Trinidad and tobago
Armenia	CzechRep.	Jordan	Pakistan	Tunisia
Australia	Denmark	Kenya	Panama	Turkey
Austria	Ecuador	Korea	Peru	Uganda
Azerbaijan	Egypt	Korea south	Philippines	Ukraine
Bahrain	El Salvador	Kuwait	Poland	United Arabe emirate
Bangladesh	Estonia	Laos	Portugal	United Kindom
Belgium	Ethiopia	Latvia	Romania	Uruguay
Benin	Finland	Lebanon	Russia	USA
Bolivia	France	Liberia	Rwanda	Venezuela
Bosnia	Gabon	Lithuania	Saudi arabia	Vietnam
Botswana	Gambia	Luxembourg	Senegal	Zambia
Brazil	Georgia	Macedonia	Serbia Montengro	
Brunei	Germany	Madagascar	Sierra leone	
Bulgaria	Ghana	Malawi	Singapore	
Burkina faso	Greece	Malaysia	Slovakia	
Burundi	Guatemala	Mali	Slovenia	
Cambodia	Guinea	Mauritania	South Africa	
Cameroon	Hungary	Mayanmar	Spain	
Canada	Iceland	Mexico	Sri Lanka	
Chad	India	Moldova	Suriname	
Chile	Indonesia	Morocco	Swaziland	
China	Iran	Mozambique	Sweden	
Colombia	Ireland	Namibia	Switzerland	

Source: authors' construction

Appendix C: Controlling for other measures of gender equality

	(1)	(2)	(3)	(4)	(5)	(6)
	OLS	OLS	OLS	OLS	OLS	OLS
	Gender equality	Ratio on family planning	Ratio on education	Ratio on labor force	Ratio on national parliament	Gender wage gap
Disease pathogen	**-6.480*****	**-5.286**	**-14.905*****	**5.690***	**-0.350**	**3.792**
	(1.994)	**(3.673)**	**(3.121)**	**(3.182)**	**(1.683)**	**(2.454)**
Culture	3.953	13.239**	-5.325	7.394*	2.215	1.366
	(3.218)	(6.031)	(4.702)	(4.019)	(2.429)	(2.935)
German legal origin	0.063	7.202	-4.441	-1.546	1.818	6.879
	(2.778)	(5.176)	(3.858)	(3.744)	(2.702)	(4.184)
French legal origin	-0.002	1.113	1.081	-2.543	2.119	-4.208
	(2.307)	(3.113)	(3.141)	(3.181)	(1.903)	(2.637)
Scandinavian legal origin	3.995	-1.446	-7.429	3.235	13.877***	-12.980**
	(5.347)	(6.846)	(5.958)	(5.152)	(5.069)	(5.353)
Catholic trust	0.056	-0.007	0.025	-0.048	0.080***	-0.058
	(0.037)	(0.070)	(0.055)	(0.052)	(0.030)	(0.046)
Muslim trust	-0.207***	-0.176***	-0.136**	-0.328***	-0.007	-0.114**
	(0.043)	(0.061)	(0.055)	(0.066)	(0.031)	(0.046)
Protestant trust	0.120*	0.119	0.105	0.058	0.097*	0.102
	(0.072)	(0.105)	(0.087)	(0.083)	(0.058)	(0.076)
Democracy	0.113*	0.159*	0.225***	-0.048	-0.020	-0.110**
	(0.061)	(0.088)	(0.076)	(0.083)	(0.039)	(0.052)
America dummy	2.838	19.517***	12.248***	-16.022***	-1.701	2.021
	(2.918)	(6.143)	(4.266)	(4.651)	(2.676)	(3.507)
Asia dummy	4.509*	17.875***	16.300***	-16.723***	-2.200	2.375
	(2.687)	(4.576)	(3.800)	(4.492)	(2.005)	(5.952)
Other dummy	-1.288	-3.881	-4.802	8.833**	-1.530	-0.923
	(2.889)	(6.912)	(4.455)	(4.448)	(2.125)	(2.707)
Constant	64.631***	58.628***	89.661***	77.278***	15.552***	18.925***
	(2.714)	(6.824)	(4.088)	(3.770)	(2.538)	(4.254)
Observations	108	107	109	109	109	35
R^2	0.68	0.58	0.57	0.56	0.43	0.74
Fisher	30.38	24.35	12.75	29.16	16.49	31.14

Source: authors' construction