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Ancient nomadic corridors and long-run development in the highlands of Asia

Christopher Paik*, Keshar Shahi

Division of Social Science, New York University Abu Dhabi, United Arab Emirates

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A B S T R A C T

In this paper we explore the long-run settlement and economic activities in the highlands of Asia. The highland terrains uniquely determined seasonal migration paths by nomadic pastoralists (so called "nomadic corridors"), along which trade routes and settlements formed. Using simulated nomadic corridors as a proxy for ancient transportation networks, we study how closely contemporary economic activities remain around these routes. We find that in the highlands, the ancient routes are associated with positive economic outcomes in the long run; trade hubs along the routes continued to draw people and are more populated today relative to other areas in the region.

1. Introduction

The highlands of Asia have historically been inhabited by nomadic populations and defined by challenging topography, high cost of mobility, and low agricultural suitability. Given these conditions, the regional development path has differed markedly from those that typically characterize standard economy models. Many parts of the highlands with similar geographic characteristics traditionally depended on animal herding. Over time, seasonal pastoralism emerged as an efficient ecological strategy to exploit the increased seasonal productivity of highland pastures in the region. The seasonal migration of livestock and humans between agro-ecological zones, often called transhumant pastoralism, is an age-old practice found in many mountain regions across nearly all continents (Little, 2015). Archaeological and ethnographic evidence from Asia show that for over 4500 years, herders looked for pastures for grazing in the highlands during summers and returned to the lowlands in colder months, carving out seasonal migration paths (Frachetti et al., 2017).

In this paper we show that historical transportation networks were the channel through which the ancient migration paths determined the highlands' economic activities in the long run. Transportation infrastructure and its networks have been frequently associated with increased economic outcomes around the world, with its development being critically dependent on the local environment.[1] The highlands of Asia, in this regard, provide a valuable context based on a set of unique geographic characteristics. More importantly, Frachetti et al. (2017) provide evidence that the ancient herders' seasonal migration patterns practiced over millennia laid the foundation for transportation networks in inner Asia. They introduce the Pastoralist Participation Model, a geographic information system (GIS) algorithm designed to simulate ancient migration corridors carved out by nomadic herders. The authors importantly find that there is a high spatial correlation between the corridors and the actual Silk Road sites in inner Asia.[2] This result

* Corresponding author.
E-mail addresses: christopher.paik@nyu.edu (C. Paik), keshar.shahi@nyu.edu (K. Shahi).

[1] Several works have shown positive returns of transportation infrastructure around the world including India (Donaldson, 2018), Africa (Jedwab and Moradi, 2016), the US (Atack et al., 2010), and Europe (Dalgaard et al., 2018)

[2] Specifically, the authors use seasonal pasture quality and annual herding "flow accumulation" across the highlands to simulate pastoralist migration patterns with their animals. Appendix provides more details on modelling pastoralist mobility as flow accumulation.

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gives empirical support to the authors claim that the nomadic migration corridors were eventually adopted by traders to become part of the Silk Roads. Travellers were better off following these existing local paths since there was no incentive in diverging away from the locally established and refined routes, as discovering new paths in these hard-to-navigate terrains was costly.[3]

Building on Frachetti et al. (2017), we expand the simulation exercise to a broader region covering the highlands of Asia.[4] As in Frachetti et al. (2017), we argue that the simulated corridors serve as suitable proxies for the region's ancient trade routes and address the potential issue of reversal causality (i.e. regional economic development causing more trade routes to connect to the region, rather than vice versa). There was little consideration of trading activities when pastoralists initially moved from one place to another millennia ago; the pastoralists were looking for the best available grazing opportunity, which meant that each herder likely had an incentive to move away from other groups of herders. The simulation model thus takes the region's terrains as its main input and excludes human interaction, population centers, or any trading activities.

Using relevant spatial data on economic development and urbanization, we then assess if contemporary economic outcomes in the Asian highlands correlate with access to these ancient routes. Specifically, we evaluate whether population density, modern city location, and night-time light intensity can be explained by proximity to the simulated nomadic migration corridors. In our empirical exercise, we find a strong and robust correlation between the location of simulated nomadic travel paths and modern-day economic activities in the highlands. Places near ancient nomadic routes are likely to be more densely populated than others in the region, and these places correspondingly have relatively higher night-time light intensity. Our results are robust across alternate measures of explanatory variables, model specifications, and estimation strategies. We use historical population modeling to show that economic activities like population density have been positively linked to locations of nomadic paths consistently over time. Using mediation analysis, we also confirm that the ancient transportation infrastructure likely did not have an impact on economic outcomes today through contemporary road networks. This finding suggests that contemporary transportation infrastructure and networks may not necessarily follow along ancient routes (as in for example the Roman roads predicting contemporary transport infrastructure in Europe (Dalgaard et al., 2018)), but rather depend on the traditional geographic environment and accompanying challenges in transport from one destination to another.

Taken together, these results suggest another plausible mechanism: there were agglomeration economies established early on along the ancient travel routes as trade hubs. These places, in turn, consistently remained more populated than others in the region, given the lack of alternative settlement locations. The persistence outcome is remarkable as there appears to be little correlation between historical and contemporary transportation networks today. As technological advances helped to overcome historical difficulties of traveling across the highlands, China's recent efforts to expand transportation infrastructure in the region have resulted in railways and highways that have drastically shortened the distances between destinations without following the ancient networks.

2. Literature

Our findings contribute to existing studies on the economic impact of transportation infrastructure as well as those on long-run economic development. Unlike the highland context in which transportation networks historically connected sparsely populated regions, many works in the literature focus on contemporary urban vs. rural settings and find contrasting results.[5] Other works on the historical impact of transportation infrastructure look at railway construction and find an overall positive effect on the local economy. Donaldson (2018), for example, finds that in colonial India, building railways in the region led to positive economic outcomes through reduced costs of trading, diminished inter-regional price gaps, and increased trade volumes. Banerjee et al. (2020) and Jedwab and Moradi (2016) find similar positive economic outcomes from building transportation networks in China and Ghana, respectively.[6] Atack et al. (2010) suggest that the railroads played a significant role in the growth of urbanization in the American Midwest around the middle of the nineteenth century but were much less important in the growth of population density. Furthermore, their findings imply that railroads were the "cause" of urbanization.

On the long-run economic development, Spolaore and Wacziarg (2013) and Nunn (2014) survey a growing body of evidence showing the impact of historical events on current economic development and their persistence in a wide variety of time periods and locations. These works involving interactions among geography, history, and comparative development primarily seek to answer fundamental questions such as time persistence in development and mechanisms on how geographic and historical factors determine present-day outcomes.

[3] Historians have noted that secondary options did not exist for many of the routes (Schafer, 1963).

[4] The nomadic seasonal travel routes in the model occur in the elevation range between 750 and 4000 m. The lowlands below this range are excluded from the analysis as their economy differs fundamentally in terms of infrastructure development, population growth, agriculture, and irrigation. Places situated above 4000 m are also not considered in the model as permafrost limits the growth of any pasture and herding opportunities. Frachetti et al. (2017) limit the extent of their study to a certain geographical coverage: 30 N to 55 N and 60 E to 100 E. This leaves out a significant area of China, Mongolia, Afghanistan, Nepal and other countries in the region that have a history of pastoralism. In our study, we extend the region of study to include these countries: 25 N to 56 N, and 25 E to 136 E.

[5] Albarran et al. (2011); Duranton and Turner (2012); Hsu and Zhang (2014) find a positive relationship between building transportation infrastructure and economic activities in rural settings, while Helpman and Krugman (2002) point out a potential negative impact due to agglomeration effects. Under the urban setting, studies show that transportation networks cause suburbanization (Baum-Snow, 2007; Glaeser and Gottlieb, 2009).

[6] In China, regions closer to historical transport networks have higher GDP per capita, higher income inequality, higher number of firms, and higher average firm profits. The railroads built during the colonial period in Ghana show that there is a long-term positive impact of connectivity in a developing country; the infrastructure still have effects to date despite their collapse and expansion of road networks after independence.

A seminal paper closely relevant to our research is Bleakley and Lin (2012), in which the authors show a strong path dependence in the location of economic activity. They find that historical portage sites with temporary advantages had permanent effects on the spatial distribution of population. Portage sites were focal points in the early to the mid-nineteenth century for commercial activities and entrepot trade when the shipment of goods by boat was a dominant form of transportation in the United States. Once canals and railways were developed, the relevance of portage sites declined. However, examining population density from 1790 to 2000, the paper shows that population remains concentrated more (not less) at these portage sites. In our paper, nomadic corridors in the highlands also may not be as economically relevant as in the past[7] but their historical presence remains a strong predictor of economic outcomes today.

Barjamovic et al. (2019) provide a similar geographic context as ours (Anatolia with its clearly defined mountain ranges and valleys) where natural roads are more identifiable and show persistence of city size as determined by ancient transport links, which in turn are determined by first-nature topography. In our paper, we expand the geographic extent of the analysis to cover the rest of Asian highlands and derive general trends. We also explore various channels through which historical trade routes and settlement affect economic development today in a pastoralist setting. One important takeaway from our findings is that the impact of these historical developments on contemporary outcomes is not obtained through contemporary transportation infrastructure development. Instead, we explore how nomadic corridors likely impacted contemporary economic activity early through the historical establishment of agglomeration economies along the ancient travel routes. Once established, these places remained more populated than others in the region.

In a different context, Barsanetti (2021) finds that historical settlements near indigenous, pre-Columbian travel paths ("Peabiru") can explain higher population density and urbanization in Brazil today. Barjamovic et al. (2019); Barsanetti (2021) and others (ex. Allen and Donaldson, 2020; Fujita et al., 1999) further find support for the persistence of agglomeration economies that establish themselves along natural and historical routes. Barsanetti (2021) shows that modern transportation infrastructures, especially railroads, can explain some of the indirect effects, although some of the towns already existed prior to the arrival of railroads and the direct effect of proximity to Peabiru on the economic outcomes remains strong. In this paper, we attribute the lack of correlation between the ancient and contemporary transportation networks in the highlands to the vast improvements in technology and government-led economic initiatives that have overcome the region's topographical challenges.

Finally, Dalgaard et al. (2018) look at the long-term impact of road networks with a much longer time span. The study on the Roman roads shows that infrastructure development during the Roman period has persistently led to more significant economic growth in the region even after centuries. The authors find that a location with a higher density of Roman roads has a persistently greater modern road density and more significant economic activities today. In the case of the Roman roads, the quality and the size of roads and geographic features of Europe made it possible to continue using the travel networks to engage in major economic activities in its peripheries. Our paper takes a similar long-run perspective but from a different geographic context and time period. We introduce the unique context of the Asian highlands to show that trade hub settlements established themselves along the ancient transportation networks determined by the region's challenging topography, but these networks also eventually gave way to new ones providing much more direct access to destinations with advances in technology.

3. Historical trade routes, settlements and long-term economic development in the highlands

How has economic development in the highlands become markedly different from other regions in their settlement patterns and persistence? The exploitation of highland pastures by herders in the region was followed by active inter-regional trade and development of trade-dependent population settlements as far back as the Bronze Age, which in Central Asia is defined as ca. 2500-1000 B.C. (Benecke and von den Driesch, 2003; Frachetti, 2009; Rogers, 2012). The prosperity and permanence of urban centers in the highlands were not guaranteed, however, especially when compared to those located in sedentary societies. Pastoralist polities would build urban centers that would become abandoned and never resettled, while others would be reused; these settlement patterns differed from those based on agriculture, where "urban centers themselves are tied to a particular location and therefore embody a complicated history of change" (Rogers, 2012, pg. 211).[8]

Blaydes and Paik (2021a) and Blaydes and Paik (2021b) provide some insight as to why cities in the highlands may have followed a different trajectory from those in other regions. Due to their fortuitous locations these cities thrived as trade hubs but not as producers of specialized goods or centers of agricultural productivity. Over time as trade profit waned by the end of the Silk Road era and European breakthroughs in seafaring, trade and exploration, so did the prosperity of these cities. Compared to the rest of the highlands that offered even less for settlers, the cities nevertheless maintained their status as regional urban centers in the long run. Places with access to trade paths also coordinated transactions among traders and persisted in their economic relevance. At the same time, given limited production of specialized goods and agricultural resources, people looking to settle continued to migrate to these existing population centers that were also trade hubs. These agglomeration economies continually fared better than other places in the region that benefited from neither access to trade nor production of goods. We thus find a similar persistence mechanism of urban centers in support of Barsanetti (2021) and Barjamovic et al. (2019). Even in the highlands where cities remained relatively small and

[7] While seasonal migration is still practiced among the herding societies in the region as an operational economic activity (Dong, 2016), contemporary highways and railways are likely much more utilized for the majority of transport and trade across the region.

[8] Kharakhorum, the capital of the Mongol empire from 1235 AD to 1260, serves as an example of the rulers' practice of shifting their residences periodically, similar to seasonal nomadic migration. By historical accounts, the city was seen as small and unimpressive to visitors (Rogers, 2012, pg. 233; Boyle, 1972; Shiraishi, 2004).

population spread thin, both coordination mechanism and agglomeration economies were at work to explain the rise and persistence of economic activities near the ancient nomadic routes today.

4. Data

For our analysis, we divide the region of interest into 10-by-10 km grid cells. In total, there are 186,386 grid cells. Appendix Table 1 provides the summary statistics for all the variables employed in our analysis, and Appendix Table 18 provides the sources.[9]

We replicate the "Pastoralist Participation" (PastPart) Model in Frachetti et al. (2017) to simulate pastoralists seasonal migration patterns across Asian highlands. First, the model creates random settlement points in lower-elevation areas where pastoralists return during the winter. During the summer, the pastoralists migrate to higher altitudes with suitable pasture lands for their cattle. When returning to their winter settlement, the pastoralists try to take paths that allow for the best grazing opportunities for their cattle. To create these pathways toward the lowland, the model uses ArcGIS tools Flow Direction and Accumulation to simulate the direction and scale of the flow of herds of cattle based on the pasture's quality. The model iterates this exercise 500 times to reflect 500 unique yearly flow patterns of seasonal migration. Next, all yearly flows are merged to obtain a file that illustrates the 500 years' worth of seasonal pastoralist migration in Asian highlands as shown in Fig. 1.[10]

To construct our primary explanatory variable, we assess whether a grid cell has one or more simulated nomadic paths passing through it. Based on the presence of such nomadic activity, we create a dichotomous variable called PNP (Presence of Nomadic Path). Around 64 percent of the grid cells have one or more paths passing through them. As additional robustness checks, we test our model with two other measures of nomadic paths as well. The second explanatory variable, DIST, gives us the distance from the center of each grid cell to the nearest simulated nomadic path, which on average is 58 km. For the third explanatory variable, we make use of the magnitude of a nomadic path's importance in the network. The Pastoralist Participation Model suggests that some routes were more important than others by quantifying how well connected these routes are with each other. In the Model, each pixel obtains a numeric score based on the number of flows accumulated in the pixel, and thus shows how vital those routes were in the network. Each grid cell in our data contains about one hundred such pixels. We take the average of these pixels' numeric scores in each grid cell to create an explanatory variable. About 36 percent of the grid cells have scores of zero and the largest average score is over three hundred million, which means that the distribution is positively skewed. For our analysis, we take the inverse hyperbolic sine (IHS) transformation of this magnitude and call the variable MAG. MAG is similar in spirit to Barjamovic et al. (2019)'s natural road variable, in that we are able to capture the magnitude of path-crossings for each observation unit. The empirical findings based on MAG (in the Appendix) thus align well with those in Barjamovic et al. (2019), where the authors find that places where the natural routes crossed became more densely populated.

We use a number of available development measures as our outcome variables: population density, proximity to major cities, and night-time light intensity. The panels in Fig. 2 give spatial representations of these variables. First, it is well established in the literature that population density is historically correlated with economic development. Population centers allow for sufficient supply of labor, innovation at work, and economies of scale.[11] In the contemporary period, the relationship likely does not hold to the same extent, but still captures the level of economic activity in a region. Our estimation of population density is based on counts consistent with national censuses and population registers for the year 2010.

Second, as a proxy for modern-day urbanization, we use a grid cell's distance to the nearest city in and around the highlands. There are 322 major cities in the highlands of Asia, based on population and their significance in their country. For instance, over 90 percent of the cities in our data are either provincial or national capital cities. Around 32 percent of the cities have a population lower than 50,000, and there are four cities with a population of over five million. On average, a grid-cell's distance to the nearest city is 269 km. Third, we use the night-time light intensity from 2010 as another measure of economic activity today. Due to its availability across state boundaries and the nature of the data coming directly from the satellites that are arguably subject to less reporting bias, the use of night-time light satellite data as a proxy for economic activities has become widespread in the literature.[12]

The highlands, on average, have around 33 persons per kilometer-squared (SD = 180) and 1.03 units of night-time light intensity (SD = 4.11). 75 percent of the region has a population density below 23 persons per kilometer-squared. Moreover, a similar portion of the region has a night-time light intensity of zero (no light), suggesting that it is mostly underdeveloped and lacks urbanization. On the other end, the highest population density in our dataset exceeds 18,500 persons per kilometer-squared and night-time light intensity reaches the maximum value of 63. Both variables are highly skewed to the right and the distribution of these indicators suggests that the region is sparsely populated and has minimal economic activities except for a small number of places.

[9] All the replication files for our analysis are available at Paik and Shahi (2022).

[10] We discuss the model in detail in the Appendix.

[11] Long and Shleifer (1993); Stasavage (2014) present supporting evidence in the case of cities in pre-industrial Europe, and Acemoglu et al. (2002) show cross-sectional and time-series evidence for cities around the world in the pre-industrial period.

[12] Several papers have shown a positive correlation between night-time light intensity and economic activities (Croft, 1978; Doll et al., 2006; Elvidge et al., 1997; Ghosh et al., 2010; Sutton and Costanza, 2002; Sutton et al., 2007). Michalopoulos and Papaioannou (2018) provide an overview of the use of satellite data in the literature.

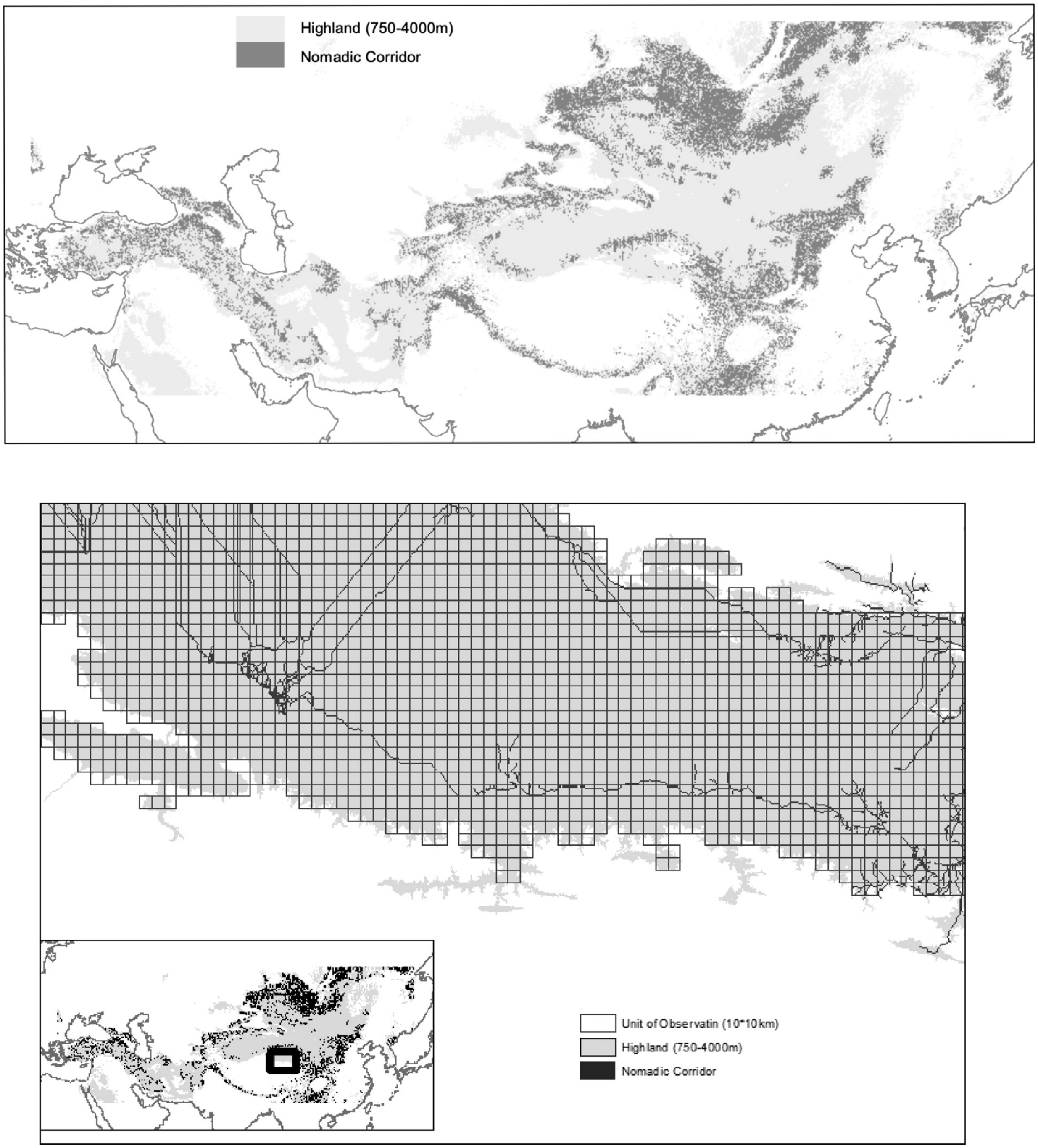

Fig. 1. Highlands and nomadic corridors (Top); zoomed in map with grid cells (Bottom).

5. Findings

The highlands in our study spread over 31 countries. We use the following cross-sectional specification with country fixed effects to study the impact of historical transportation networks on contemporary economic outcomes:

$$Y_{gc} = \delta_c + \beta \text{PNP}_{gc} + X'_{gc}\gamma + \epsilon_{gc} \tag{1}$$

The dependent variable Y_{gc} in Eq. (1) is grid cell g's development outcome in country c. We run variants of the specification with the three measures of economic activities: population density, proximity to cities, and night-time light intensity. PNP_{gc}, a dummy

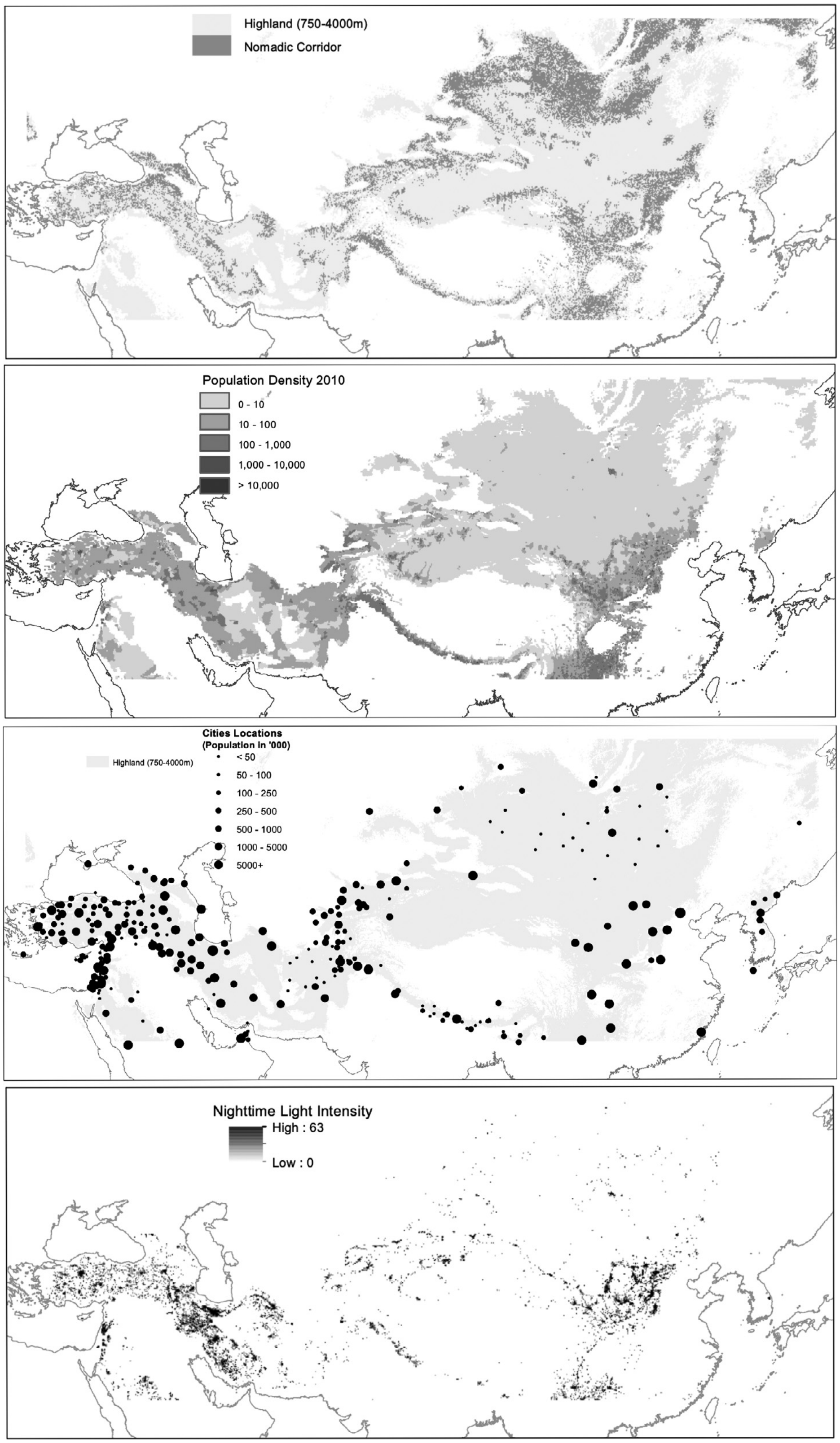

Fig. 2. Spatial representation of nomadic corridors and contemporary measures of development in asian highlands: (From Top) nomadic corridors, population density, location of cities, and night-time light intensity.

Table 1
The effect of historical presence of nomadic travel path on contemporary population density, nightlight intensity, and proximity to city.

	Population density		Distance to city		Nightlight intensity	
	(1)	(2)	(3)	(4)	(5)	(6)
PNP	37.09	21.68	−81.81	−34.98	1.109	1.161
	(0.91)***	(1.05)***	(0.90)***	(0.97)***	(0.02)***	(0.02)***
	[9.05]***	[5.62]***	[24.43]***	[16.38]*	[0.32]***	[0.30]***
Constant	9.530	−208.7	320.9	292.4	0.329	−4.120
	(0.71)***	(20.71)***	(0.70)***	(19.16)***	(0.02)***	(0.46)***
	[9.27]*	[133.09]	[14.22]***	[497.87]	[0.19]*	[3.96]
Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Controls	No	Yes	No	Yes	No	Yes
Observations	186,386	186,386	186,386	186,386	186,386	186,386

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.
Note: Standard errors in parentheses. Standard errors corrected for spatial autocorrelation are in brackets.
The main explanatory variable, PNP (Presence of Nomadic Path), equals one if the grid cell (unit of observation) has at least one simulated nomadic corridor passing through it. The population density is in persons/km^2. Nightlight data are expressed as yearly averaged digital number (DN) values in the range 0–63, where 0 represents complete darkness and 63 substantially bright areas. Distances are in km. Control variables include elevation, latitude, longitude, annual average precipitation and temperature, agricultural suitability, terrain ruggedness index, proximity to coast, and proximity to river.

variable for ancient nomadic corridor presence in g, is the main independent variable. δ_c is a full set of country dummies, and X_{gc} contains a vector of geographic controls including the latitude and longitude, elevation, agricultural suitability, terrain variations, proximity to water bodies, temperature, and precipitation.

The geographic coordinates control for potential location factors that correlate with our variables of interest. The elevation variable likewise plays a role in our context; human settlements and transportation infrastructure decline with a rise in altitude. Agricultural suitability of the land is also crucial for determining the types of economic activity and urbanization. We use the Caloric Suitability Indices (CSI) in Galor and Özak (2016), in which the authors capture the potential agricultural output (measured in maximum obtainable calories per hectare per year) based on crops available for cultivation. We thus account for the variation in economic activities in the highlands due to a lack of historical agricultural productivity, where pastoralism tends to be more common than agriculture. To account for slope and terrain variations, we use Nunn and Puga (2012)'s ruggedness index. River and coastal distances are both crucial for economic development. Historically, humans settled by rivers for water, food, and transportation. In many instances, roads are developed parallel to rivers for easier navigation. Furthermore, climate factors are determinants of economic development and are well documented in the literature.[13] We take the annual average temperature and precipitation for each grid cell from WorldClim.org[14] to account for any climate factors that could have impacted the region's economic development from the beginning.

Table 1 shows that the presence of nomadic corridors is associated with positive economic outcomes in the region. In each specification, we control for country-level fixed effects. In Columns 1 and 2, we take the population density as our dependent variable. Column 1, without any additional controls, indicates that a historical presence of a corridor leads to an additional expected population density of 37 persons per kilometer-squared. Once we control for other covariates in Column 2, the effect declines but remains statistically significant. A grid cell that is a part of nomadic migration, on average, has almost 22 persons more per kilometer-squared than a grid cell that is not. The coefficient's magnitude of the historical corridor presence is large considering that the average population density in our dataset is only around 33 persons per kilometer-squared. A decrease in the coefficient's magnitude is expected as we control for geographical features; there is substantial evidence in the aforementioned literature showing geography's vital role in determining a location's productivity.

Columns 3 and 4 show that the grid cells with nomadic corridors are closer to cities relative to those without. With and without the control variables, access to ancient transportation networks is inversely correlated with the distance to cities. With the control variables, a grid cell with a nomadic corridor is 35 km closer to cities today (Column 4). The effect is substantial, again considering that the average distance to the nearest major city is 269 km. The results from using the night-time light intensity, in Columns 5 and 6, are similar to other specifications, suggesting a strongly positive and statistically significant association between historical nomadic corridors and contemporary economic outcomes. Column 5 shows that a grid cell is likely to be brighter by 1.11 units when it has a nomadic corridor passing through. With control variables in Column 6, we find that a grid cell with the nomadic corridor is associated with 1.16 units of higher night-time light intensity. For comparison, the average light intensity value in our dataset is 1.0,

[13] Dell et al. (2014) for example reviews the body of research that considers the role of climate on economic outcomes.
[14] https://worldclim.org/data/v1.4/paleo1.4.html

since most of the areas are not lit. Having historical access to the corridors for an average grid cell translates to an increase in the night-time luminosity by 116 percent.

In the above, we have controlled for a wide range of variables in our specifications to include geographical characteristics that may explain economic outcomes in the region. Nevertheless, we may have an omitted variable problem that leads to a spurious correlation between our nomadic corridor and contemporary economic activities. In addition, our controls may have a non-linear influence and as such the functional form misspecified. In the Appendix, we describe in detail the unobservable selection and coefficient stability test based on Oster (2019) and the least absolute shrinkage and selection operator (LASSO) test controlling for higher-order polynomials.

First, Oster (2019) provides guidance on how to calculate the magnitude of the relative importance of potential unobserved variables needed to nullify the relationship between observed and dependent variables. In our case, we test the unobserved variables importance required to destabilize the coefficients we see between nomadic corridors and contemporary economic activity. In Appendix Table 2, we find that in order to fully drive away the nomadic corridors impact on contemporary population density, the unobservables need to be at least 2.03 times as large as the observables. Similarly, the relative size of unobservables need to be 1.29 times as large for distance to city and 5.17 times as large for night-time light intensity. In other words, the correlation of unobserved confounders with nomadic corridors have to be significantly larger than what we have in the model as observables in order to undermine the validity of a causal relationship between nomadic corridors and contemporary economic outcomes. This exercise thus provides an empirical validation of robustness of our results.

In addition to a potential omitted variables bias problem, the relationship between economic outcomes and existing controls may not be linear as specified in Eq. (1). We use the LASSO test to check the validity of variables selection and a potential non-linear relationship in our models. This exercise performs a cross-fit partialling-out regression estimating coefficients and standard errors, and tests for the variables of interest by making different selections among the control variables. All LASSO models include country-level dummies and potential variables including second-order polynomials and interactions among all the geographical variables. The model selection and inference in Appendix Table 3 uphold the robustness of our findings.

Next, while Table 1 above presents standard errors adjusted for spatial autocorrelation among the grid cells within a 500 km radius distance in square brackets,[15] we can further test whether our observed long-term persistence effects are driven by artificially generated spatial noise. For this exercise, we use the two-step procedure developed by Kelly (2019). First, we conduct the Moran test for spatial autocorrelation among regression residuals in Columns 2, 4, and 6 of Table 1. We then simulate spatial noises to assess the extent to which these randomly generated noises can account for the significance of our actual variables of interest. The two-step procedure is further elaborated in the Appendix. With the Moran test, we fail to reject the spatial autocorrelation hypothesis at the 1-percent level of significance as shown in Appendix Table 4. With randomly generated spatial noise, we find an almost non-existent probability of random noise having any significant explanatory power for contemporary night-time light intensity, proximity to cities, and population density. Similarly, we find no evidence of nomadic paths explaining the spatial noise as seen in Appendix Tables 5–7.

Finally for further robustness checks, we use two alternate measures of historical nomadic paths: proximity to the corridors from a grid cell and accumulated intensity of paths' network in a grid cell. In Appendix Table 8, we examine the impact of nomadic migration on our dependent variables by taking a grid cell's proximity to the nearest nomadic corridor as our explanatory variable. The results in this table remain consistent with our main findings; that is, access to the nomadic corridors remains a strong predictor of positive economic activities. For instance, an increase in distance from a grid to a nomadic corridor by 100 km, after controlling for country-level fixed effects and geographic controls, is associated with a decrease in the average population density of the grid by 4 persons per kilometer-squared. Appendix Table 9 also shows that the main findings are consistent with the third measure of flow accumulation intensity (MAG) as well. Given that our measures of economic activity are skewed to the right, we also show that our results hold with inverse hyperbolic sine (IHS) transformed dependent variables as well in Appendix Table 10.

5.1. Exploring channels of persistence

How far back can one trace the divergence between regions with nomadic corridor access and those without? To check whether the present-day difference in economic activity is indeed a function of historical divergence, we use the time series population data from the last 3000 years. We employ the historical population density based on the History Database of the Global Environment (HYDE 3.2) from Klein Goldewijk et al. (2017), and the following empirical strategy to show the relationship between locations of nomadic corridors and population density over time:

$$P_{gc} = \delta_c + \beta \mathrm{PNP}_{gc} + X_{gc}^{'} \gamma + \epsilon_{gc} \tag{2}$$

where P is the standardized historical population density from HYDE for grid cell g in country c.

Table 2 shows a continued positive relationship between population density and the location of nomadic corridors. The population density was higher around nomadic corridors in the region early on, and this pattern continued to persist over time.[16]

This finding is aligned with our proposed mechanism that nomadic corridors impacted economic activity early through the historical establishment of trade routes and settlements, and that this relationship persisted over time. But there are other plausible explanations, some of which we discuss here. One alternative channel of persistence different from the establishment of trade routes

[15] We use Colella et al. (2019)'s acreg function on STATA to get standard errors corrected for spatial correlation. Colella et al. (2019)'s approach follows Conley (1999)'s to calculate the standard errors.

[16] We also present the same exercise with non-standardized population density data from HYDE in Appendix Table 12.

Table 2
The effect of historical presence of nomadic travel path on historical population density.

	HYDE standardized population density					
	(1) 1000 BC	(2) 1 AD	(3) 500 AD	(4) 1000 AD	(5) 1500 AD	(6) 2000 AD
PNP	0.227	0.371	0.266	0.309	0.409	0.177
	(0.01)***	(0.01)***	(0.01)***	(0.01)***	(0.01)***	(0.01)***
	[0.03]**	[0.04]***	[0.03]***	[0.04]***	[0.04]***	[0.03]***
Constant	−0.143	−0.234	−0.168	−0.195	−0.258	−0.112
	(0.00)***	(0.00)***	(0.00)***	(0.00)***	(0.00)***	(0.00)***
	[0.81]***	[1.05]*	[0.93]**	[1.26]**	[1.25]*	[0.60]
Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Observations	149,550	149,550	149,550	149,550	149,550	149,550

Note: Standard errors in parentheses. Standard errors corrected for spatial correlation are in brackets.
The main explanatory variable, PNP (Presence of Nomadic Path), equals one if the grid cell (unit of observation) has at least one simulated nomadic corridor passing through it. The historical population density has been standardized to allow easier comparison across time. Control variables include elevation, latitude, longitude, annual average precipitation and temperature, agricultural suitability, terrain ruggedness index, proximity to coast, and proximity to river.

could be the migration of nomads into other territories in response to economic shocks (due to natural disasters, for ex.).[17] Such movements could in turn lead to long-term economic consequences due to conflict with incumbents. McGuirk and Nunn (2020) for example find that in Africa, droughts have led transhumant pastoralists to come into violent conflict with sedentary agriculturalists in dispute over arable lands.

In the case of pastoralists in the highlands, their expansions historically appear to have been much more driven by social factors than extreme weather events, such as opportunities to identify an external enemy and thereby reducing infighting and offering collective gains (Rogers, 2012 pg.238). Nevertheless, one can still imagine that pastoralist societies close to agricultural sedentary societies may have had more interactions different from those that were farther away, spurring potential conflicts and long-term consequences. In order to address this alternative channel, we run our baseline analysis including a variable that measures each grid cell's distance to the nearest lowland. This variable controls for the extent of potential interactions between the pastoralists of the highlands and the agriculturalists in the lowlands.

Another potential channel of persistence found in the literature is the pastoralist polities' relation with China. In discussing hierarchy and hegemony within the Asian political sphere, Blaydes and Paik (2021a) note China's hegemony over other Asian states and quote scholars claiming that the tributary order was a "viable and recognized international system with military, cultural, and economic dimensions that all intersected to create a ... stable security system." (Kang, 2010, pg.591), and that "the entire world economic order was Sino-centric" until the eighteenth century (Frank, 1998, pg.116–117). The authors also argue that based on the hegemonic stability theory (Krasner, 1976), the regional hegemony could have positive effects on trade openness, which in turn could have a long-term effect on economic development based on the trade routes carved out by nomadic migration. A key theoretical question is thus whether the pastoralist polities should be viewed as by-products of the states that formed earlier in China and elsewhere (Rogers, 2012, pg.215).

Going further back in history, however, pastoralist polities emerging from as early as the Late Bronze Age (approx. 1400 BC), developed independently in their social structure and commerce. Rogers (2012) (pg.217) presents a study by Houle (2010) of northern Mongolia as the evidence of a pastoralist society that had relatively restricted movements, economic self-sufficiency, and some status differentiation, against "the China-dependency hypothesis as a source for sociopolitical developments amongst the pastoralists." The author further finds evidence that "the resource base, trade connections, and native social systems for the steppe pastoralists are diverse and self-sustaining... (pg. 216)," and that "the foundations of control, in the form of social hierarchies, are consistently present and are not the by-product of pressures or opportunities originating in China"(pg. 238), noting that Xiongnu, the first steppe political entity practicing multiresource pastoralism to be identified as an empire, was in fact a serious threat and a rival for the newly emerging Han dynasty (202 BC-220 AD) (Brosseder and Miller, 2011) .

We can address the region's potential dependence on China by controlling for proximity to Chang'an (currently Xi'an), the capital of Han Dynasty.[18] Appendix Table 11 presents our baseline results including the proximity to lowlands and to Chang'an; we find that our main results remain substantively the same.

[17] We thank an anonymous reviewer for this suggestion.

[18] Both Chang'an and Xianyang, the capital of Qin dynasty (the first dynasty of Imperial China (221-206BC), are essentially located in the same vicinity.

Table 3
Current road networks and population density.

	Distance to road		Population density					
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
PNP	−8.110 (0.16)*** [4.98]	−3.710 (0.18)*** [3.29]			37.09 (0.91)*** [9.05]***	21.68 (1.05)*** [5.62]***	35.35 (0.92)*** [8.32]***	21.66 (1.05)*** [5.49]***
Dist to Road			−0.273 (0.01)*** [0.11]**	−0.0197 (0.01) [0.07]			−0.214 (0.01)*** [0.07]**	−0.00630 (0.01) [0.06]
Constant	22.15 (0.13)*** [2.80]*	5.151 (3.55) [71.52]	37.76 (0.47)*** [12.91]**	−210.6 (20.73)*** [134.65]	9.530 (0.71)*** [9.27]*	−208.7 (20.71)*** [133.09]	14.28 (0.77)*** [9.17]*	−208.7 (20.71)*** [133.16]
Controls	No	Yes	No	Yes	No	Yes	No	Yes
Country Dummy	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	186,386	186,386	186,386	186,386	186,386	186,386	186,386	186,386
ACME via *Road Network*							1.739*** (0.0538)	0.0234 (0.02)

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.
Note: Standard errors in parentheses. Standard errors corrected for spatial autocorrelation are in brackets.
The main explanatory variable, PNP (Presence of Nomadic Path), equals one if the grid cell (unit of observation) has at least one simulated nomadic corridor passing through it. The population density is in persons/km^2. Distances are in km. Control variables include elevation, latitude, longitude, annual average precipitation and temperature, agricultural suitability, terrain ruggedness index, proximity to coast, and proximity to river.

Yet another channel is that nomadic corridors may have affected economic activities through the establishment of contemporary transportation infrastructure (roads and railways), which we rule out in the following analyses. To test whether the historical routes had an impact on economic development through modern transportation networks, we specify the relationships between three measures: historical infrastructure, modern road networks, and modern economic outcomes. We first employ a mediation analysis based on MacKinnon (2012) where we use the modern road network as a mediating variable. We estimate the following simple form:

$$PD_{gc} = \delta_c + \alpha_1 PNP_{gc} + \alpha_2 X_{gc} + \epsilon_{gc1} \tag{3}$$

where PD_{gc} is the population density, a measure of economic activity outcome, in cell g of country c, PNP_{gc} is the indicator for the historical presence of nomadic routes, X_{gc} is the vector of control variables, and ϵ is the error term. We are interested in α_1 as it shows the reduced-form impact of historical infrastructure on current economic activity. Since road networks today may play a significant role as an intermediary, we employ the standard estimation of mediation effects. Mediation analysis is based on the following set of equations:

$$Road_{gc} = \delta_c + \beta_1 PNP_{gc} + \beta_2 X_{gc} + \epsilon_{gc2} \tag{4}$$

$$PD_{gc} = \delta_c + \theta_1 PNP_{gc} + \theta_2 Road_{gc} + \theta_3 X_{gc} + \epsilon_{gc3} \tag{5}$$

where PNP_{gc} again is the indicator of nomadic path presence in grid cell gc, $Road_{gc}$ represents the mediating variable, the distance to the contemporary road network for gc, and PD_{gc} is the current level of population density. X_{gc} represents the set of observed exogenous covariates. The product of coefficients $\beta_1 \times \theta_2$ estimates the average causal mechanism effect (ACME) and is obtained by separately fitting the least squares regressions based on the above equations. A significant θ_1 would indicate that the nomadic paths had an impact on economic activity independent of road networks. Based on our previous set of analyses, we hypothesize that θ_1 is positive.

In Table 3 Columns 1 and 2, we first assess how closely the modern road network is associated with our simulated nomadic corridor. This exercise allows us to see if the contemporary transportation network continues to build on the ancient mobility patterns. With controls, a grid cell with a historical nomadic path is predicted to be closer to a modern road network by 3.7 km. Once standard errors are corrected for spatial autocorrelation (in square brackets), however, the impact of pastoralist migration activities on modern road networks is no longer statistically significant. This lack of association suggests that the ancient transportation networks are unlikely to explain the buildup of the present-day transportation networks.

The distance to road networks and the population density of a grid cell have a negative relationship. The result in Column 3 suggests that a decrease in the road's distance by 100 km leads to an increase in population density by 27 persons per kilometer-squared. The effects go away once controlling for geographical characteristics in Column 4. Columns 7 and 8 results show that access to the ancient nomadic corridors continues to have an effect on population density that is independent of the grid cell's proximity to the modern road infrastructure. The nomadic corridors' effect (coefficient's) magnitude is significantly higher than the average causal mechanism effect (ACME) in Column 8 (21.66 versus 0.02). We observe similar findings when we use the proximity to cities and night-time light intensity as our dependent variables in this analysis (see Appendix Tables 13 and 14). These findings thus fail to support the proposed alternative channel; nomadic corridor access does not appear to affect contemporary economic activities through modern road infrastructure.

In Appendix Tables 15–17, we replicate the mediation analysis using proximity to railroads in the region instead. We continue to see minimal influence of nomadic corridor access through this mode of transportation on population density, proximity to city, and night-time light intensity.

6. Conclusion

Our findings suggest that ancient nomadic corridors have a positive long-term association with economic activities in the Asian highlands. These migration routes eventually served as part of inter-regional trade routes including the Silk Roads (Frachetti et al., 2017). When there was an increase in the path usage, people naturally converged toward the trade hubs connected by the paths. Given few alternative locations for settlement, these places turned into permanent establishments bringing larger scale economic activities. The population centers became cities and remained more developed relative to other places in the region over millennia.

Although the presence of ancient routes continues to be a good predictor of economic activities in the region today, we find that the contemporary transportation networks do not necessarily follow the nomadic corridors. In other words, the ancient network effect on local development appears to persist even after at least some of the corridors eventually got replaced by those established later. This apparent lack of association between ancient and modern transportation infrastructure suggests that the network-building process might have moved away from the traditional approach of transforming nomadic corridors into trade routes.

The highlands have evolved in particular with advances in technology, which have enabled road constructions independent of existing routes. Blasting through mountains and paving roads up in the high altitudes, the modern transportation infrastructure has drastically shortened the distances between population centers in the region. China's Western Development Program in particular, started in 2000, to oversee some of the landmark rail projects, such as the Qinghai-Tibet Railway, built across the difficult terrains, as well as highways linking the western provinces to China's core regions (Han and Paik, 2017).

The subsequent Belt and Road Initiative officially announced in 2013 and hailed as a new Silk Road has also seen China investing in infrastructure development to promote the country's economic integration with the neighboring regions, resulting in road and railway connections that have hitherto been difficult to access by modern transport. With these government-led economic initiatives, we expect that the association between ancient infrastructure and modern-day road networks will likely further decrease as we witness faster urbanization and greater regional connectivity among countries across the highlands.

Data Availability

Replication data are available in the Open-ICPSR website.

Supplementary material

Supplementary material associated with this article can be found, in the online version, at 10.1016/j.eeh.2022.101482

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