Cultural transmission, ancient trade routes, and contemporary economic activity: Evidence from Australia*

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Abstract

Can economic outcomes be determined by the transmission of ancient cultural norms and practices? We use the case of colonisation in Australia where Europeans relied on the Aboriginal knowledge of the landscape to explore, map, and settle. Using anthropological data, we construct a newly digitised and georeferenced dataset of all known trade routes that were created by Aborigines based on orally transmitted maps that were passed between generations by word of mouth. We find that Aboriginal trade routes are a strong and positive predictor of contemporary economic activity –as measured by satellite light density at night. We demonstrate that this association can be explained by the early transport infrastructure developed by Europeans along these routes. This suggests path dependence in the trajectory of European settlement and subsequent economic development in Australia.

JEL Codes: Z1; N77; O10; O56
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1 Introduction

Cultural norms encompass not only a set of beliefs and values but also an accumulation of knowledge in the form of practices, techniques and tools that individuals acquire intergenerationally. According to a leading hypothesis from cultural evolution, it is this latter bundle of norms that allowed societies to survive and evolve over millennia in different environments (Henrich, 2015). Yet little is known about its long-run economic implications for present-day societies. In this paper, we shed light on this issue in the context of Australia, where the Aboriginal knowledge of the landscape was used by Europeans to explore, map and settle in their quest of colonisation (Kerwin, 2010; Norris and Harney, 2014).

At the time of European contact in early seventeenth century, Aborigines remained hunter-gatherer societies since they first occupied Australia in 38,050 BCE (Diamond, 2013). Yet Aborigines created an extensive network of trading routes based on orally transmitted maps that were passed through generations by word of mouth (Flood, 1983; Veth and O'Connor, 2013; Kerwin, 2010; McBryde, 2000). Anthropologists describe this Aboriginal trading network as "multitudinous", spreading in every single direction across Australia (Mountford, 1976; Kerwin, 2010, p. 63). With one of the world's driest land, most infertile soils and unpredictable climates, these routes provided essential know-how for Europeans to explore and map inland Australia (Kerwin, 2010; Norris and Harney, 2014). Therefore, as Australia was mapped by European explorers, early settlements were then founded along these routes.

Motivated by this view, a natural question is whether the transmission of Aboriginal knowledge of the landscape towards Europeans played a crucial role in laying the foundations of modern development in Australia. Our main hypothesis is that Australian regions that were more exposed to Aboriginal trade routes show higher economic activity today. We posit that the persistence of Aboriginal trade routes can be explained by the early transport infrastructure that was put in place by Europeans as they settled in Australia. Specifically, and guided by recent anthropological evidence, as early settlements were established along these routes, essential infrastructure was developed to connect them, thus given way to higher connectivity over time and via this to more economic activity today.

To examine empirically our main hypotheses, we construct a new dataset on Aboriginal trade routes in Australia. To do so, we first collated anthropological data on Aboriginal trade routes published in a series of research articles by the anthropologist and archaeologist Frederick David ḾcCarthy (1939). In this collection of published articles, McCarthy provided one of the most comprehensive qualitative descriptions of all known origins and destinations that Aborigines used to exchange goods in Australia

and its neighboring islands before colonisation. Our first contribution is therefore to extract systematic information on the different locations through which Aborigines travelled across Australia by carefully reading the texts from these publications. We construct a catalog of 1,642 origins and destinations in mainland Australia.

Our second contribution is to construct a georeferenced map of Aboriginal trade routes in Australia. This work involves joining the 1,642 origins and destinations using a least cost path algorithm. Given that Aborigines travelled along Australia for thousands of years, they rationally chose the travel paths with the optimal environment and climatic conditions considering their biological constraints. This assumption is supported by recent anthropological evidence of Aboriginal knowledge of the Australian landscape (Kerwin, 2010).

The least cost path algorithm then employs the Human Mobility Index (HMI) constructed by Özak (2018). The HMI estimates the time (in hours) spent by humans during the pre-industrial period to travel a squared kilometer of land taking into account its temperature, relative humidity, cloud cover, slope, type of terrain, and heat-exhaustion risk. Using this index, we estimate the optimal routes between origins and destinations that Aborigines used to exchange goods in Australia prior to colonisation. The complete network of Aboriginal trade routes in Australia comprises a total of 821 routes. Indeed, these optimal paths are in line with McCarthy (1939)'s non-georeferenced maps.

Our third contribution is to document the long-run effects of Aboriginal trade routes on contemporary economic activity in Australia. To conduct this analysis, we divide Australia into grid cells of 50km X 50km and calculate for each cell an indicator on satellite light density at night in 2015 to proxy for contemporary economic activity. Specifically, we use the Visible Infrared Imaging Radiometer Suite (VIIRS) sensor. Unlike similar measures on light density used in the literature, which are usually drawn from the Defense Meteorological Satellite Program (DMSP), VIIRS provides 45 times smaller pixel footprints, thus increasing the quality of the data in settings with more remote areas. This is particular important in Australia where a large proportion of areas are covered by rural countryside or desert.

We examine empirically the relationship between Aboriginal trade routes and contemporary economic activity using probit regressions in a cross-sectional approach. We begin by controlling for unobserved local government-specific characteristics, such as present-day institutions, by means of local government fixed effects. Our results show a positive and statistically significant association between Aboriginal trade routes and economic activity across Australian regions. Having an Aboriginal trade

route in a pixel increases the probability of observing economic activity by 7.1% in Australia today.

Given that Aborigines sought to travel along optimal environment and climatic conditions, geographical characteristics may confound the relationship between Aboriginal trade routes and contemporary economic activity in Australia. We then control for a rich battery of geographical characteristics in our models. Furthermore, we consider historical explorations of mining activities to account for the "gold rushes" undertaken during the colonial period and that led to a rapid growth in urbanisation in Australia.

We also tackle empirical issues around omitted variable problem. In particular, one could argue that cells with a legacy of Aboriginal trade route may exert better unobservable characteristics than neighbour cells. As a result, more economic activity would be expected over time in cells that host an ancient trade route relative to adjacent cells without it. To overcome this empirical challenge, we follow Dube et al. (2010) and Michalopoulos and Papaioannou (2013) and develop a contiguous pair analysis. Specifically, this analysis allows us to control for all unobservable characteristics among adjacent cells via pairs fixed effects. Results confirm our main hypothesis: Aboriginal trade routes remain an important predictor of present-day economic activity in Australia,

Our final contribution is to explore a potential mechanism linking the persistence of Aboriginal trade routes. As outlined above, we hypothesise that the early European transport infrastructure played an important role in this link. In particular, as Europeans established early settlements by relying on Aboriginal know-how on the landscape, these were connected with major colonies through transport infrastructure. This would suggest that such early infrastructure was generally built along Aboriginal trade routes, thus giving way to the persistence of ancient Aboriginal trade routes.

To investigate the above mechanism quantitatively, we digitise and georeference a series of maps of Australian network of railways and highways in the nineteenth and twentieth centuries, respectively. We document a strong and positive relationship between Aboriginal trade routes and early transport infrastructure. This mechanism should be read between the lines of a similar channel of persistence that was recently introduced by Dalgaard et al. (2018) and Flückiger et al. (2021), who analyse the effects of ancient trade routes on contemporary outcomes in Western Europe. Specifically, these studies argue that regions with early transport infrastructure often develop higher connectivity over time through lower transport costs and further infrastructure investments.

Our findings complement the growing literature that explores the role of culture in shaping societal outcomes (Fernández and Fogli, 2005; Giuliano, 2007; Fernandez, 2007; Algan and Cahuc, 2010;

Voigtländer and Voth, 2012; Giuliano and Nunn, 2021). In this literature, scholars have put much attention on how cultural norms, particularly beliefs and values, tend to persist (Voigtländer and Voth, 2012), and what factors make them more changeable over time (Giuliano and Nunn, 2021). We add to this literature by examining another important angle of ancient cultural norms: the accumulation of knowledge in the form of practices, techniques and tools. We demonstrate that the knowledge that Aborigines gained over millennia to travel across Australia to exchange goods has had important implications for economic activity today.

The main findings of the present paper also contribute to the literature on cultural evolution (Bisin and Verdier, 2000; McElreath et al., 2005; Toelch et al., 2009; Henrich, 2015; Doepke and Zilibotti, 2017). A leading hypothesis from this literature, formally developed by Henrich (2015) in his recent book "*The Secret of our Success: How Culture is Driving Human Evolution, Domesticating Our Species, and Making Us Smarter*", is that cultural norms have determined the successful development of societies by socially learning key information from their ancestors. Indeed, Henrich (2015) argued how a bundle of cultural norms from natives helped European explorers to succeed in their voyages to map new territories for the colonial expansion of their Empires. We add to this literature by showing how this transmission of native knowledge towards Europeans determined the paths of development in Australia.

Our work also adds to the recent literature analysing the long-term effects of ancient trade routes (Wahl, 2017; Dalgaard et al., 2018; Barjamovic et al., 2019; De Benedictis et al., 2018; Michalopoulos et al., 2018; Garcia-López et al., 2015; De Benedictis et al., 2018; Flückiger et al., 2021; Baniya et al., 2020; Ahmad and Chicoine, 2021). Much focus has been towards societies where transport infrastructure projects were put in place by centralised states. We depart from this line of studies by focusing on societies for whom economic interactions were also important despite the absence of States and thus physical infrastructure. We show that Aboriginal trade routes in Australia served as key gateways for the emerging of a new society.

Our work also contributes to enhance our understanding of the well-established literature on colonialism and contemporary development (Sokoloff and Engerman, 2000; Acemoglu et al., 2001; Acemoglu et al., 2002; Glaeser et al., 2004; Glaeser et al., 2004; Acemoglu and Johnson, 2005; Dell, 2010; Bruhn and Gallego, 2012; Kampanelis, 2019). These studies argue that the long-run effects of European colonisation vary depending in part on the type of societies that Europeans encountered at their arrival. Specifically, in places where natives had more characteristics of tribal societies, Europeans could not use

them to build their new nations. In this context, Europeans relied on their own features that they themselves brought from their country of origins, thus enabling them to establish a more progressive path of development. Such contexts include regions of present-day countries like United States or Canada, for instance. Our findings add to this literature by demonstrating that even in these particular settings, key characteristics of tribal societies can also have a relevant impact on development over the very long-run.

Finally, our results also contribute to the recent studies that have documented the role of pre-colonial factors in shaping contemporary outcomes. Gennaioli and Rainer (2007) and Michalopoulos and Papaioannou (2013) demonstrate how pre-colonial Indigenous institutions have benefited present-day economic development in Africa, whereas Arias and Girod (2011); Angeles and Elizalde (2017); and Elizalde (2020) have shown this for the case of Latin America. Moreover, Dincecco et al. (2020) explore the long-run effects of pre-colonial warfare on contemporary development for India. Our results differ from these studies in two ways. First, we show that the persistence of pre-colonial factors can still be salient in countries that emerged as the "winners" from the process of colonisation. Second, we focus on a particular pre-colonial factor that is often overlooked in this literature: pre-colonial trade routes. Because in our context all societies lacked centralised states, we are able to disentangle the long-run effects of pre-colonial economic interactions on current day outcomes.

The remaining of the paper proceeds as follows. Section 2 outlines a brief background on Aboriginal people, Aboriginal trade routes, and European colonisation in Australia. Section 3 describes the data and presents the main empirical results and robustness checks. Section 4 provides evidence of a plausible mechanism. Section 6 concludes.

2 Background

The first human migration in Australia dates back approximately 40,000 years ago. Anthropological evidence indicates that the first migrants (Aborigines hereafter) entered through the Insular Southeast Asia and occupied the Kimberley region in Western Australia (Flood, 1983, p. 77). It then took between 1,350 and 2,200 years for Aborigines to settle across the whole continent, traveling either via to the inland regions or along the coasts (Ibid, p. 77-80). The settlement of Aborigines in Australia meant the occupation by humans in the third (out of four) habitable continent in the world —the first being Africa and the second Eurasia (the latter comprising Europe and Asia).

Despite such an early settlement, Aborigines never developed hierarchies beyond the band level. In the own words of Diamond, *'Australia is the sole continent where, in modern times, all natives peoples still lived without any of the hallmarks of so-called civilisation...Aborigines were nomadic or seminomadic hunter-gatherers, organized into bands...'*(Diamond, 2013, p. 44).

The absence of possessing domestic animals could explain why Aborigines remained hunter-gatherers until the European colonisation in the seventeenth century. While in all other continents humans had an abundance of big mammals, Australian "megafauna" extincted just after the arrival of Aborigines (Veth and O'Connor, 2013). This was a fundamental limitation in the extent of how Aborigines were able to develop as a society. Essentially, without the domestication of animals, Aborigines could not increase food production, which constitutes a prerequisite for the development of denser societies and more complex political hierarchies (Diamond, 2013, p. 81-88).

Moreover, given that Australia is among the world's driest places and has one of the most infertile soils and unpredictable climates (Flood, 1983, p. 243), the adaptation of plants to cultivation was limited, thus hampering the shift from hunter–gatherer to agricultural societies (Diamond, 2013, p. 296-297). Under these conditions, food resources were restricted, leading to a small population density. At the time of European contact, Aboriginal population was only around 300,000 (Kerwin, 2010, p. 57).

And yet, Aborigines developed advanced ancient traits such as long-distance trading routes. Exchanges of ochre pigment have been documented to be as old as 30,050 BCE, which was transported within distances between 125 to 500 kilometres (Veth and O'Connor, 2013). Aboriginal trade routes reached remarkable distances thousand years later. Shell ornaments manufactured in Dampier Peninsula in north-western Australia was traded as far as the south coast of the continent, a travel distance of 1,600 kilometres (Flood, 1983, p. 247). Anthropologists describe the Aboriginal trading network as "multitudinous", spreading in every single direction across Australia (Mountford, 1976; Kerwin, 2010, p. 63). According to McBryde (2000), Australia *'is overlain by a matrix of* [Aboriginal trade routes], *often continent-wide, binding individuals and societies'*.

Given the poor quality of the Australian soils, trade routes were essential for the very ex-

istence of Aborigines. With one of the most infertile soils in the world, Aborigines needed to travel long distances constantly in the search of food. Such nomadic lifestyle led Aborigines to develop exchanges of goods with neighbouring groups as well as to accumulate essential know-how on the landscape. Indeed, anthropologists have documented how Aboriginal trade routes tended to lead to different water sources such as wells and springs (Reynolds, 1990). Early accounts from European explorers provide evidence of the rich Aboriginal knowledge of the landscape: *'The localities selected by Europeans...are those that would be equally valued...by the natives themselves...as places...in which they could most easily procure food'* (Ibid, p.17).

Naturally, since Aborigines did not develop a written language, the Aboriginal know-how of the landscape was transmitted intergenerationally by word of mouth. 'Songlines' or Dreaming Tracks' are a clear example of Aboriginal oral traditions, which were used to connect long-distance trading routes.[1] Recent evidence even documents that Aborigines could map orally their trading routes thanks to their deep knowledge of the sky, which anthropologists have identified in different Aboriginal stories (Cairns and Harney, 2004; Norris and Harney, 2014). Wositsky and Harney (1999) define these 'songlines' as '*epic creation songs passed to present generations by a line of singers*...[They] *have various names according to which language group they belong to*...[and] *provide maps for the country...Some songlines describe a path crossing the entire Australian continent*'.

An example of a long-distance trading route connected through 'songlines' was the 'Two Dog Dreaming' story. Along these routes, Aborigines traded pituri —stimulant leaves that were chewed or smoked before tobacco was brought by Europeans. The length of this route is estimated to have been approximately 3,800 km long, thus exceeding in extent and history ancient routes such as the Silk, Incense or Inca Roads (Kerwin, 2010, p. 89). Today, part of this network of 'songlines' is situated along the Transcontinental railway in Australia.[2]

Aboriginal trade routes could even join trading centres where Aborigines exchanged goods and knowledge from various regions. Queensland was an important area that held multiple trading centres. For example, the pituri trade route linked six trading centres, spanning from

[1]Trade routes were also connected along tracks. Tracks were usually used for travelling short distances (Norris and Harney, 2014). European explorers noted how these Aboriginal tracks supported their expeditions by leading them to vital water supplies (Kerwin, 2010, p. 138).

[2]The Transcontinental railway was completed in 1917, connecting the east and west of Australia, a distance of 1,693 km

Marree in the south up to Dajarra and Urandangi in the north, thus covering a distance of 1,200 km (Kerwin, 2010, p. 107).[3]

Europeans began to colonise Australia in the early seventeenth century. From the very beginning, explorations set the way for early European settlements, particularly in inland Australia. Soon after the establishment of the first British colony in Sydney Cove in 1788, settlers sought for more land to increase agricultural production. In the early 1810s, expeditions to cross the Blue Mountains, a large mountainous region bordering Sydney, were then arranged. These expeditions not only allowed Europeans to exploit more land but also to establish the first inland settlement in Australia in what is known today as Bathurst —a location discovered by the explorer George Evans.

While successful in their own ways, European explorations were generally supported via the transmission of Aboriginal knowledge of the landscape. In the own words of Reynolds (1980), "*Local Aborigines frequently provided explorers with valuable information about fords, passes, short-cuts and easy gradients*". Indeed, such transmission towards Europeans not only involved information about vital routes but also on practical skills to endure their expeditions in harsh environments. In particular, explorers were taught by Aborigines how to obtain clean water and a variety of food sources from hunting and fishing to food derived from flora and fauna (a.k.a. bush tucker) (Reynolds, 1980).

There is therefore clear evidence that suggests how the Aboriginal knowledge of the landscape led Europeans to establish early settlements in Australia.[4] According to an influential colonial officer, "*The natives were the parties who first guided the White Man through the intricacies of their forests, led them to their Rivers, their springs, and rich pastures, assisted them in keeping their stock, watched their working oxen, tracked their stray Horses, and rendered other essential assistance . . . The knowledge of their Country was thus acquired, was turned to account*"(Reynolds, 1980).

In light of this evidence, a natural question is then how the transmission of Aboriginal

[3]The trading centres running through the pituri track are Marree, Birdsville, Bedourie, Boulia, Dajarra, and Urandangi.

[4]For excellent accounts of the relations between European explorers and Aborigines, see Reynolds (2006) and Kerwin (2010).While not historical in its focus, the recent book by Henrich (2015) also provides an interesting account about the dependency on Aboriginal local knowledge to make early European expeditions more successful.

knowledge of the landscape could influence the paths of development in Australia over the long-run. Certainly, one would argue that while this transmission of Aboriginal knowledge and practices guided Europeans towards more suitable locations, this became trivial once settlements were established, mapped and connected to the main colonies. Yet, it is plausible to suggest that by joining early settlements to major colonies through transport infrastructure, the effects of Aboriginal trading routes could persist even after Europeans no longer relied on them to travel across settlements.

Indeed, as explorations opened up new land for permanent settlements, settlers built essential transport infrastructure to connect them. For instance, soon after the explorer George Evans discovered the Bathurst plains, a road was built to connect it to the main colonies and ports in Australia (Herald, 1912 [Online]). Recent anthropological evidence has documented numerous examples of railways and roads crossing along Aboriginal trading routes (Kerwin, 2010). A clear example is the Transcontinental railway, which in the early 1910s connected major colonies from the east and west of Australia. This route once formed part of the Dog Dreaming paths and was mapped, among other explorers, by John Forrest in the 1870s.[5]

3 Data and Empirical Results

3.1 Construction of variable of interest

Our variable of interest consists of all known Aboriginal trade routes along the whole Australian land. Each trade route has one starting point and one destination point. We collect these data using a trilogy of research articles on Aboriginal trade routes that was published by the anthropologist and archaeologist Frederick David MćCarthy (1939).

We extract the above information manually by carefully identifying from the text itself the different locations that should form an Aboriginal trade route based on MćCarthy (1939)'s detailed anthropological work. In the Appendix, we provide further details on our method to collect this anthropological data, as well as the main potential empirical challenges that we may

[5]Forrest's accounts towards Aboriginal know-how on the landscape is well known in the literature on European explorations in Australia (Reynolds, 1980).

face in using it.

We construct a catalog of 1,642 origin and destination points that cover all Australian States (apart from Tasmania). Therefore, the main variable of interest consists of 821 Aboriginal trade routes.

In order to draw the lines between all starting and destination points, we consider all climatic, environmental, and physiological constraints of human beings. Given that Aborigines were travelling along the whole Australian land for thousands of years, they should have rationally chosen the travel paths with the optimal environmental and climatic conditions considering their biological constraints.

Therefore, we employ the Human Mobility Index (HMI) constructed by Özak (2018). This index provides the travel time on each square kilometer on land during the pre-industrial era. More specifically, the HMI is a travel time index that considers the temperature, relative humidity, cloud cover, slope, type of terrain (such as natural paths or loose sand), and heat-exhaustion risk. Regarding the last variable, it refers to the effect of heat on a soldier's metabolic rates and speeds to avoid exhaustion. Therefore, the HMI is an estimation of the time that a human being needs to cross each square kilometer on land. Using this limitation as a parameter, we estimate the least cost path between all origin and destination points.

The least cost path is a distance analysis function, which calculates the optimal paths between two places considering other parameters as obstacles. For instance, if between two places exist mountains, a traveller would choose to detour and follow plains to avoid climbing hills. Therefore, altitude and slope represent a cost that a traveller would likely avoid. In our case, the constraint is the travel time between two places. The more time a human needs to cross a place, the less favourable conditions (s)he experiences while travelling on foot. For this reason, our main variable of interest is not just straight lines between two places.

FIGURE I: Aboriginal trade routes in Australia

Notes: This map shows the Aboriginal trade routes in Australia based on MćCarthy (1939)'s work. Whites lines denote trade routes. Trade routes were created using a least cost path algorithm. Authors' own elaboration using MćCarthy (1939) and Özak (2018).

Figure I shows the complete network of Aboriginal trade routes in Australia. We observe that apart from the coastline, hundreds of trade routes traverse the Australian mainland. This is in line with both early MćCarthy (1939)'s maps as well as more recent evidence on Aboriginal trade routes.

3.2 Construction of uniti of analysis and outcomes

Our unit of analysis is a grid cell of about 50km X 50km, which comprises roughly a land area of 250 km^2. This selection overcomes potential discrepancies of our historical measure of ancient trade routes based on our algorithm. Specifically, even if we were to move the trading routes lines significantly (within cell borders), we would likely get similar findings. Yet, results were subject to a smaller cell size.

For each cell, we construct an indicator on economic activity by using night light emission data following Elvidge et al. (2017). They extract their measure from the Visible Infrared Imaging Radiometer Suite (VIIRS) sensor that detects detailed light images from human-made

establishments for 2015. This remote sensing data excludes background noise, solar and lunar contamination as well as features unrelated to electric lighting such as sunlight, glares, moonlight, aurora, fires, and volcanoes.

The main difference between VIIRS data and similar widely-used satellite night light data, such as the DMSP (Defense Meteorological Satellite Program), is that the former provides 45 times smaller pixel footprints. This provides us with a more detailed light data that are associated to more accurate results, especially in cases of local analysis.

Indeed, Gibson et al. (2021) compare VIIRS lights with DMSP and conclude that the former source provides 100% less noisy relationship between city lights and GDP. Moreover, they find that DMSP data are a poor proxy for GDP outside of cities as well as for spatial inequality, and miss much of the intra-city heterogeneity in brightness even after pareto-based adjustment by Bluhm and Krause (2022) who try to deal with top-coding. Therefore, the results render DMSP data inappropriate for analyses that include areas such as the Australian rural countryside or desert.

We therefore use the VIIRS data in order to find the average night light in each grid cell for the whole Australia, thus reflecting economic activity at the local level.[6]

3.3 Covariates and Methodological issues

Our main argument is that Europeans adopted Aboriginal trade paths because of their lack of knowledge of the Australian environment. Moreover, we argue that Aborigines were following optimal paths in terms of environmental conditions to develop their trade routes. Therefore, a key question is whether Australian localities developed economic activity in line with their environmental conditions or due to their legacy of Aboriginal trade paths. The former would suggest that places with ancient trade routes would have developed economic activity even if they have not been used by Aborigines to exchange goods.

To address the above empirical issues, we develop a large pool of environmental, topographic, and geographic variables to compare grid cells independently of their exogenous natu-

[6]We use the "vcm-orm-ntl" version which sets the background (non-lights) pixels equal to zero.

ral characteristics. Therefore, we work towards the idea of comparing areas with similar characteristics based on their dissimilar historical legacy of Aboriginal trade routes. Most of our exogenous variables are standard measures in the economic development, history, and geography literature. These are the coordinates of each grid cell, agriculture suitability, elevation, ruggedness (standard deviation of elevation), precipitation and standard deviation of precipitation, temperature and standard deviation of temperature, distance to the sea, and a binary that shows whether the cell is aligned to a shore.

A more sophisticated group of controls includes the distance from Sydney and State capitals. Although these variables could not be considered fully exogenous for each cell, we believe that capitals would exert a significant influence on places close to them.

Moreover, we expand our bundle of potential confounding factors by calculating the distance from the closest historical mine. We only select historical mines since the less advanced technology during the beginning of the 20th century suggested the distance of each cell from a mine as a more exogenous factor. In other words, recent mine numbers and places could be driven by their corresponding State's wealth, thus suggesting an endogenous "bad" control. Consequently, the distance from a historical mine considers the gold rush period, which played a significant role in developing economic activity at the local level in Australia during the 19th century.

Lastly, we compute the percentage of water (expressed by rivers and lakes) that exist in each cell. This exogenous variable reflects economic activity based on the availability of water such as shipping, cultivation, and fishing.

In Table I, we investigate any relationship between our main variable of interest, the Aboriginal trade routes, and our environmental and topological variables. All regression include local government areas fixed effects. We select the variables that could have driven Aborigines to select places to create their trade routes. The results suggest a positive relationship between trade routes and agriculture suitability, ruggedness, temperature, distance to the sea, and water percentage, thus suggesting that Aborigines did not necessarily prefer places close to the shore or plains to establish their trade routes. They possibly followed shorter paths without considering environmental conditions as a main selection criterion.

TABLE I: Balancedness analysis: The effects of environment on Aboriginal trade routes selection

	Dependent Variable: Binary dummy for Aboriginal trade routes								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Agriculture Suitability	0.0399								
	(0.0280)								
Elevation		-0.0002							
		(0.0002)							
Ruggedness			0.0015***						
			(0.0006)						
Precipitation				-0.0001					
				(0.0002)					
Temperature					0.0006				
					(0.0030)				
Distance to the Sea						0.0011			
						(0.0024)			
Coastal Dummy							-0.1515**		
							(0.0733)		
Water Percentage								0.0020	
								(0.0018)	
Distance to Historical Mine									-0.0011
									(0.0022)
Local Government F.E.	✓	✓	✓	✓	✓	✓	✓	✓	✓
N	3,519	3,519	3,519	3,519	3,519	3,519	3,519	3,519	3,519
R^2	0.392	0.393	0.396	0.392	0.392	0.392	0.396	0.392	0.392

Notes: Variables descriptions are provided in Appendix Table . The estimations include a constant term, which is omitted for space considerations. Robust standard errors are in parentheses. *, ** and *** mean that the coefficient is statistically significant at 10%, 5% and 1% respectively.

Moreover, the results in Table I show a negative association between ancient trade routes and elevation, precipitation, and coastal dummy. Surprisingly, we would expect the opposite results for at least two variables. In either case, all associations are non-significant, apart from ruggedness and coastal dummy that provide opposite signs to the expected. Therefore, our results suggest that environmental characteristics were not necessarily an underlying determinant of Aboriginal trade routes. Although in our specification we control for several potential confounders, this exercise aimed at ameliorating concerns on selection bias.

Finally, it is worth highlighting the issue around blooming, i.e., the potential spillover of light to tangent cells of the "actual" light. Indeed, our selected measure of luminosity (see Section 3.2) allows us to increase the precision of our empirical analysis by avoiding getting spurious results due to night light being spread in cells with zero economic activity.

3.4 Empirical strategy

To investigate the effects of ancient Aboriginal trade routes on current economic activity, we estimate the following probit regression, with standard errors clustered at the local government area level:

$$Nightlight_i = \alpha_i + \beta TradeRoutes_i + Z_i'\rho + \varepsilon_i \tag{1}$$

In equation 1, i shows grid cells for Australia. Our depended variable $Nightlight$ is a dummy, which takes the value 1 if cell i has night light (and therefore economic activity), and 0 otherwise. $TradeRoutes_i$ is our main variable of interest, which takes the value 1 if a grid cell hosts at least one ancient Aboriginal trade route. Z'_i is a vector of climatic, topographic, and geographic variables. Moreover, our model includes local government areas fixed effects, α_i, to capture for all unobserved local characteristics such as market institutions. The coefficient of interest, β, reflects the effect of ancient Aboriginal trade routes on current economic activity.

3.4.1 Main results

Column (1) of Table II presents the relationship between ancient Aboriginal trade routes and contemporary economic activity. We only condition and cluster at the local government areas level. Our results are positive and significant at the 1% level, thus suggesting a higher economic activity in places where Aborigines travelled to exchange goods. Results are robust to adding all covariates at our disposal. In column (2) of Table II, we employ latitude and longitude, while in columns (3) and (4), we include all our climatic, geographic, and topological control variables. The significant variables ,i.e. the distance from the sea and historical mines as well as the coastal dummy, enter the model with an expected sign. Our basic and most conservative coefficient in column (4) suggests that the probability of having economic activity in a cell is almost 6% higher when we observe an ancient trade path.

TABLE II: Aboriginal trade routes and contemporary economic activity

	Dependent Variable: Binary dummy for night light			
	(1)	(2)	(3)	(4)
Trade routes	0.0710***	0.0766***	0.0681***	0.0589**
	(-0.0245)	(-0.0227)	(-0.0232)	(-0.0245)
Latitude		-0.0210***	-0.0156	-0.0351
		(-0.0078)	(-0.0155)	(-0.0338)
Longitude		-0.0160	-0.0150	0.0531
		(0.0162)	(0.0167)	(0.0423)
Agriculture Suitability			-0.0083	-0.0521
			(0.0297)	(0.0423)
Elevation			-0.0000	-0.0002
			(0.0002)	(0.0002)
Ruggedness			0.0002	-0.0006
			(0.0012)	(0.0012)
Precipitation			0.0000	-0.0002
			(0.0002)	(0.0002)
StDev Precipitation			0.0011*	0.0014**
			(0.0006)	(0.0006)
Temperature			-0.0014	-0.0045***
			(0.0024)	(0.0017)
StDev Temperature			0.0125	0.0181
			(0.0203)	(0.0204)
Distance to the Sea				-0.0002
				(0.0010)
Coastal Dummy				0.0736
				(-0.047)
Distance to Sydney				0.0054
				(-0.0051)
Distance to State Capital				0.0013
				(0.0008)
Distance to Historical Mine				-0.0122***
				(0.0014)
Water Percentage				0.0028
				(0.0036)
Local Government F.E.	✓	✓	✓	✓
N	3,519	3,519	3,519	3,519
R^2	0.374	0.378	0.382	0.415

Notes: Variables descriptions are provided in Appendix Table . The estimations include a constant term, which is omitted for space considerations. Robust standard errors are in parentheses. *, ** and *** mean that the coefficient is statistically significant at 10%, 5% and 1% respectively.

As a second measure of economic activity at the local level, we employ population density in 2015. In Table A.I of the Appendix, we explore the effect of ancient Aboriginal trade routes on population density. In our most conservative specification, the sign and significance of the trade routes and control variables follow column (4) in Table II, thus confirming our initial findings. The population density is higher in cells where we observe ancient routes, however, the coefficient is much smaller than that of Table II.

As an additional exercise, we include population density as a control variable in our basic regression of Table II in order to disentangle between potential development due to population and other forces at the local level. The coefficient becomes 0.38 and remains highly significant at the 99% confidence level, thus suggesting that something else beyond population density (as a development factor) associates ancient Aboriginal trade routes and current economic activity.

3.5 Robustness checks

3.5.1 Homogenizing sample

Given the large size of Australian land area, its environment is highly diversified, thus hosting places with different climate and natural characteristics. Therefore, one may be concerned whether our results are driven by different areas i.e. cells with high rainfall and tropical forests with dry in desert. For this reason, we start excluding cells having the lowest and highest 25% of our observed precipitation and temperature in our sample, respectively.

In Table A.II of the Appendix, columns (1) and (2) suggest that even if we homogenize our sample by excluding the most arid local government areas, our main variable of interest remains highly significant. Furthermore, its size remains unchanged, thus ameliorating concerns regarding different coastal and inland places in Australia.

We augment this exercise by restricting our cells in several distances away from ancient Aboriginal trade routes. Therefore, in columns (3)-(5) of the Table A.II, we keep cells that are 200km, 100km, and 50km away from these trade routes. Although the sample size reduces significantly, we still observe highly significant and positive effects of ancient Aboriginal trade routes on contemporary economic activity.

3.5.2 Reducing cell size

To continue investigating whether current economic activity at the local level has deep historical roots in Aborigines' navigation knowledge, we change (narrow) the size of the cells. This is important as someone could argue that our baseline cell size is relatively large, and therefore, the probability of observing both light at night and an ancient Aboriginal trade route is much higher than when using a significantly smaller cell size. Indeed, in recent studies, such as Montalvo and Reynal-Querol (2005), they find different results when estimating the relationship between ethnic diversity and growth when they use alternative sizes of geographical units.

Consequently, we develop 10km to 10km cells to minimize the above scenarios. Our sample increases significantly to 81,309 from 3,519 observations. We regress our night light economic activity measure on our main variable of interest, alongside with our controls from Table II. Surprisingly, in all specifications from Table A.III, the main coefficient remains stable and similar to our basic regression. The results reassure that our main findings are not influenced by the cell size as the effect of the ancient Aboriginal routes on current economic activity is still visible.

3.5.3 Along the routes analysis

Although our results by using a 10kmX10km analysis suggest that our main inferences hold, we now proceed to a more conservative pixel analysis by keeping cells that have trade routes and all their tangent that may also host (or not) a trade route. This analysis allows us to perform a local based analysis in which only considers neighborhoods in Australia with a legacy of ancient trade route. Given that the size of the cells are too small, we further reduce concerns on incomparable long-distant areas.

In columns (1)- (4) of Table III, we explore our hypothesis by using our restricted sample. The coefficients of our main variable of interest are always positive and significant. This exercise is akin to Table A.II, column (5). However, the smaller cell size suggests an analysis that considers spatial heterogeneities, which may be observed in larger areas.

TABLE III: Aboriginal trade routes and contemporary economic activity: Neighbourhood analysis

	Dependent Variable: Binary dummy for night light				
	Cell with Paths and Neighbors				Neighbourhood Fixed Effects
	(1)	(2)	(3)	(4)	(5)
Trade routes	0.0345**	0.0372***	0.0320***	0.0223***	0.0142***
	(0.0087)	(0.0091)	(0.0038)	(0.0036)	(0.0018)
Local Government F.E.	✓	✓	✓	✓	✓
Geographical & Historical controls	✓	✓	✓	✓	
N	19,490	19,490	19,490	19,490	124,186
R^2	0.079	0.120	0.252	0.274	0.759

Notes: Variables descriptions are provided in Appendix Table . The estimations include a constant term, which is omitted for space considerations. Robust standard errors are in parentheses. *, ** and *** mean that the coefficient is statistically significant at 10%, 5% and 1% respectively.

3.6 Contiguous analysis

In our specifications, we control for an array of significant and exogenous variables in order to isolate the effect of ancient trade routes on contemporary economic activity. Moreover, in our robustness tests, we reduce our sample size as a way to homogenise it in terms of environmental characteristics. However, one could still argue that our cells that include an ancient trade route have also unobservable favorable characteristics (comparing them with their neighbor cells), which may attract more population and economic activity in the long-run.

For this reason, we build on work by Dube et al. (2010) and Michalopoulos and Papaioannou (2013) to perform a contiguous pair analysis. More specifically, we develop a model that includes all 10km X 10km cells that host an ancient trade route and their neighbor cells that do not. For instance, if cell A has an ancient trade route and it is tangent to cells B and C without ancient trade routes, we keep both pairs in our sample. For each pair, we include a fixed effect, and therefore any difference in contemporary economic activity between the two cells can be attributed to the ancient Aboriginal trade routes. The contiguous-cell specification is the following:

$$Nightlight_{i(j)} = \alpha_{i(j)} + \beta TradeRoutes_{i(j)} + Z'_{i(j)}\rho + \varepsilon_{i(j)} \tag{2}$$

In equation 2, our independent variable is a dummy that takes value of 1 if there is night light

in cell i with ancient trade routes and that is also contiguous and pair with cell j, which does not include a route. The same structure applies for the $TradeRoutes$ and all control variables $Z'_{i(j)}$. Lastly, $\alpha_{i(j)}$ is the pairs fixed effects.

In column (5) of Table III, we present the results from the contiguous-cell analysis. The coefficient of Aboriginal trade routes variable remains positive and significant at the 99% confidence level. This exercise suggests that even if we consider most (if not all) unobserved characteristics among 10km X 10km cells in the same neighbourhood in Australia, ancient trade routes still continue exerting a significant effect on current economic activity.

4 Mechanisms

According to the historical evidence from Section 2, Europeans often relied on Aboriginal knowledge of the landscape to explore and settle in Australia. Therefore, as early settlements were discovered, essentially transport infrastructure was built to connect them with major colonies. This would suggest that such infrastructure would have been developed along the lines of trade routes, a conjecture that is well supported by recent anthropological evidence (Kerwin, 2010). Importantly, this means that early transport infrastructure could be a plausible mechanism behind the relationship between Aboriginal trade routes and contemporary economic activity in Australia.

Indeed, the above mechanism should be understood in a similar fashion as in recent studies that explore the effects of ancient trade routes on historical and contemporary outcomes (Dalgaard et al., 2018; Flückiger et al., 2021; Ahmad and Chicoine, 2021). Specifically, because regions more exposed to these ancient trade networks developed better patterns of connectivity by means of lower transport costs, a more intensive exchange of goods endured within them through further infrastructure investments over time. As a result, these regions show higher economic outcomes today than those with a lower legacy of ancient trade routes.

In order to explore our main argument, we georeference two maps on early transport infrastructure in Australia. The first map (Figure A.II) shows all early railways that were built from 1880 until 1920, which we construct using a set of historical maps. The second map (Fig-

ure A.III) illustrates all early highways that Europeans constructed by the early 1950s. From this map, we only digitise the main Interstate and State highways in Australia.

In addition to the above two maps, we also digitise the map published by Robinson (1927) showing all early European inland explorations from 1813 until 1901. Although this is a detailed map showing both nodes and segments of early explorations, we should also consider the limited technology in geographical tools at the beginning of the 20th century.

We construct dummy variables for each map, thus showing whether cells have early economic activity or not. For example, we measure early railway infrastructure via a dummy variable that takes on the value 1 if there is at least one railway in a grid cell, and 0 otherwise. The same applies to the other two maps.

In Table IV, we regress each of our dummies on our main variable of interest as well as on all our baseline control variables and local government fixed effects. Columns (1)-(2) of Table IV show that both early railways and highways were significantly influenced by Aboriginal trade routes. In line with our historical evidence, these results suggest that contemporary development follows ancient trade paths, an effect that we argue may be explained by the transmission of ancient Aboriginal norms and practices towards Europeans. Indeed, if the latter is true, we should also observe a strong association between Aboriginal trade routes and early European exploration routes. Column (3) confirms this argument. The coefficient on Aboriginal trade routes seems to be a strong predictor of European explorations. In particular, this coefficient suggests that the probability of exploring an area (cell) with ancient Aboriginal trade routes is 12% higher than in areas without such legacy.

TABLE V: Balancedness analysis: The effects of environment on Aboriginal trade routes selection

	Dependent Variable: Binary dummy for night light								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Agriculture Suitability	0.0005								
	(0.0258)								
Elevation		0.0000							
		(0.0002)							
Ruggedness			0.0005						
			(0.0006)						
Precipitation				-0.0001					
				(0.0002)					
Temperature					-0.0001				
					(0.0024)				
Distance to the Sea						0.0006			
						(0.0023)			
Coastal Dummy							-0.0526		
							(0.0660)		
Water Percentage								-0.0010	
								(0.0018)	
Distance to Historical Mine									-0.0029
									(0.0028)
Local Government F.E.	✓	✓	✓	✓	✓	✓	✓	✓	✓
N	3,519	3,519	3,519	3,519	3,519	3,519	3,519	3,519	3,519
R^2	0.290	0.290	0.290	0.290	0.290	0.290	0.290	0.290	0.292

Notes: Variables descriptions are provided in Appendix Table . The estimations include a constant term, which is omitted for space considerations. Robust standard errors are in parentheses. *, ** and *** mean that the coefficient is statistically significant at 10%, 5% and 1% respectively.

TABLE IV: Aboriginal trade routes and channels of persistence

	Early Railways	Early Highways	Early Explorations
	(1)	(2)	(3)
Trade routes	0.0400**	0.0816***	0.1219***
	(0.0189)	(0.0275)	(0.0328)
Local Government F.E.	✓	✓	✓
Geographical & Historical controls	✓	✓	✓
N	3,519	3,519	3,519
R^2	0.552	0.456	0.303

Notes: Variables descriptions are provided in Appendix Table . The estimations include a constant term, which is omitted for space considerations. Robust standard errors are in parentheses. *, ** and *** mean that the coefficient is statistically significant at 10%, 5% and 1% respectively.

5 Further evidence for selection bias

As a final piece of evidence, we explore the possibility of selection bias in early European settlements. Indeed, an underlying argument in this paper is that Aborigines transmitted their knowledge of the landscape towards European explorers whom discoveries set the way to the establishment of early settlements in Australia. This suggests that European explorations should have largely followed Aboriginal trade routes and thus neglected other favorable environmental and topological conditions in line with their own navigation skills and knowledge.

To investigate the above issue, we use the dummy variable on early European explorations and regress it on our exogenous environmental, topological, and geographical measures. In Table V, the results suggest a positive relationship with agriculture suitability, elevation, ruggedness, and distance to the sea. Besides, we find negative relationship with precipitation, temperature, coastal dummy, and water percentage. Importantly, in all cases, the coefficients are negligible, thus suggesting that environment was not the primary criterion under which Europeans explored Australia.

6 Conclusion

In this paper, we document how the transmission of ancient cultural norms and practices affects present-day economic outcomes. We focus on the case of Australian colonisation where Europeans relied on the Aboriginal knowledge and practices of the landscape to explore and settle. By developing multiple tests, we show that regions with an Aboriginal trade route have a higher probability of observing more economic activity today in Australia. In line with the recent literature that explores the long-term effects of ancient trade routes, we provide evidence that the transport infrastructure that Europeans built to connect early settlements can explain the persistence of Aboriginal trade routes.

We view our results as an important contribution to enhance our understanding of the role of culture in shaping societal outcomes over the long-run. Every society has developed a unique set of cultural norms and knowledge which have allowed us to adapt and survive in different

environments. Indeed, while this bundle of ancient cultural norms and knowledge tends to persist and change throughout time, its transmission across societies can lead to its persistency as well and thus have important implications for economic outcomes over the long-run.

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Appendices

A Tables and Figures

TABLE A.I: Aboriginal trade routes and contemporary economic activity

	Dependent Variable: Population density			
	(1)	(2)	(3)	(4)
Trade routes	0.2107	0.2698**	0.2589*	0.2390**
	(0.1333)	(0.1366)	(0.1424)	(0.1188)
Latitude		0.0528	0.0322	-0.0001
		(0.0872)	(0.1582)	(0.2604)
Longitude		-0.1802	-0.1569	0.0582
		(0.1590)	(0.1559)	(0.3583)
Agriculture Suitability			-0.0274	-0.1602
			(0.1149)	(0.2683)
Elevation			0.0014	0.0029
			(0.0020)	(0.0019)
Ruggedness			0.0010	-0.0038
			(0.0078)	(0.0063)
Precipitation			0.0009	-0.0011
			(0.0013)	(0.0013)
StDev Precipitation			0.0040	0.0071**
			(0.0039)	(0.0028)
Temperature			0.0002	0.00135
			(0.0182)	(0.0150)
StDev Temperature			0.0079	0.0002
			(0.0882)	(0.0814)
Distance to the Sea				-0.0368**
				(0.0151)
Coastal Dummy				1.0626***
				(0.2221)
Distance to Sydney				0.0040
				(0.0373)
Distance to State Capital				0.0142
				(0.0092)
Distance to Historical Mine				-0.0709***
				(0.0150)
Water Percentage				0.0146
				(0.0190)
Local Government F.E.	✓	✓	✓	✓
N	3,519	3,519	3,519	3,519
R^2	0.652	0.658	0.662	0.695

Notes: Variables descriptions are provided in Appendix Table. The estimations include a constant term, which is omitted for space considerations. Robust standard errors are in parentheses

TABLE A.II: Aboriginal trade routes and contemporary economic activity: Homogeneous sample

	Dependent Variable: Binary dummy for night light				
	> 25% Precipitation	< 25% Temperature	Distance To Paths=200km	Distance To Paths=100km	Distance To Paths=50km
	(1)	(2)	(3)	(4)	(5)
Trade routes	0.0670**	0.0617**	0.0592**	0.0607**	0.0750***
	(0.0305)	(0.0304)	(0.0244)	(0.0249)	(0.0252)
Local Government F.E.	✓	✓	✓	✓	✓
Geographical & Historical controls	✓	✓	✓	✓	
N	2,645	2,637	3,451	3,216	2,726
R^2	0.425	0.476	0.420	0.424	0.419

Notes: Variables descriptions are provided in Appendix Table . The estimations include a constant term, which is omitted for space considerations. Robust standard errors are in parentheses. *, ** and *** mean that the coefficient is statistically significant at 10%, 5% and 1% respectively.

TABLE A.III: Aboriginal trade routes and contemporary economic activity: 10 X 10 km analysis

Dependent Variable:	Binary dummy for night light				Population density
	(1)	(2)	(3)	(4)	(5)
Trade routes	0.0564***	0.0616***	0.0577***	0.0479***	0.5940***
	(0.0120)	(0.0134)	(0.0086)	(0.0079)	(0.1071)
Local Government F.E.	✓	✓	✓	✓	✓
Geographical & Historical controls	✓	✓	✓	✓	
N	81,312	81,312	81,309	81,309	81,309
R^2	0.063	0.078	0.146	0.162	0.443

Notes: Variables descriptions are provided in Appendix Table . The estimations include a constant term, which is omitted for space considerations. Robust standard errors are in parentheses. *, ** and *** mean that the coefficient is statistically significant at 10%, 5% and 1% respectively.

FIGURE A.I: European exploration routes by Robinson (1927)

Notes: This map shows the European explorations routes as drawn by Robinson (1927).

(A) 1880

(B) 1890

(C) 1900

(D) 1920

FIGURE A.II: Maps of the railway network in Australia between 1880-1920.

Notes: This figure shows the development of railway infrastructure in Australia between 1880 and 1920.

FIGURE A.III: Highway network in Australia by 1950

Notes: This map shows the Highway network in Australia by 1950