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Landlockedness and Economic Development: Analyzing Subnational Panel Data and Exploring Mechanisms

Abstract

This paper revisits the hypothesis that landlocked regions are systematically poorer than regions with ocean access, using panel data for 1,527 subnational regions in 83 nations from 1950-2014. This data structure allows us to exploit within-country-time variation only (e.g., regional variation within France at one point in time), thereby controlling for a host of unobservables related to country-level particularities, such as a country's unique history, cultural attributes, or political institutions. Our results suggest lacking ocean access decreases regional GDP per capita by 10 - 13 percent. We then explore potential mechanisms and possible remedies. First, national political institutions appear to play a marginal role at best in the landlocked-income relationship. Second, the income gap between landlocked and non-landlocked regions within the same nation widens as i) GDP per capita rises, ii) international trade becomes more relevant for the nation, and iii) national production shifts to manufacturing. Finally, we find evidence consistent with the hypothesis that national infrastructure (i.e., transport-related infrastructure and rail lines) can alleviate the lagging behind of landlocked regions.

JEL-Codes: F430, H540, O180, O400, R120.

Keywords: landlockedness, geography, GDP per capita, trade openness, infrastructure.

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1 Introduction

Country-level studies on the effects of landlockedness on income levels generally produce a negative and statistically relevant relationship.[1] On average, lacking access to the sea is suggested to decrease GDP per capita by approximately 20 percent, holding other determinants constant (see, e.g., Redding and Venables, 2004; Freund and Bolaky, 2008; Putterman and Weil, 2010; UN-OHRLLS, 2013; Carmignani, 2015). To understand whether and, if so, *how* landlockedness may systematically be associated with diminished economic prosperity, researchers have largely been constrained to analyzing data on the *national* level. Thus, the corresponding studies cannot eliminate the possibility of unobservable country-specific characteristics driving results, such as national cultural particularities, historical events, or political institutions.

Analyzing *submational* data on the regional level permits us to isolate such dynamics: if landlockedness was indeed an independent determinant of income levels, we would expect landlocked regions within a country to systematically exhibit different income levels. Only recently have researchers turned their interest to the subnational level and derived comparable databases in extensive collection efforts.[2] Henderson et al. (2017) find night-time light intensity in coastal grid-cells to be 50 percent higher; Mitton (2016) studies a cross-sectional sample of regions around the world, suggesting that ocean access raises GDP per capita by nine percent.

We aim to contribute to that emerging literature in two ways. First, we analyze the effect of landlockedness on GDP per capita using *panel* data on the subnational level. This allows us to free the landlockedness-income relationship from any country-time-specific unobservables, i.e., anything that is unique for a specific nation and time period (e.g., France in 2010). Thus, national policies, culture, and any other nation-wide shocks are accounted for. To the best of our knowledge, this paper is the first to offer such level of statistical precision in analyzing

[1] A country or region is defined as landlocked if it lacks territorial access to the sea (UN-OHRLLS, 2016). Countries whose only coastlines lie on closed seas are also considered landlocked. Worldwide, there are 44 landlocked sovereign states, 32 of which are classified as "landlocked developing countries" by the United Nations (UN-OHRLLS, 2016).

[2] A notable early exception comes from Mellinger et al. (2000), who analyze the spatial distribution of global GDP, ignoring national borders. They suggest that 67.6 percent of global GDP is generated within 100km of the sea. An entire strand of research analyzes the general link between geography and income levels (e.g., see Redding and Venables, 2004, or Nordhaus, 2006, among many others).

the link between landlockedness and income levels. The corresponding results suggest that landlockedness decreases regional GDP per capita by 13 percent relative to non-landlocked regions in the same nation and time period. This link between landlockedness and regional GDP per capita remains statistically significant on the one percent level throughout our analysis, even after controlling for potentially confounding effects on the *regional* level, such as latitude, malaria ecology, oil and gas production, educational attainment, and population density.

We also explore at which development stages landlocked regions are particularly disadvantaged. Results from quantile regressions suggest that the within-country inequality between landlocked and non-landlocked regions *increases* with GDP per capita. In the poorest decile of our sample regions, a landlocked region is about 6.6 percent poorer than non-landlocked regions in the same nation. In the richest decile, on the other hand, a landlocked region is 14.6 percent poorer than non-landlocked regions in the same nation.

Our second contribution lies in an exploration of potential mechanisms regarding how landlockedness relates to GDP per capita. We begin by exploring the roles of several aspects of government with its political institutions, government size, government effectiveness, and federalism. Interestingly, the landlocked-income relationship appears to be largely uniform across those dimensions. As a next step, we turn to international trade and the sectoral distribution of a nation's production between agriculture, manufacturing, and services. Trade emerges as an important mechanism: a one standard deviation increase in national trade openness (i.e., raising the sum of exports and imports by 33 percent of GDP) leaves a landlocked region more than six percent poorer than a non-landlocked region. Similarly, raising the share of production coming from manufacturing by one standard deviation (equivalent to 5.3 percent of GDP) carries about the same effect.

Finally, we present evidence concerning a potential solution to the landlockedness curse. Our empirical results suggest that raising the quality of national transport-related infrastructure may be one way for landlocked regions to catch up to their domestic counterparts with ocean access. In terms of magnitude, a one standard deviation increase in the extent of railroad coverage as a proxy for infrastructure is associated with about a 8.2 percent increase in income levels for landlocked regions. Although this effect would not appear to be sufficient to completely close the gap to non-landlocked regions overall, these results are encouraging for policymakers aiming to improve the performance of landlocked regions.

The paper proceeds with a summary of our data and methodology, followed by a discussion of our main findings in Subsection 3.1. Subsections 3.2, 3.3, and 3.4 discuss our extensions and mechanisms. Finally, Section 4 concludes.

2 Data and Methodology

2.1 Data

In an enormous data collection effort, Gennaioli et al. (2014) provide information on GDP per capita and other variables at the subnational level, compiling a panel dataset for up to 1,527 regions in 83 nations from official statistical sources. Using these data, we take five-year averages of all variables, producing 13 time periods from 1950-1954 to 2010-2014. Regarding geographic coverage, Figure 1 shows that regions on all continents are included, although Africa remains under-represented. Noticeably, almost all Asian, South American, and Oceanian regions are included in the sample, as well as all of North America and Europe. We refer to Table A1 for a detailed list of sample nations included, along with their respective number of subnational regions and time periods.

We create three geographical variables using the information system *ArcGIS* to ensure exact geographic matching of the regions: a binary indicator for landlocked regions, distance to the coast, and length of coastline.[3] Of the 83 sample nations, 59 consist of landlocked *and* landlocked regions, whereas nine of them display no landlocked region and the remaining 15 nations are entirely landlocked.[4] In Table A1, we indicate those nations with both landlocked and non-

[3]Distance to coast is calculated as the shortest geodesic distance in 100km from a region's border to the national coastline in case of coastal countries, and the shortest distance to any coastline for landlocked countries. Gennaioli et al. (2014) also provide a measure for distance to the sea by taking the (inverse) distance from a region to *any* coastline – not the distance to a nation's own coastline. Given the obstacles associated with border-crossings, it seems more reasonable to measure distance to the own coastline where applicable.

[4]The nations displaying no landlocked regions are Denmark, Greece, Indonesia, Malaysia, Panama, Philippines, Portugal, the United Arab Emirates, and the United Kingdom. The nations consisting of *only* landlocked regions

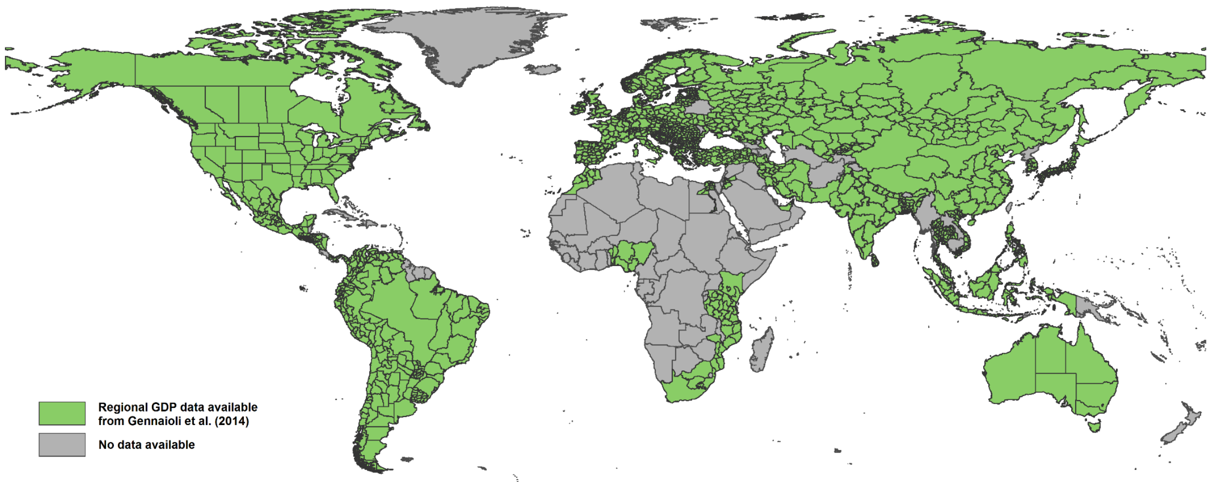

Figure 1: Data coverage from Gennaioli et al. (2014).

landlocked regions with an asterisk.

In our empirical analysis, we control for a comprehensive list of regional-level variables from Gennaioli et al. (2014) that could independently affect GDP per capita. Specifically, we include *i*) latitude, *ii*) malaria ecology, *iii*) population density, *iv*) average educational attainment, *v*) oil and gas production, and *vi*) a binary indicator for whether a nation's capital is located in the respective region. Summary statistics are referred to Table A2.

We wish to briefly explain the economic intuition for each control variable. First, latitude and malaria ecology are potentially relevant explanatory variables when investigating GDP per capita (e.g., see Sachs and Malaney, 2002, or Easterly and Levine, 2003). Second, population density can be interpreted as a proxy for access to the domestic market since a higher population density implies lower aggregated domestic transport costs (e.g., Boulhol et al., 2008, page 9). Third, educational attainment at the regional level provides an important covariate to account for the well-known effects of education in explaining GDP per capita (e.g., see Glaeser et al., 2004). Fourth, natural resources have been suggested as potential determinants of income levels (e.g., see Van der Ploeg, 2011, Gradstein and Klemp, 2016, or Van Der Ploeg and Poelhekke,

are Austria, Bolivia, the Czech Republic, Hungary, Kazakhstan, the Kyrgyz Republic, Lesotho, Macedonia, Mongolia, Nepal, Paraguay, Serbia, the Slovak Republic, Switzerland, and Uzbekistan.

2017), motivating the inclusion of regional oil and gas production. Finally, whether the region is home to the nation's capital carries potentially meaningful information regarding political relevance of the region, which could independently affect GDP per capita.

2.2 Methodology

Our empirical strategy uses a conventional OLS framework to predict the logarithm of GDP per capita, as is common in the associated literature. However, contrary to conventional cross-country analyses, our setting allows us to analyze *regional* GDP per capita and account for country-, time-, and country-time-specific heterogeneity via including a set of country-time-fixed effects.[5] Specifically, we explain GDP per capita of region r in country i and five-year time period t with

$$Ln(GDP/cap)_{i,r,t} = \beta(Landlocked)_{i,r,t} + \boldsymbol{X_{i,r,t}}\gamma + \omega_i + \lambda_t + \mu_{i,t} + \delta_{i,r,t}, \tag{1}$$

where $\boldsymbol{X_{i,r,t}}$ represents the vector of control variables discussed above. ω_i, λ_t, and $\mu_{i,t}$ introduce country-, time-, and country-time-fixed effects. Country-fixed effects control for any country-specific unobservables that do not change over time (e.g., the French history of political institutions or its nationwide legal system and cultural traits); time-fixed effects account for contemporary global phenomena (e.g., the Global Financial Crisis or technology shocks); country-time-fixed effects control for everything that is specific in a given country *and* time period (e.g., French institutions and national policies in the 2010-2014 period).[6] $\delta_{i,r,t}$ constitutes the usual error term and standard errors are clustered on the regional level throughout our analysis.

[5] We note that our data do not allow us to account for certain regional differences that may change over time (e.g., regional political institutions or regional cultural norms) apart from what is captured by our control variables.

[6] We acknowledge that national policies aimed at specific regions are not captured by country-time-fixed effects such as devolution of power to Scotland after the vote on Scottish independence. However, we explore national devolution policies by analyzing whether federalism mediates the role of landlockedness.

3 Empirical Findings

3.1 Main Results

Figure 2 visualizes how landlocked regions fare in terms of GDP per capita and economic growth, as opposed to regions that enjoy ocean access. On average, landlocked regions are over $3,000 poorer ($10,442 versus $13,552) and grow at 0.395 percentage points less than non-landlocked regions (2.463 versus 2.858 percent).

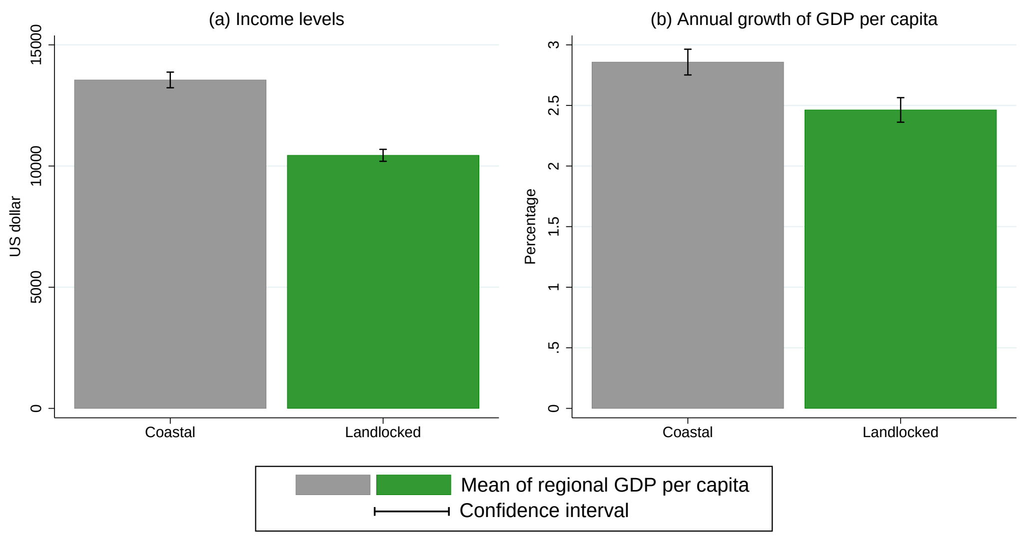

Figure 2: Economic performance in landlocked versus non-landlocked regions.

Table 1 displays our main findings, where we subsequently add control variables from columns (2) – (6), predicting regional GDP per capita. In column (1), we display results from a univariate regression, where only landlockedness is used to predict income levels. The derived coefficient suggests that a landlocked region is over 30 percent poorer than a non-landlocked region in our sample. In column (2), we add country-fixed effects and the coefficient drops by about one third to 19 percent. Incorporating time-fixed effects in column (3) then leaves the coefficient of interest virtually unchanged. Accounting for the additional covariates suggested in Section 2.2 further decreases the effect of landlockedness to -0.157.

The estimation displayed in column (5) presents our benchmark regression, where we control

Table 1: The effect of regional landlockedness on regional GDP per capita.

Dependent variable: Ln(regional GDP per capita)	(1)	(2)	(3)	(4)	(5)	(6)
Landlocked	-0.302***	-0.190***	-0.193***	-0.157***	-0.127***	-0.101***
	(0.062)	(0.027)	(0.027)	(0.020)	(0.019)	(0.022)
Distance to coast						-0.010***
						(0.004)
Length of coastline						0.000
						(0.001)
Country-fixed effects		yes	yes	yes	yes	yes
Time-fixed effects			yes	yes	yes	yes
Control variables[a]				yes	yes	yes
Country-time-fixed effects					yes	yes
# of regions	1,527	1,527	1,527	1,505	1,505	1,504
# of countries	83	83	83	81	81	81
N	9,472	9,472	9,472	7,504	7,504	7,494
Adjusted R^2	0.017	0.771	0.859	0.899	0.925	0.925

Notes: Standard errors clustered on the regional level are displayed in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. [a]Includes regional latitude, malaria ecology, the log of regional cumulative oil and gas production, a dummy variable indicating whether the nation's capital is in the region, regional years of education, and the log of regional population density. Moving from column (3) to (4), we lose all observations from Nepal and Uzbekistan (as well as individual observations from other nations) because of the unavailability of educational attainment data.

for country-, time-, and country-time-fixed effects, in addition to the discussed control variables. The coefficient associated with the binary indicator for landlockedness remains statistically significant on the one percent level and sharply different from zero with a t-value of 6.7. In terms of magnitude, landlocked regions are suggested to be 12.7 percent poorer, on average. This magnitude is somewhat lower than those suggested by parts of the cross-country literature, but higher than that produced by Mitton's (2016) cross-regional analysis.

Finally, in column (6), we include two additional variables related to ocean access: the shortest distance to the coast and the length of a region's coastline. The results suggest that distance matters, whereas it appears irrelevant *how much* ocean access a region enjoys. One interpretation of the latter finding relates to the idea that *any* access to the sea is sufficient, perhaps to facilitate trade via sea but we acknowledge that alternative interpretations are of course possible given our evidence so far. We will revisit the role of trade openness shortly in Section 3.4.

Before turning to our extensions, we also want to briefly mention the results of robustness checks and extensions that will not explicitly be discussed in the main part of the paper. In particular, our findings are virtually identical when accounting for the number of neighboring states or studying subsamples split by continent or time periods (Tables A3 and A4). In addition, incorporating regional area in km^2 as a covariate leaves our results virtually unchanged (results available upon request). Further, the relationship between landlockedness and GDP per capita is unlikely to suffer from omitted variable problems when investigating the relevance of selection on unobservables (see Table A5, following Oster, 2016).[7]

3.2 The Effect of Landlockedness Along Development Stages

It is possible that the link between landlockedness and regional GDP per capita changes along different development stages. For instance, studies focusing on prehistoric time periods suggest that societies could have *benefitted* from geographical isolation millennia ago (e.g., see Ashraf

[7] Oster (2016) suggests that δ values above one provide evidence for robustness. In our case, δ values range from 1.86 to 9.31.

et al., 2010). More specific to our setting and timeframe, landlockedness may carry differential effects along development paths.

To test for such dynamics, we employ a quantile regression approach. Specifically, we follow Koenker (2005) and investigate our benchmark estimation at the following points of the income distribution: the 10th, the 25th, the 50th, the 75th, and the 90th percentile. Note that, due to convergence constraints of the quantile regression methodology, we exclude country-time-fixed effects from these estimations, although country- and time-fixed effects are accounted for individually.

The corresponding results are displayed in Table 2 and Figure 3 visualizes the respective coefficients, along with their 95 percent confidence intervals. Column (1) of Table 2 and the first coefficient of Figure 3 display the corresponding OLS results for comparison. It is straightforward to see that the landlockedness effect becomes more relevant as regions become *richer*. In terms of magnitude, we move from a 6.6 percent penalty for landlocked regions at the 10th percentile over 10.6 percent at the median to 14.6 percent at the 90th percentile. Figure 3 shows that some of these coefficients are not only economically different from each other, but also statistically in terms of non-overlapping confidence intervals (e.g. the difference of the magnitude of the link between landlockness and GDP per capita at the 75th or 90th percentile to the 10th percentile). To better explore these differences, we now investigate political institutions, trade, and the sectoral distribution of production as potential mediators.

3.3 The Role of Political Institutions

While the above results provide us with more clarity as to when regional landlockedness is most detrimental for regional income levels, they remain less informative about potential mechanisms. To explore which national characteristics may mediate the link between regional landlockedness and GDP per capita, we now first investigate national political institutions. Following Acemoglu et al.'s (2001) reasoning on colonization patterns, Carmignani (2015) argues that landlocked countries did not offer favorable conditions for permanent settlements to colonizers.[8] As a

[8] Acemoglu et al. (2001) argue that colonization policies were determined by the feasibility of settlements. In regions where geographic conditions and the disease environment were favorable, the colonizers settled and built

Table 2: Results from quantile regressions to analyze whether the effect of landlockedness varies along the lines of income levels.

Dependent variable: Ln(regional GDP per capita)						
	(1) OLS	(2) Q 0.1	(3) Q 0.25	(4) Q 0.5	(5) Q 0.75	(6) Q 0.9
Landlocked	-0.157***	-0.066***	-0.093***	-0.106***	-0.125***	-0.146***
	(0.020)	(0.015)	(0.010)	(0.008)	(0.011)	(0.013)
Country- and time-fixed effects	yes	yes	yes	yes	yes	yes
Control variables[a]	yes	yes	yes	yes	yes	yes
N	7,504	7,504	7,504	7,504	7,504	7,504
Adjusted R^2	0.899					

Notes: Standard errors clustered on the regional level are displayed in parentheses in column (1). In columns (2) – (6), we display unclustered standard errors due to the specification constraints with the *bsqreg* command in Stata. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. [a]Includes regional latitude, malaria ecology, the log of regional cumulative oil and gas production, a dummy variable indicating whether the nation's capital is in the region, regional years of education, and the log of regional population density.

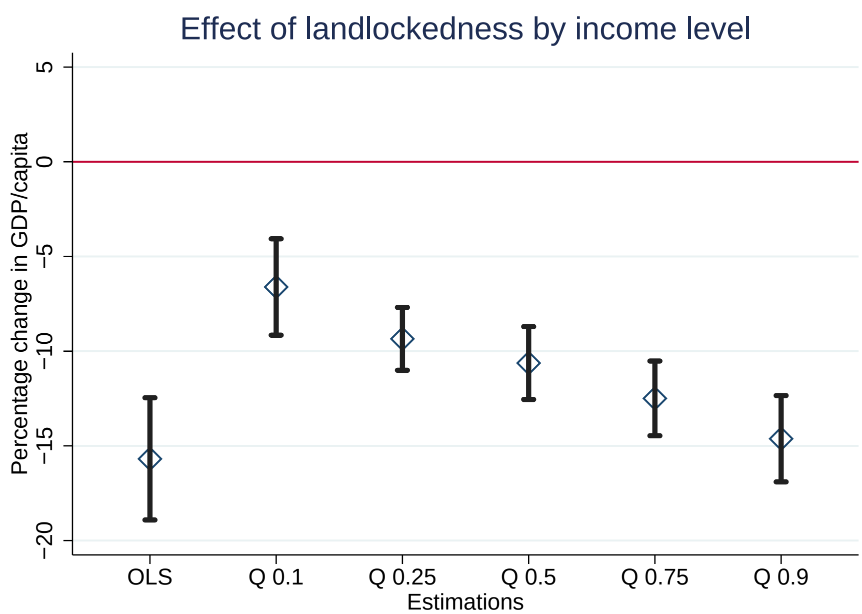

Figure 3: Visualizing results from quantile regressions with their respective 95% confidence intervals (see Table 2).

consequence, states without direct access to the sea were less likely to receive human capital and more prone to end up with 'extractive' or 'bad' institutions installed by the colonizers. As institutions endure over time and matter for economic outcomes (Acemoglu et al., 2001), development in landlocked countries could have been persistently impeded through this chain of causality. Naudé (2004, p.845) also hypothesizes that landlockedness hampers economic performance via the quality of institutions.

In Table 3, we return to the OLS structure and introduce interaction terms between *regional* landlockedness and several commonly used *national* indicators of political institutions: *i*) the *polity*2 variable from the Polity IV database (Marshall and Jaggers, 2017), measuring democratization; *ii*) the individual democracy and autocracy indicators; *iii*) government size (government expenditure as a share of GDP); *iv*) government effectiveness; as well as *v*) a binary indicator for federal nations. To allow the respective interaction terms sufficient statistical variation to develop, we again exclude country-time-fixed effects in these estimations, but still account for country- and time-fixed effects. Nevertheless, the corresponding results from incorporating country-time-fixed effects are consistent with the results displayed in Table 3 (see Table A6).

The results displayed in Table 3 show that the baseline effect of landlockedness on GDP per capita remains consistently negative and statistically significant. However, throughout the corresponding estimation results, we find little statistical evidence for any interactions and the economic magnitudes of the interactions remain negligible. Thus, the design of national political institutions *per se* does not present itself as a meaningful mediator for the landlockedness-income relationship on the subnational level. Only in column (4), when introducing government size, do we see a marginally significant effect – landlocked regions in nations with bigger governments appear to suffer less from diminished income levels. This result is consistent with an intuitive explanation of government spending acting as a redistributive tool between regions. However, a one standard deviation increase in government size (equivalent to 4.6 percent of GDP) merely raises the income levels of a landlocked region within a nation by 2.8 percentage points. Com-

up inclusive institutions. Conversely, in unfavorable environments where settler mortality was high, they set up extractive institutions.

Table 3: Exploring the role of political institutions in the effect of regional landlockedness on regional income levels. The variables *Polity IV*, *Democracy*, *Autocracy*, *Government size*, *Government effectiveness*, and *Federal* are measured on the national level.

Dependent variable: Ln(regional GDP per capita)	(1)	(2)	(3)	(4)	(5)	(6)
Landlocked	-0.186***	-0.194***	-0.145***	-0.234***	-0.158***	-0.164***
	(0.057)	(0.044)	(0.020)	(0.057)	(0.027)	(0.027)
Landlocked × Polity IV	0.002					
	(0.003)					
Landlocked × Democracy		0.007				
		(0.005)				
Landlocked × Autocracy			-0.002			
			(0.007)			
Landlocked × Government size				0.006*		
				(0.003)		
Landlocked × Government effectiveness					0.020	
					(0.021)	
Landlocked × Federal						0.012
						(0.039)
Respective institutional variable[a]	yes	yes	yes	yes	yes	yes
Country- and time-fixed effects	yes	yes	yes	yes	yes	yes
Control variables[b]	yes	yes	yes	yes	yes	yes
N	7,252	7,252	7,252	7,106	3,817	7,400
Adjusted R^2	0.905	0.905	0.904	0.900	0.917	0.898

Notes: Standard errors clustered on the regional level are displayed in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. [a]Indicates whether the respective institutional variable is included individually. In column (1): the *Polity IV* indicator; column (2): democracy; column (3): autocracy; column (4): government size; column (5): government effectiveness; column (6): federal. [b]Includes regional latitude, malaria ecology, the log of regional cumulative oil and gas production, a dummy variable indicating whether the nation's capital is in the region, regional years of education, and the log of regional population density.

pared to the 12.7 percent benchmark magnitude from column (5) of Table 1, this effect appears relatively modest. It is also noteworthy to point out that once country-time-fixed effects are accounted for, this result disappears (see Table A6, column 4).

3.4 Trade and Sectoral Distribution

From political institutions, we now move to international trade as a potential channel via which landlocked regions may be disadvantaged. For example, estimations of the gravity equation show that bilateral trade flows are significantly lower if one or both countries are landlocked (Frankel and Romer, 1999; Rose, 2004; Silva and Tenreyro, 2006; Chang and Lee, 2011). Although this result is a 'by-product' in most of these studies as they usually do not explicitly focus on the effect of landlockedness, it illustrates that regions with ocean access may naturally be able to benefit more from international trade opportunities. This hypothesis receives further support from the fact that approximately 90 percent of the global trade volume continues to be carried by sea (see IMO, 2017).[9] Consequently, landlocked economies may find it more difficult to realize gains from specialization and trade due to long distances to sea ports and higher transport costs via land or air (Sachs and Warner, 1997; Gallup et al., 1999; Faye et al., 2004; UN-OHRLLS, 2013). Geographic remoteness and high transport costs might also prevent nations from exploiting and exporting natural resources (Carmignani, 2015).

To test for such effects on the subnational level, and thereby taking advantage of the rich information contained in subnational data, we introduce an interaction term between national trade openness (commonly defined as $\frac{exports+imports}{GDP}$) and regional landlockedness in column (1) of Table 4. If trade was a possible channel, we would expect a negative and statistically significant coefficient. Indeed, we find support for this hypothesis: a one standard deviation increase in trade openness (equivalent to $\frac{exports+imports}{GDP} = 0.33$) is associated with an additional decrease in GDP per capita by as much as 6.3 percent for landlocked regions.

In columns (2) and (3), we then further distinguish by exports and imports, both measured

[9] While air shipment has gained importance over the last decades due to falling prices (Hummels, 2007), it remains four to five times more expensive than road transport and twelve to 16 times costlier than sea transport (World Bank, 2009; also see Arvis et al., 2007).

Table 4: Exploring the role of trade, the sectoral distribution (between agriculture, manufacturing, and service), and infrastructure in the effect of landlockedness on income levels.

Dependent variable: Ln(regional GDP per capita)	(1)	(2)	(3)	(4)	(5)	(6)
Landlocked	-0.062**	-0.065**	-0.076**	0.099	-0.524***	-0.231***
	(0.031)	(0.030)	(0.032)	(0.068)	(0.200)	(0.035)
Landlocked × Trade openness	-0.190***					
	(0.056)					
Landlocked × Exports (share in GDP)		-0.388***				
		(0.105)				
Landlocked × Imports (share in GDP)			-0.326***			
			(0.114)			
Landlocked × Manufacturing (share in GDP)				-1.362***		
				(0.352)		
Landlocked × Agriculture (share in GDP)				0.175		
				(0.175)		
Landlocked × Infrastructure					0.102*	
					(0.052)	
Landlocked × Rail lines per km^2						3.258***
						(0.904)
Respective additional variable[a]	yes	yes	yes	yes	yes	yes
Country- and time-fixed effects	yes	yes	yes	yes	yes	yes
Control variables[b]	yes	yes	yes	yes	yes	yes
N	7,177	7,073	7,073	5,364	488	5,335
Adjusted R^2	0.901	0.900	0.900	0.908	0.912	0.920

Notes: Standard errors clustered on the regional level are displayed in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. [a]Indicates whether the additional variable is included. In column (1): trade openness; column (2): exports; column (3): imports; column (4): manufacturing and agriculture (individually included); column (5): infrastructure; column (6): rail lines per km^2. [b]Includes regional latitude, malaria ecology, the log of regional cumulative oil and gas production, a dummy variable indicating whether the nation's capital is in the region, regional years of education, and the log of regional population density.

as shares of GDP. The corresponding results are suggestive of both trade directions playing meaningful roles. Note that the corresponding results are statistically consistent when including country-time-fixed effects, albeit magnitudes decrease by approximately one third (see Table A7).

Further, it is possible that the sectoral distribution of production between agriculture, manufacturing, and services can alter the link between landlockedness and GDP per capita. For example, in largely agricultural nations, a landlocked region may not be as disadvantaged. However, as manufacturing becomes more important, regional development patterns might change and ocean access may gain importance for transportation, among other reasons. To explore such heterogeneity, we include interaction terms between the regional landlocked indicator and national shares of production in agriculture and manufacturing (with the share of services providing the reference point). The corresponding results, displayed in column (4), support the hypothesis that the sectoral makeup of a nation's economy influences the landlocked-income link (also see Henderson et al., 2017). In fact, a region in a hypothetical nation that does not manufacture at all would, if anything, enjoy a marginally *higher* GDP per capita than the other regions in that same nation (although the corresponding coefficient of 0.099 is not statistically distinguishable from zero). Then, as the share of manufacturing rises, landlocked regions fall behind.

3.5 Infrastructure To The Rescue?

In our final estimations, we now ask what could be done to alleviate the effect of regional landlockedness. Specifically, if trade and manufacturing are indeed important characteristics, then improved national infrastructure through transport links may be able to mitigate the detrimental role of landlockedness as transportation to the coast would be facilitated (e.g., see Limao and Venables, 2001). To check for such dynamics, column (5) tests whether interacting *landlocked* with a nation's *Logistics performance index* (measuring the quality of trade and transport-related infrastructure; taken from the World Bank Group, 2017) enhances our benchmark finding. Note that this index is only available for the 2010-2014 time period, which means we resort to measuring within-country variation only in a purely cross-sectional setting. Indeed, a one standard deviation increase in this infrastructure index (0.76 points) alleviates the effect of landlockedness on income levels, resulting in 7.8 percent less of a decrease in GDP per capita. Nevertheless, such a change does not compensate for the sizeable base effect of landlockedness.

Finally, in column (6) we use information about rail lines, measured in km per km^2. The corresponding data from the World Bank Development Indicators (World Bank Group, 2017) are available from 1980 to 2014, which gives us the opportunity to conserve over 71 percent of our initial observations (5,335 of 7,504 data points). Again, the respective results are promising and landlocked regions in nations with better rail connections are less disadvantaged, relative to non-landlocked regions in the same nation and time period. These results are consistent when introducing country-time-fixed effects, although magnitudes, again, decrease by approximately one third (see column 6 of Table A7).

To put the corresponding results in perspective, Figure 4 plots the effects implied by the interaction terms for a one standard deviation increase of trade openness, manufacturing, and the two infrastructure measures on income levels for landlocked regions. It is interesting to see that, in terms of magnitude, improving national infrastructure by one standard deviation approximately compensates for the effects from a one standard deviation increase in trade openness or the share of manufacturing in production.

These results are also notable when compared to those from considering broad political institutions (see Table 3). Although democracy, a larger government, or a more effective public sector appear unlikely to mediate the landlockedness-income relationship, infrastructure may present a fruitful avenue for policymakers to close the income gap between landlocked and non-landlocked regions within a nation.

4 Conclusion

This paper aims to enrich our understanding of whether and, if so, how landlockedness can explain differences in income levels. Using panel data for 1,527 subnational regions in 83 nations

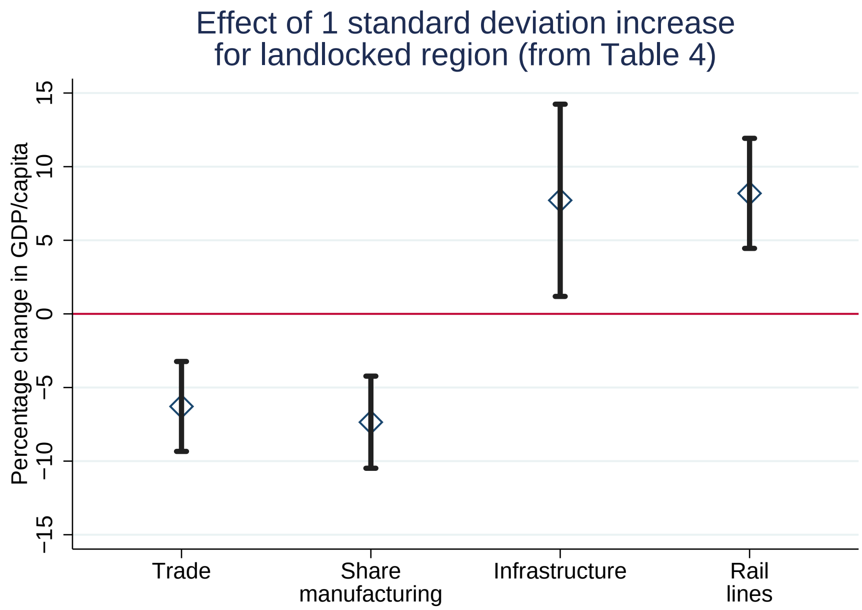

Figure 4: Visualizing results from extensions displayed in columns (1), (4), (5), and (6) of Table 4, displaying the effect of a one standard deviation increase of the respective variables on GDP per capita for landlocked regions. 95% confidence intervals are displayed.

from 1950–2014 allows us to control for country-, time-, and country-time-fixed effects for the first time in the literature.

Our results suggest that, on average, landlocked regions are 10–13 percent poorer than non-landlocked regions in the same nation and same time period. This magnitude is marginally smaller than in most cross-country studies. However, it is noteworthy to point out that several obstacles landlocked *nations* face, such as the dependence on transit neighboring countries, should be less relevant for landlocked *regions* within coastal nations. Consequently, a negative effect of landlockedness at the regional level likely remains a lower-bound estimation of the adverse impacts of national landlockedness.

Interestingly, as regions become richer, the gap between landlocked and non-landlocked regions within the same nation *increases*. A region in the 10th percentile of income levels is only 6.6 percent poorer than their non-landlocked counterparts in the same nation, whereas that magnitude rises to 14.6 percent for regions within the 90th percentile.

We then turn to potential mediators and mechanisms, exploring national political institutions and the extent of international trade. Surprisingly, the landlockedness-income relationship appears largely uniform along political dimensions, prevailing with a statistically indistinguishable magnitude in democracies and autocracies alike. We find quantitatively small effects suggesting larger governments could alleviate the effect, but government effectiveness and federalism do not present themselves as meaningful factors to influence the landlockedness-income link.

However, trade openness does seem to matter: as a nation trades more with the rest of the world, the gap between its landlocked and non-landlocked regions widens. The same is true once production shifts to manufacturing. In terms of magnitude, a one standard deviation increase in either variable (trade openness relative to GDP; share of manufacturing in GDP) widens the gap by 6.3 and 7.4 percent, respectively.

Finally, we investigate national infrastructure as one possible remedy. Indeed, we find quantitatively sizeable effects from improving transport-related infrastructure and rail connectivity. These results are consistent with the hypothesis of infrastructure being an important determinant of transport costs, especially for landlocked areas (Limao and Venables, 2001; Nordås and Piermartini, 2004). A back-of-the-envelope calculation suggests that a one standard deviation improvement in either of these infrastructure indices would absorb the effects from a one standard deviation rise in trade openness or manufactured output.

Overall, we hope that these results help to improve our understanding about whether and specifically how landlockedness could be associated with economic development, both in general and with respect to subnational regions. In further research, it may be interesting to investigate more detailed measures for regional infrastructure to explore how landlocked regions may be able to catch up to their non-landlocked counterparts.

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A1 Tables

Table A1: Sample countries with the total number of five-year time periods and regions per time period. An asterisk indicates the nation consists of landlocked *and* non-landlocked regions.

Country	Periods	Regions	Country	Periods	Regions	Country	Periods	Regions
Albania *	3	12	India *	7	27	Poland *	5	15
Argentina *	6	24	Indonesia	5	26	Portugal	8	5
Australia *	7	8	Iran, Islamic Rep. *	3	25	Romania *	4	42
Austria	11	9	Ireland *	7	7	Russian Federation *	4	77
Bangladesh *	4	20	Italy *	9	20	Serbia	2	25
Belgium *	7	9	Japan *	11	46	Slovak Republic	4	8
Benin *	3	6	Jordan *	3	12	Slovenia *	5	12
Bolivia	7	9	Kazakhstan	5	14	South Africa *	9	4
Bosnia and Herzegovina *	2	12	Kenya *	2	5	Spain *	7	50
Brazil *	13	19	Korea, Rep. *	6	13	Sri Lanka *	5	9
Bulgaria *	5	28	Kyrgyz Republic	3	7	Sweden *	6	21
Canada *	12	9	Latvia *	3	26	Switzerland	10	24
Chile *	10	13	Lesotho	3	6	Tanzania *	7	20
China *	12	27	Lithuania *	4	10	Thailand *	7	72
Colombia *	12	24	Macedonia, FYR	5	8	Turkey *	6	61
Croatia *	4	21	Malaysia *	8	12	Ukraine *	3	26
Czech Republic	4	14	Mexico *	9	32	United Arab Emirates	5	7
Denmark	9	5	Mongolia	5	20	United Kingdom	7	10
Ecuador *	3	21	Morocco *	4	7	United States *	13	51
Egypt, Arab Rep. *	3	21	Mozambique *	4	10	Uruguay *	4	19
El Salvador *	3	14	Nepal	2	5	Uzbekistan	3	12
Estonia *	4	15	Netherlands *	6	11	Venezuela, RB *	5	23
Finland *	8	5	Nicaragua *	3	7	Vietnam *	5	39
France *	12	21	Nigeria *	2	4			
Germany, East *	5	5	Norway *	6	19			
Germany, West *	11	10	Pakistan *	8	4			
Greece	9	8	Panama	4	9			
Guatemala *	3	22	Paraguay	3	18			
Honduras *	4	16	Peru *	9	23			
Hungary	4	20	Philippines	7	7			

Table A2: Summary statistics for all variables. All variables are averaged over 5-year periods (e.g., 2010-2014). For more details regarding Gennaioli et al.'s (2014) variables, we refer to their Table 11.

Variable	Mean	(Std. Dev.)	Min.	Max.	N	Source	Description
Regional GDP per capita	11,857	(11,882)	189	166,007	9,472	Gennaioli et al. (2014)	Ln(regional GDP per capita)
Landlocked	0.545	(0.498)	0	1	9,472	own	= 1 if region is landlocked
Latitude	33.501	(16.471)	0.022	69.954	9,472	Gennaioli et al. (2014)	Latitude of the centroid of each region calculated in ArcGIS
Malaria ecology	1.09	(2.724)	0	28.683	9,472	Gennaioli et al. (2014)	Malaria ecology index from Gennaioli et al. (2014) and Kiszewski et al. (2004)
Oil & gas production	0.001	(0.007)	0	0.122	7,504	Gennaioli et al. (2014)	Ln(Cumulative oil, gas and liquid natural gas production, measuring the fraction of the petroleum assessment areas within the region)
Capital	0.05	(0.218)	0	1	7,504	Gennaioli et al. (2014)	= 1 if nation's capital city is in region
Years of education	7.212	(3.251)	0.388	13.757	7,504	Gennaioli et al. (2014)	Average years of schooling from primary school onwards for the population aged 15 years or older
Population density	4.022	(1.726)	-4.646	10.009	7,504	Gennaioli et al. (2014)	Ln(population per regional area, in square kilometers)
Distance to coast	1.676	(3.049)	0	20.993	7,494	own	Shortest geodesic distance in 100km from region's border to national coastline or shortest distance to any coastline for landlocked countries
Length of coastline	3.71	(15.629)	0	269.48	7,494	own	Measured in 100km
Polity IV	15.94	(5.568)	1	20	7,252	Marshall and Jaggers (2017)	Variable *polity2*, re-scaled to run between 0 (total autocracy) and 20 (total democracy)
Democracy	7.11	(3.415)	0	10	7,252	Marshall and Jaggers (2017)	Variable *democ*, measuring institutionalized democracy on an additive eleven-point scale
Autocracy	1.17	(2.326)	0	9	7,252	Marshall and Jaggers (2017)	Variable *autoc*, measuring institutionalized autocracy on an additive eleven-point scale
Government size	14.643	(4.561)	4.724	35.845	7,106	World Bank Group (2017)	General government final consumption expenditure (% of GDP)
Government effectiveness	0.437	(0.9)	-1.016	2.244	3,817	World Bank Group (2017)	Government Effectiveness: Estimate
Federal	0.355	(0.478)	0	1	7,400	Jetter and Parmeter (2017)	= 1 if country has federal structure
Trade	0.533	(0.331)	0.092	2.204	7,177	World Bank Group (2017)	Trade openness, measured as $\frac{exports+imports}{GDP}$
Export (share in GDP)	0.262	(0.171)	0.044	1.198	7,073	World Bank Group (2017)	Exports of goods and services (% of GDP)
Imports (share in GDP)	0.271	(0.168)	0.042	1.006	7,073	World Bank Group (2017)	Imports of goods and services (% of GDP)
% manufacturing	0.203	(0.054)	0.055	0.357	5,364	World Bank Group (2017)	Manufacturing, value added (% of GDP)
% agriculture	0.112	(0.096)	0.007	0.471	5,364	World Bank Group (2017)	Agriculture, value added (% of GDP)
Logistics	3.266	(0.757)	2.3	4.25	488	World Bank Group (2017)	Logistics performance index: Quality of trade and transport-related infrastructure
Rail lines per km^2	0.026	(0.025)	0.001	0.121	5335	World Bank Group (2017)	Rail lines (total route-km) divided by country area in km^2

Table A3: Various robustness checks, re-estimating column (4) of Table 1. Column (1) controls for the number of neighboring states; columns (2) – (5) focus on regional subsamples; columns (6) and (7) analyze federal and non-federal states individually.

Dependent variable: Ln(regional GDP per capita)							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Sample:		Africa	Asia	Europe	Americas	Federal nations	Non-federal nations
Landlocked	-0.129^{***}	-0.105	-0.207^{***}	-0.094^{***}	-0.049	-0.145^{***}	-0.111^{***}
	(0.018)	(0.064)	(0.039)	(0.024)	(0.031)	(0.028)	(0.025)
# of neighbor states	0.013						
	(0.012)						
Country- and time-fixed effects	yes	yes	yes	yes	yes	yes	yes
Country-time-fixed effects	yes	yes	yes	yes	yes	yes	yes
Control variables[a]	yes	yes	yes	yes	yes	yes	yes
N	7,504	252	2,372	2,603	2,277	2,625	4,775
Adjusted R^2	0.925	0.895	0.906	0.906	0.902	0.933	0.916

Notes: Standard errors clustered on the regional level are displayed in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. [a]Includes regional latitude, malaria ecology, the log of regional cumulative oil and gas production, a dummy variable indicating whether the nation's capital is in the region, regional years of education, and the log of regional population density.

Table A4: Re-estimating column (4) of Table 1 for individual time periods.

Dependent variable: Ln(regional GDP per capita)	(1)	(2)	(3)	(4)	(5)	(6)
Time:	1950-1955	1960-1965	1970-1975	1980-1985	1990-1995	2000-2005
Landlocked	-0.212	-0.111***	-0.089***	-0.117***	-0.114***	-0.135***
	(0.173)	(0.040)	(0.026)	(0.027)	(0.022)	(0.022)
Country-, time-, and country-time-fixed effects	yes	yes	yes	yes	yes	yes
Control variables I[a]	yes	yes	yes	yes	yes	yes
N	70	494	814	1,329	2,156	2,153
Adjusted R^2	0.739	0.862	0.923	0.937	0.930	0.923

Notes: Standard errors clustered on the regional level are displayed in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.
[a]Includes regional latitude, malaria ecology, the log of regional cumulative oil and gas production, a dummy variable indicating whether the nation's capital is in the region, regional years of education, and the log of regional population density.

Table A5: Oster (2016) tests: Potential bias from unobservables.

Uncontrolled model	*Panel A: Univariate*			*Panel B: Univariate with Fixed Effects*		
Proportional selection assumption $\tilde{\delta}$	0.5	0.75	1	0.5	0.75	1
Uncontrolled $\dot{\beta}$	-0.30	-0.30	-0.30	-0.19	-0.19	-0.19
Controlled $\tilde{\beta}$	-0.13	-0.13	-0.13	-0.13	-0.13	-0.13
Uncontrolled $\dot{R^2}$	0.02	0.02	0.02	0.86	0.86	0.86
Controlled $\tilde{R^2}$	0.93	0.93	0.93	0.93	0.93	0.93
Bounding set Δ_s	[-0.13; -0.12]	[-0.13; -0.12]	[-0.13; -0.11]	[-0.13; -0.09]	[-0.13; -08]	[-0.13; -0.06]
Zero excluded from Δ_s?	yes	yes	yes	yes	yes	yes
δ for which $\beta = 0$	9.31	9.31	9.31	1.86	1.86	1.86

Notes: In *Panel A*, the uncontrolled $\dot{\beta}$ and the uncontrolled $\dot{R^2}$ are taken from a regression only controlling for landlockedness, whereas for *Panel B* they are taken from a regression controlling for landlockedness and country-fixed effects. The controlled $\tilde{\beta}$ and the controlled $\tilde{R^2}$ always include the full set of control variables from Table 1, specification (4). We assume $R_{max} = 1$ in all calculations.

Table A6: Replicating Table 3, including country-time-fixed effects. Exploring the role of political institutions in the effect of regional landlockedness on regional income levels. The variables *Polity IV*, *Democracy*, *Autocracy*, *Government size*, *Government effectiveness*, and *Federal* are measured on the national level.

Dependent variable: Ln(regional GDP per capita)	(1)	(2)	(3)	(4)	(5)	(6)
Landlocked	-0.173***	-0.159***	-0.117***	-0.171***	-0.144***	-0.121***
	(0.063)	(0.048)	(0.020)	(0.058)	(0.027)	(0.025)
Landlocked × Polity IV	0.003					
	(0.004)					
Landlocked × Democracy		0.005				
		(0.006)				
Landlocked × Autocracy			-0.007			
			(0.009)			
Landlocked × Government size				0.003		
				(0.003)		
Landlocked × Government effectiveness					0.009	
					(0.022)	
Landlocked × Federal						-0.022
						(0.036)
Country- and time-fixed effects	yes	yes	yes	yes	yes	yes
Control variables[a]	yes	yes	yes	yes	yes	yes
N	7,252	7,252	7,252	7,106	3,817	7,400
Adjusted R^2	0.926	0.926	0.926	0.924	0.923	0.924

Notes: Standard errors clustered on the regional level are displayed in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.
[a]Includes regional latitude, malaria ecology, the log of regional cumulative oil and gas production, a dummy variable indicating whether the nation's capital is in the region, regional years of education, and the log of regional population density.

Table A7: Replicating Table 4, including country-time-fixed effects [with the exception of column (5), as infrastructure is only available for the 2010-2014 time period]. Exploring the role of trade, the sectoral distribution (between agriculture, manufacturing, and service), and infrastructure in the effect of landlockedness on income levels.

Dependent variable: Ln(regional GDP per capita)	(1)	(2)	(3)	(4)	(5)	(6)
Landlocked	-0.068**	-0.070**	-0.078**	0.118	-0.524***	-0.185***
	(0.031)	(0.030)	(0.033)	(0.076)	(0.200)	(0.035)
Landlocked × Trade openness	-0.121**					
	(0.060)					
Landlocked × Exports (share in GDP)		-0.252**				
		(0.112)				
Landlocked × Imports (share in GDP)			-0.206*			
			(0.122)			
Landlocked × Manufacturing (share in GDP)				-1.346***		
				(0.397)		
Landlocked × Agriculture (share in GDP)				0.154		
				(0.178)		
Landlocked × Infrastructure					0.102*	
					(0.052)	
Landlocked × Rail lines per km^2						2.029**
						(0.910)
Country- and time-fixed effects	yes	yes	yes	yes	yes	yes
Country-time-fixed effects	yes	yes	yes	yes		yes
Control variables[a]	yes	yes	yes	yes	yes	yes
N	7,177	7,073	7,073	5,364	488	5,335
Adjusted R^2	0.924	0.923	0.923	0.923	0.912	0.932

Notes: Standard errors clustered on the regional level are displayed in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.
[a]Includes regional latitude, malaria ecology, the log of regional cumulative oil and gas production, a dummy variable indicating whether the nation's capital is in the region, regional years of education, and the log of regional population density.