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THE WEB OF TRANSPORT CORRIDORS IN SOUTH ASIA

Background Paper

Wider Economic Benefits of Transport Corridors

Evidence from International Development Organizations

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Abstract

This paper collects meta data on transport corridor projects financed by the Asian Development Bank, Japan International Cooperation Agency, and World Bank and links them to one important wider economic benefit—local economic activity. The meta data cover 47 projects in 16 countries, with appraisal dates between 1991 and 2007. First, the paper reviews the variation in project design and implementation—including the local initial conditions, complementary non-transport interventions, and private sector involvement. Second, using the difference-in-differences methodology, the paper links this variation to a measure of local economic activity—the geocoded intensity of nighttime lights. The effect of the supported corridor projects on local economic activity could be very heterogenous and significantly depend on certain initial conditions and project characteristics. The latter could include locations with access to the sea, as well as projects with a strong theory of change and better engagement of the private sector.

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Wider Economic Benefits of Transport Corridors:

Evidence from International Development Organizations[*]

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1. Introduction

The number of ongoing and proposed initiatives for transport corridors is increasing. One ambitious proposal is to revive the Grand Trunk Road from Kabul, Afghanistan, to Chittagong, Bangladesh, connecting areas that are home to a significant share of the world's poor. An even more ambitious initiative is the Belt and Road Initiative proposed by China, which aims to improve connectivity and cooperation on a transcontinental scale through significant infrastructure investments around the Silk Road Economic Belt and the New Maritime Silk Road (World Bank 2019).

Developing large transport corridors is increasingly seen as a way to stimulate regional integration and economic growth. Countries, often with the help of the international community, invest in these corridors hoping to boost private sector investments and trade, create jobs, and improve economic welfare. However, these wider economic benefits (WEBs) go beyond the user benefits—that is, savings in vehicle operating costs and travel time—of the specific transport improvements, which are usually the focus of appraisal of transport corridors (ADB, DFID, JICA, and World Bank 2018; Laird and Venables 2017).

Interest in studying the WEBs of large transport infrastructure projects is growing (Behrens, Brown, and Lonla 2016; Redding and Turner 2015).[1] Attention is turning to economic benefits that go beyond trade and efficiency gains at the aggregate level, to consider benefits that reach not only large national and international economic actors (corporations and foreign traders), but also smaller and more localized ones (micro, small, and medium-size enterprises), as well as poorer people. The interest has been propelled in part by the increasing number of transport corridor initiatives justified based on their potential but uncertain WEBs.

The literature on the WEBs of corridors typically looks at a single corridor to assess impacts. However, there is much to learn from differences across projects and the resulting variation in the design and implementation of transport investment projects and the practitioners working on them. This paper aims to shed light on the link between project design and implementation and WEBs and help bridge the divide between the academic literature on WEBs and the practical project design and appraisal.

The paper assesses which design and implementation characteristics of transport corridor projects and country characteristics could help maximize the WEBs from transport corridors. To analyze this question, we collected data on transport corridor projects supported by three international development organizations: the Asian Development Bank (ADB), the Japan International Cooperation Agency (JICA), and the World Bank.

The paper contributes to two strands of the literature. One strand focuses on estimating the WEBs of large transport infrastructure, using detailed locational data. Several studies summarize the estimated impacts of transport infrastructure investments and applied estimation approaches using qualitative approaches (Berg et al. 2017; Redding and Turner 2015; Straub 2011) or quantitative methods, such as systematic reviews and meta-analyses (Melo, Graham, and Brage-Ardao 2013; Roberts et al. forthcoming). The literature estimates that, on average, the impacts of corridor investments on economic welfare and equity tend to be beneficial, although they are often detrimental for environmental quality. Roberts et al. (forthcoming) highlight that, around this positive average impact, the local impacts could vary widely depending on the

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[1] For a review of the literature, see Roberts et al. (forthcoming).

initial local conditions of markets and institutions.[2] This paper contributes to this literature by studying the role of project design and implementation characteristics as well as heterogenous effects depending on local initial conditions.

Another strand of the literature studies the performance of projects supported by international development organizations. Several studies analyze the macro and micro determinants of World Bank projects (Denizer, Kaufman, and Kraay 2013) and the performance of ADB projects and programs (Feeny and Vuong 2017). Other studies analyze the determinants of success for selected projects of other international development organizations, such as the African Development Bank (Mubila, Lufumpa, and Kayizzi-Mugerwa 2000). However, these studies do not focus on large investments in transport corridors and their particular challenges, such as geographic specificity and the net economic benefits in their vicinity as well as further away. This paper contributes to the literature on development projects supported by international organizations by highlighting the aspects of project design and implementation that could matter the most for the success of large transport investments.

The analysis focuses on answering three main questions. Which design and implementation characteristics of transport corridors made them more successful in generating WEBs? Which country contexts helped spur local economic activity and generate WEBs? Which complementary policies and institutions—such as development policy reforms—can help ensure and amplify WEBs?

We find that certain initial conditions and project characteristics can help determine whether increased connectivity through a transport corridor will spur economic activity around the corridor. Large transport infrastructure investments in countries that have direct access to the sea are more likely to spur economic activity. Similarly, some project design characteristics can better stimulate local economic activity than others. For instance, projects with a strong rationale or theory of change can generate significantly more economic activity in the surrounding areas. Although consulting on the project design with the private sector could generate higher WEBs, involving the private sector in the project implementation has so far dampened local economic activity. Our evidence on the role of complementary policies and reforms is inconclusive and requires further research for more robust conclusions.

The remainder of the paper is structured as follows. Section 2 sets out a simple canonical model to conceptualize how transport corridor investments can lead to WEBs. Section 3 describes the data. Section 4 presents the empirical approach. Section 5 reports the results of the analysis, and section 6 concludes.

2. Framework

To motivate and structure the analysis, we adopt the following simple canonical model. The model summarizes the problem that a benevolent policy maker faces when trying to maximize the WEBs (net of costs) of a potential corridor (see also Roberts et al. 2018)[3]:

$$\max_{R}\{Y'Y - \mathrm{j}(R - \bar{R})\} \quad (1)$$

[2] For instance, Roberts et al. (2012) report that the construction of the NEN increased real income across Chinese prefectures by, on average, just less than 4 percent. However, in a fair number of prefectures, the construction had a negative impact on real wages in the urban and rural sectors.

[3] By assuming a benevolent policy maker, in effect, we assume that the problem that he or she faces is equivalent to that of a social planner.

where R is a column vector of corridor characteristics (such as location, length, and mode of transport) plus "complementary" policies and institutions that might help to amplify the targeted WEBs captured by the vector Y.[4] Note that $\text{j}(R - \bar{R})$ represents the cost of the new transport corridor intervention package including trunk transport infrastructure, transport and trade facilitation measures, as well as complementary market policies and cross-cutting institutions. It is assumed that this cost increases with the distance between the new set of policies, R, and the preexisting set of policies, $\bar{R}$.[5] For simplicity, we abstract here from time notation, because the problem can be readily translated into a maximization problem with a finite or infinite time horizon.[6] We also abstract from cross-sectional notation, because the underlying relationships presented here can hold at different levels of aggregation: local (for instance, subnational units such as districts and counties), national, and transregional (for instance, the population of India and Bangladesh in the neighborhood of a potential corridor spanning the two countries).

The first constraint to this optimization describes how R influences Y, along with other structural factors, X, that can interact with (conditionally increase or decrease) the effect of R on Y:

$$Y = f(R, X) \tag{2}$$

The WEBs, Y, can be affected by corridors (and their vector of characteristics) directly, conditional on other structural factors, X. These other structural factors may include initial conditions in local product and factor (land, labor, and capital) markets. The function $f(.)$ describes this direct conditional mapping between R and allows for various types of nonlinearities, including simple interactions of variables.[7] The impact of R on Y can vary from beneficial to detrimental across individual outcomes in the vector Y. Essentially, $f(.)$ subsumes a covariance matrix that is lower triangular and captures potential trade-offs and synergic impacts of R on Y. The off-diagonal elements (co-variances) could thus be negative, close to zero, or positive.[8]

The structural factors, X, can themselves be affected by R. For instance, if the corridor reduces commuting and migration costs, it also reduces frictions in the labor market. This set of constraints to the optimization can be written as:

$$X = g(R, \bar{X}) \tag{3}$$

where $\bar{X}$ is the initial value of X before the corridor intervention and $g(\cdot)$ describes the conditional mapping of R onto X. Again, this mapping can be nonlinear, including the interaction between X and R. And the impact of R on X can vary from beneficial to detrimental across individual variables in vector X. Basically, $g(\cdot)$ subsumes a covariance matrix that is lower triangular and captures potential trade-offs and synergic impacts of R on X. Solving equations (1) to (3) for R then gives an "optimized policy rule." This optimized

[4] In principle, the vector Y can contain a consumption-based utility function, as is commonly used in welfare analysis.

[5] The preexisting set of policies is captured by R. R also captures, for example, if there is preexisting transport infrastructure on which the new corridor builds. For example, the cost of the intervention is likely to be less if it is based on the upgrading of a previous road or railway line.

[6] Abstracting from time notation allows us to avoid discussion of discount rates, which ultimately adds the unnecessary complexity of stochastic discount factors based on pricing kernels contingent on the state of the economy (Cochrane 2009).

[7] Nonlinearities can occur when, for example, the impact on real output of a decline in transport costs induced by the construction of a corridor contains threshold effects. The existence of such nonlinearities is predicted by new economic geography models (Krugman 1991a, 1991b; Fujita, Krugman, and Venables 1999).

[8] Underlying the relationship between R and Y are a set of "immediate outcomes," which consist of direct impacts of R on, for example, travel times and vehicle operating costs, which, in turn, influence Y.

policy rule specifies the set of corridor characteristics and associated complementary policies (that is, the "corridor intervention package"), R^*, that the policy maker should adopt in response to any given set of initial conditions to maximize the net WEBs:

$$R^* = h(\bar{X}, \bar{R}) \tag{4}$$

Although some aspects of the optimal corridor intervention package, R^*, may be needed for net WEBs to materialize regardless of the initial conditions, other features of the package will work best, or only be needed, under certain initial conditions, which include the preexisting transport network, $\bar{R}$. For instance, if a transport corridor is constructed within a setting that is characterized by poorly functioning land markets, then accompanying land market reforms may be needed for the WEBs to be fully realized and distributed equitably. By contrast, such reforms are unlikely to be needed if the corridor is instead constructed in a setting characterized by well-functioning land markets. Similar considerations apply to the need for reforms in other key markets, including product, labor, and capital markets, as well as cross-cutting institutions such as public sector governance.

For concreteness, we define R, Y, and X using the coverage that will be considered in the empirical analysis:

$$R \stackrel{\text{def}}{=} \begin{bmatrix} \text{location} \\ \text{connections} \\ \text{transport mode} \\ \text{private sector role} \\ \vdots \\ \text{market policies} \\ \text{institutions} \end{bmatrix}; X \stackrel{\text{def}}{=} \begin{bmatrix} H - \text{land} \\ L - \text{labor} \\ K - \text{capital} \\ A - \text{product} \end{bmatrix}; \quad Y \stackrel{\text{def}}{=} \begin{bmatrix} \text{economic welfare} \\ \text{social inclusion} \\ \text{equity} \\ \text{environmental quality} \\ \text{economic resilience} \end{bmatrix} \tag{5}$$

The corridor intervention package, R, describes the location of the trunk transport infrastructure; the nodal areas it will connect and its geographic alignment; the mode of transport it would contain (here, roads, rails, waterways, and their combinations); the private sector's role in design, construction, operation, and management of the corridor; policy reforms for the input and product markets (such as labor market policy reforms); and reforms of cross-cutting institutions (such as public governance or property rights). The existing conditions in the input (land, labor, and capital) and product markets are captured under vector X. Vector Y then summarizes the categories of possible WEBs: economic welfare, social inclusion, equity, environmental quality, and economic resilience. The WEB of economic activity—as measured by nightlights intensity—studied in this paper falls into the broad category of economic welfare.

By solving for equation (4), we are interested in knowing which particular characteristics of corridors (mode of transportation, length, location, nodal connections, and so on) and accompanying policies (land market reforms, improved access to finance, regulatory reforms in product markets, and so on) need to receive greater weight under different sets of initial conditions (unclear land titles, labor market frictions, financial markets imperfections, extent and state of any preexisting transport infrastructure, and so on). Ideally, we would like to uncover the "true" optimized policy rule, equation (4). This is a highly ambitious task and, indeed, it is likely to be impossible to uncover fully the optimized policy rule. Less ambitiously, we therefore focus on understanding the following:

$$\frac{\partial Y}{\partial R} = \beta + \gamma \bar{X} \tag{6}$$

More precisely, we focus on how different corridor intervention packages affect the net WEBs, considering the direct effects (equation (2)) and indirect effects (equation (3)). For instance, we may want to consider how changing the types of nodes linked by a corridor or changing the mode of transportation on which the corridor focuses can affect development outcomes—directly and indirectly, through policies improving access to markets, land use, and migration patterns. Equation (6) captures the overall impact of different aspects of a corridor package on the set of final development outcomes with which a policy maker may (potentially) be concerned (economic welfare, social inclusion, equality, environmental quality, or economic resilience). By contrast, $\bar{X}$ captures how aspects of a corridor package might interact with different initial conditions in the input and product markets to influence the set of final development outcomes. This can be seen more clearly by integrating equation (6) with respect to *R* to give the following:

$$Y = \beta R + \gamma(\bar{X}R) + K \tag{7}$$

where *K* is the constant of integration. This equation is close to the type of reduced form equation that is often used in the literature to estimate the economic impacts of a large-scale transport infrastructure project, except that typically *R* is restricted to just the transport intervention, abstracting from the potentially varied impact across localities and population groups, depending on the initial conditions of local markets and institutions (or the influence of complementary policies). That is, the potential interaction effects are typically ignored and the restriction $\gamma = 0$ is imposed. In this paper, we do not impose the latter restriction. Instead, we study the potentially important integration effects. Equation (7) sets the basis for the specification of our empirical regressions fitted to the data (see equation (8)).

3. Data

3.1 Sample Selection

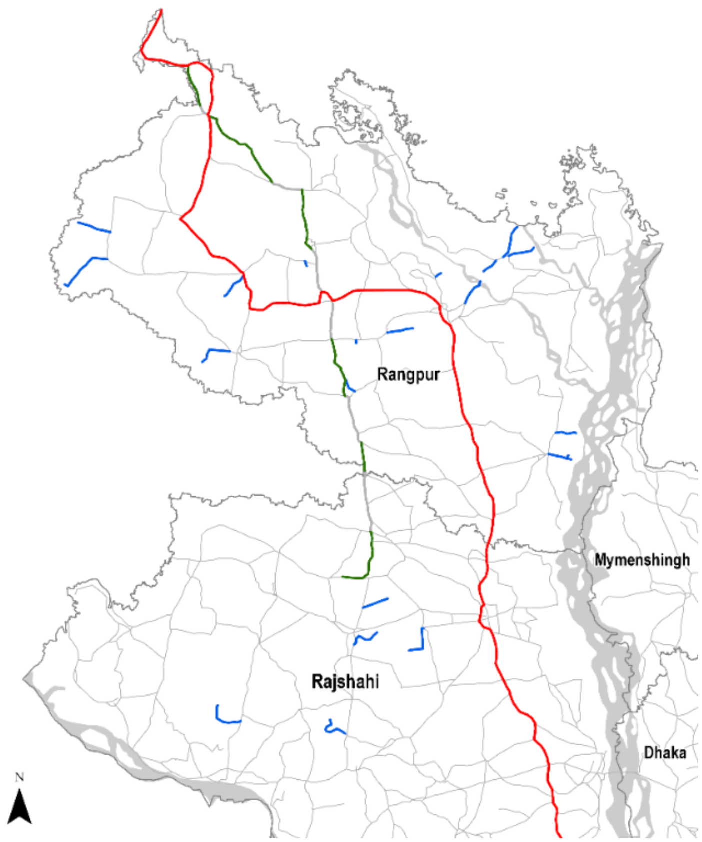
The first step in assessing the impact of transport corridor investments is defining some criteria for identifying relevant transport investments. To this end, the entire portfolios of road, rail, and waterway projects financed by the ADB, JICA, and World Bank between 1990 and 2007 were screened to assess whether they would qualify as a transport corridor.

The screening criteria classified a transport project as a *transport corridor project* based on two conditions. First, the transport investment built new, rehabilitated, or upgraded existing transport infrastructure of at least 100 linear kilometers on a given route. The length of transport investments is defined in terms of linear kilometers on the same route connecting two or more locations that do not need to be geographically contiguous. For example, the roads marked in red and green in map 1 are a potential corridor, while those in blue are not. The 100 linear kilometers threshold was selected based on discussions with transport experts across the three international development organizations. to identify projects that have the potential to enhance the regional connectivity of a country or set of countries. Second, the transport investment is in a new bridge or tunnel connecting at least two economic centers, and the loan at appraisal was for more than $50 million (in 2016 dollars). The loan amount threshold was used to remove small bridges or tunnels that may not provide a significant improvement in connectivity.

A team of trained experts reviewed the loan appraisal documents for all the road, rail, and waterway projects financed by the three international organizations, to identify transport corridor projects based on the selection criteria. The loan appraisal documents are confidential, so the authors worked with technical staff from each international organization to train the experts screening the projects. To ensure consistency, the authors reviewed the results of the screening done by the experts and made final decisions based on discussions with the experts and technical staff of each international organization working on the project and further review of appraisal documents, if needed.

Following the screening process, a sample of 47 completed transport corridor projects (across 16 countries) were selected comprising of seven projects from the ADB, 14 projects from the JICA, and 26 projects from the World Bank. For instances where a project was complemented with additional financing, the full project (parent project and additional financing) was treated as covering the same project. Similarly, if two or more projects were deemed to enhance connectivity in a linear and contiguous manner, they were also treated as the same project. The dates of appraisal for these projects range from 1991 to 2007, and the project closing dates range from 1995 to 2012.[9] Of the 47 projects, 34 are related to roads only, nine to railways only, two to inland waterways only, one to roads and railways, and one to railways and a port. The average size of the loan provided by the international organizations for the projects was $293 million (in 2016 dollars) and, on average, a project comprised investments along 330 linear kilometers (see annex 2 for details on project characteristics).

Map 1: Linear investments along corridors



A novel project-level database was built for the analysis. The team of trained experts reviewed various institutional project documents at the appraisal and closing stages to collect data capturing information relating to project characteristics, design, and monitoring and evaluation.

[9] The period of analysis is determined by the availability of comparable nightlights data, discussed below, which restricts the sample size.

3.2. Design and Implementation Characteristics of the Corridor Projects

The experts collected data on project design and implementation characteristics, including length, transport mode(s), scope of investments, private sector involvement, and theory of change. The experts also retrieved information on the location of the corridor investments, which was used to geocode them. Some projects include geospatial information (for example, maps) in their appraisal documents; for other projects, the appraisal documents have detailed descriptions of the end points and routes, which allowed easy and accurate geocoding of the projects' nodes (the geometry of a project is defined as a straight line from start node to end node). For a few of the projects, the exact location of the end node is not described accurately in the appraisal documents. In those cases, we decided to extend the corridor to the center of the closest city in the corridor route.

Project design and implementation characteristics are captured through six variables. First, the increase in connectivity provided by a corridor was measured by the scope of the investments (see annex 1 for details). The scope of most projects was to rehabilitate existing links or expand their capacity, with only a few projects building new links—this provides the largest increase in connectivity. Second, some of the investments were close to the border, but only 11 percent of the projects involved investments at the border. Investments at the border capture whether the physical investment connects a country to other countries. This could include road infrastructure investments as well as other investments at the border. Third, another important project characteristic is the underlying theory of change, which is used to measure the perceived rationale behind the project. The theory of change was used to capture expected causal linkages posited by the project that shall lead to the longer-term outcome of WEBs. An expert assessment was used to evaluate the theory of change for the project—ranging from 1 (lowest quality) to 5 (highest quality)—to capture the understanding of the constraints, challenges, and potential impacts of the project.

Fourth, the geographic scope of the project is used to measure its complexity from an implementation perspective. The geographic scope of most projects relates to national links or regional links within a country, with very few projects being local (for example, provincial) or international. Fifth, the role of the private sector in the design and implementation of the corridors is measured using two variables. One, private sector consultation captures whether the private sector was consulted before, during, or after project design or not. Two, private sector involvement captures the extent of private sector involvement in the operation or management of the transport infrastructure (see annex 1 for details). In the sample, about 53 percent of the projects involved the private sector through consultations, but fewer than 38 percent of the projects involved it in the operation or management of the corridor infrastructure.

Table 1 presents the summary statistics of these variables. Annex 1 describes in detail how the variables are defined.

Table 1: Summary Statistics for the Explanatory Variables

Variable	Mean	Standard deviation
Initial conditions		
Landlocked-ness [0−1]	0.13	0.34
Logarithm of country's land area (hectares)	19.3	1.67
Terrain ruggedness index	119.59	96.20
Logarithm of GDP per capita at appraisal (constant 2010 US$)	7.25	0.66
Project design and characteristics		
Quality of theory of change [1−5]	1.87	0.95
Private sector consultation [0−1]	0.53	0.50
Private sector involvement [0−1]	0.38	0.49
Degree of connectivity increase [1−3]	1.85	0.93
Investment at border [0−1]	0.11	0.31
Geographic scope [1−4]	2.61	0.82
Complementary policies and institutions		
Openness at approval [(Imports + Exports)/GDP]	0.50	0.22
Any development policy operation in past 5 years	0.49	0.51
Any development policy operation in past 5 years: industry-trade-services	0.40	0.50
Any development policy operation in past 5 years: public administration	0.43	0.50
Any development policy operation in past 5 years: transport	0.13	0.34

3.3. Initial Conditions and Complementary Policies and Institutions

The initial conditions in the country are captured through the country area, country gross domestic product (GDP) per capita[10] at time of loan appraisal, terrain ruggedness, and whether the country is landlocked. All initial conditions, except terrain ruggedness, are measured at the country level. Terrain ruggedness—measured at the level of our geographic unit—was extracted from the data set created by Nunn and Puga (2012). Corridors located in areas with greater terrain ruggedness may find it more difficult to generate and spread WEBs along the corridor than corridors where the surrounding area is flatter. And richer countries may not see their local economic activity boosted by as large a margin as poorer countries that still have far to go in income convergence.

The complementary policies and institutions are captured using measures of trade openness[11] of the country at the time of project appraisal and indicators on whether there were policy and institutional reforms in the five years preceding the signing of the loan agreement for the project. We use World Bank Development Policy Operations (DPOs) as a proxy for policy and institutional reforms in the country. Development policy operations support a program of policy and institutional actions that promote growth and enhance the well-being and increase the incomes of poor people. For example, some DPOs aim to improve the investment climate, diversify the economy, and create employment (World Bank 2004). Clearly, not all policy and institutional reform programs are supported by the World Bank, so the use of DPOs is an

[10] From the World Development Indicators, World Bank.
[11] Measured using imports, exports, and GDP data from the World Development Indicators, World Bank.

imperfect proxy.[12] Various indicator variables are used in relation to DPOs. In the sample, 49 percent of the projects were in countries that had DPOs relating to any sector in the preceding five years, 42 percent of the projects were in countries that had public policy reform, and only 13 percent of the projects were in countries that had transport-related DPOs (table 1).[13]

3.4. Wider Economic Benefits

We use remotely sensed measurements of nighttime lights emission intensity to measure the WEBs. Nighttime lights are considered a relatively good proxy for human and economic activity. The assumption is that the amount of light emitted at night is highly correlated with consumption, which increases with higher incomes. Following Henderson, Storeygard, and Weil (2012), who find a strong correlation between the growth of nighttime light intensity and GDP at the national level, multiple studies have expanded this approach and used nighttime lights to estimate economic development at much smaller geographic units. For example, Storeygard (2016) utilizes nighttime lights to study intercity transport costs and their impact on population income in Sub-Saharan African cities, and Harari (2017) uses nightlights to measure the shapes of urban areas in India. Because persistent light emitted at night is often associated with manmade structures, it is assumed that if the intensity of a pixel exceeds a given threshold, this pixel represents a populated location or some level of economic activity.

To measure WEBs, nighttime light data from the U.S. Air Force Defense Meteorological Satellite Program Operational Linescan System (DMSP-OLS) were used. Pixels in DMSP-OLS have a resolution of 30 arc seconds, or approximately 1 by 1 kilometer at the equator. These data are available for the period between 1992 and 2012. For each pixel, the digital number of calibrated light intensity ranges from 0 to 63, which is often referred to as the nightlight intensity (we use the "stable lights" band, where ephemeral events, such as fires, have been discarded). We inter-calibrate the data to account for the lack of on-board calibration between satellites (see annex 2).

However, there are well-known limitations to DMSP-OLS data (see, for example, Donaldson and Storeygard (2016)). These include saturation effects, in which the amplification of light detection to capture low levels of light leads to right censoring in detection in highly-lit areas (for example, city centers); and blooming effects (or the "diffusion of light"), in which light emitted in one pixel or over an area is detected in nearby pixels, making highly lit areas appear to be larger than they are.

For this paper, a grid of hexagons, each covering 260 square kilometers (20 kilometers from vertex to vertex), was created. The nighttime lights intensities at the pixel level were summed by hexagon to represent an overall value of light.[14] A global artificial hexagon data set was created to allow a standardized level of analysis for all projects across the globe. Hexagons are appropriate and efficient for management and analysis of geospatial data (Tong, Ben, and Wang 2010) and are increasingly popular as bases for discrete spatial simulations (Sahr, White, and Kimerling 2003). Hexagonal tessellation has been adopted by previous studies in the remote sensing domain (Potere 2009; Goldblatt et al. 2018). Using hexagons is advantageous over square pixels because of their higher symmetry, sampling efficiency, equidistance,

[12] We cannot use alternative measures, such as the World Bank Country Policy and Institutional Assessment scores, because the series starts only in 2005.

[13] Obvious candidates for capturing complementary policies and institutions are variables related to doing business, but there is no series that covers the entire period of the analysis.

[14] Hexagons for which the observed nighttime light was zero were excluded from the analysis. This is done to exclude areas where no economic development is expected, for example, forests and deserts. Since international development organizations tend to have strong environmental safeguards to prevent the depletion of the natural environment, the exclusion of these hexagons is intuitive.

angular resolution, lower aliasing effect, and consistent connectivity (Wang and Ai 2018). Annex 2 presents a detailed description of the methodology used to create the hexagon-level data set.

To measure nighttime light before the project, the latest year for which nightlights data are available before the project was appraised is used. To measure nightlights after the project is completed, the longest gestation period possible for WEBs to emerge is used, which runs until 2012.[15] The average sum of light (SOL) value for hexagons within 20 kilometers of the project's alignment one year prior to project appraisal is 1,337. This value increased to 2,064 in 2012—the last year for which nightlights data are available.

3.5. Human Settlements

We use the Global Human Settlement Layer (GHSL) (Pesaresi et al. 2016) to estimate built-up land cover and urban settlements within the analyzed hexagons. GHSL is based on the European Commission's Global Human Settlement Grid. This data set utilizes a degree of urbanization model to determine to what degree an area is developed. The data are separated into high-density (cities or large urban areas), low-density (towns and suburbs), and rural grids. Each of these categories is represented by a numerical value ranging from 0 to 3. These numerical values are summed as total values for each year available in the data set. The sum of values represents per-hexagon degrees of urbanization.

4. Empirical Strategy

In addition to understanding whether a large transport corridor investment can yield WEBs on average, it is important to understand the relationship between the realization of WEBs and the environment in which the project is being designed and implemented—that is, the local initial conditions and country characteristics—and the design characteristics of the project itself.

For example, the geographic scope of a project may have a significant impact on the realization of WEBs. On the one hand, projects with a larger expanse (national or transnational) may create a strategic connection with extra catalytic effects on the economy. On the other hand, the inherent difficulty in implementing such large and complex projects may significantly delay or even taper the ultimate impact on the economy. Similarly, as compared with projects on a flatter terrain, projects on more rugged terrains may preclude the local communities from benefiting from the strategic connectivity created by the project if suitable first and last mile connectivity is not provided. However, if the level of initial connectivity in more rugged terrains is lower, then the benefits from the development of a strategic transport corridor including secondary connectivity (roads) may be higher, compared with the same corridor being developed on a flatter terrain that already has a higher level of initial connectivity. Such questions should be assessed empirically to understand the key conditional relationships for successful project design.

The paper assesses whether transport corridors appear to spur higher economic activity around them, considering the following questions:

- Are the corridors initiated in countries that are richer, bigger, and easier to connect (initial conditions)?

[15] Comparable nightlights data are available between 1992 and 2012 (inclusive), which limits the number of projects in the sample. Three of the projects were appraised in 1991. For these projects, nightlights data from 1991 were used. In addition, four projects closed in 2012. For these, 2012 data for nightlights were used.

- Do the corridors have a large geographic scope, and are they more complex (project design and characteristics)?
- Do the corridor projects consult and/or involve the private sector (project design and characteristics)?
- Do the corridor projects proceed against a backdrop of complementary policies and institutions (measured through trade openness and development policy reforms)?

These are challenging questions to address for several reasons. First, project corridor placement can be endogenous, because transport corridors may be built to connect places that are already growing or have higher growth potential, or places that are underdeveloped and expected to undergo income convergence regardless of improved connectivity (Roberts et al. forthcoming). In this case, a simple ordinary least squares (OLS) estimate will also pick up the effect of unobservable traits of the places the corridor connects, which influence their growth dynamics. Second, the project characteristics that are chosen are not exogenous to the potential of the project. For example, the private sector may be engaged by project teams if the expected benefits of the project are substantial and can be monetized, to spark private sector interest. The confluence of these issues, the endogenous placement of corridors and the endogeneity of project characteristics, makes the identification of causal relationships difficult. Although we attempt to address some of the endogeneity issues, the results of the estimation should be interpreted as associations.

To test the hypotheses, the identification strategy uses a difference-in-differences approach. The first difference compares nightlights intensity observed in areas close to the corridor (treated areas) with areas far away from the corridor (control areas). This is a comparison across space. In this context, treatment is considered to be a continuous variable. The second difference compares the first difference across time, subtracting the level before the project started from the level after the project was completed and in use, to ascertain the effect of the project. By comparing nightlights close to the corridor with nightlights far away from the corridor, nightlights prior to the start of the project to nightlights after project completion and usage, and the interaction of the two, we attempt to control for changes over time in the country that may impact the level of economic activity similarly across the treatment and control locations. Namely, we use the following regression to estimate the corridor impact on local economic activity[16]:

$$N_{ijkt} = \left(\beta_{00} + \beta_{01}P_{ijt} + \beta_{02}T_{ijk} + \beta_{03}\,T_{ijk}P_{ijt}\right) + \boldsymbol{D'_{ij}}\left(\beta_{11}\,P_{ijt} + \beta_{12}\,T_{ijk} + \beta_{13}\,T_{ijk}P_{ijt}\right) + \boldsymbol{I'_j}(\beta_{21}\,P_{ijt} + \beta_{22}\,T_{ijk} + \beta_{23}\,T_{ijk}P_{ijt}) + \boldsymbol{C'_{ij}}(\beta_{31}\,P_{ijt} + \beta_{32}\,T_{ijk} + \beta_{33}\,T_{ijk}P_{ijt}) + \varepsilon_{ij} \quad (8)$$

where N_{ijkt} is the nightlights for project *i* in country *j* at location *k* and year *t*. Location *k* is a hexagon of 250 square kilometers. P_{ijt} is a binary variable that takes the value one if the transport project *i* in country *j* has been completed in year *t*. T_{ijk} is a continuous variable that ranges from zero to one, depending on the shortest linear distance between location *k* (the center of the hexagon) and the transport corridor project *i* in country *j*. The variable takes on the value one if location *k* is in the corridor and the value zero if location *k* is 100 kilometers away from the corridor. D_{ij} is a vector of design and implementation characteristics of the trunk transport project *i* in country *j*. I_j is a vector of initial conditions observed in country *j*. C_{ij} is a vector of complementary policy and institutional interventions implemented before or around project *i* in country *j*.

Here, β_{13}, β_{23}, and β_{33} estimate how project design/implementation, initial conditions, and complementary interventions, respectively, could affect a WEB—local economic activity. There is a growing body of

[16] The specification also controls for level differences between the ADB, JICA, and World Bank, by including international organization fixed effects.

literature that demonstrates that development of large transport infrastructure on average leads to economic activity. By focusing on the above-mentioned parameters, this paper focuses on when the resulting WEBs should be expected to be higher/lower.

The specification addresses some of the discussed concerns about the placement of transport corridors in this analysis. However, it does not fully control for the endogenous placement of transport corridors and endogenous selection by international organizations. If countries make the decision of building these corridors in areas connecting existing economic hubs, then the inclusion of these economic hubs in the analysis would lead to endogeneity issues. We address this issue by performing two sensitivity analyses (robustness checks).

The first sensitivity test excludes points that are close to the nodes of the corridor. Typically, transport corridor projects are designed to connect two or more cities, which could create endogeneity bias if the nodes are included in the analysis. An approach followed in the literature to deal with the potential bias is to remove the nodes (see, for example, Michaels (2008) and Ghani, Goswami, and Kerr (2016)). The nodes typically fall at the ends of the corridor; hence, in one approach, 20 percent of the corridor area around its ends is excluded. However, it is also possible that the transport investment was done to connect nodes along the corridor that have economic potential. If this is the case, then the exclusion of the nodes at the ends of the corridor is not suitable. To address this issue, we use the Global Human Settlement data to identify urban centers along the corridor that existed before the start of the project. To remove possibly problematic nodes, all areas with an average human settlement value of 2.5 or above are excluded. By excluding these nodes from the analysis, attention is restricted to the areas along the corridor that got connected by chance. This allows the analysis to correct for the endogenous placement of the corridor.

The second sensitivity test involves excluding partially treated locations surrounding the corridor. To accomplish this, the treatment group is considered to comprise hexagons for which the center of the hexagon is within 20 kilometers of the corridor alignment, and the control group is considered to comprise hexagons for which the center of the hexagon is 80-100 kilometers from the corridor. In this case, the treatment variable, T_{ijk}, is a dummy variable rather than the continuous variable used in the baseline specification of the estimated regression.

Despite these sensitivities, it is not possible to randomize project characteristics. Therefore, the findings should be interpreted as associations. Understanding the relationship between project characteristics and the creation of WEBs is important for policy makers and practitioners who decide about and design corridor projects. Thus, performing a robust analysis of these associations is of great interest.

5. Results

5.1. Main Results

The results of the analysis shed light on three questions. First, what country characteristics may help produce WEBs? Second, what design and implementation characteristics of large transport projects may help generate WEBs? Third, which complementary policies and institutions (such as reforms to improve development policy) may help ensure or amplify WEBs?

Two types of results are reported. Table 2 (columns 1 and 2) presents the results for the baseline estimation strategy that uses nightlights data for all hexagons within 100 kilometers of the transport corridor projects. In this baseline specification, the treatment variable is continuous, with locations further from the corridor acting as a control. Table 3 (columns 1 and 2) presents the estimation results using hexagons 0-20 kilometers from the corridor as the treatment group and hexagons 80-100 kilometers from the corridor as the control group.

The values reported in tables 2 and 3 are the regression coefficients (and corresponding standard deviations) for the average effect (treatment x post) and interaction effects of each variable with the treatment and post dummy variables. The coefficient for each variable indicates how a given variable affects economic activity (WEBs) around the corridor. Across tables 2 and 3, in columns 1 to 6, the average treatment effect appears insignificant. This finding suggests possible heterogeneity in project effects across different country and local contexts. We investigate this possible heterogeneity by using the interactions of the (treatment x post) dummy with project context variables: country/location characteristics, project design and implementation characteristics, and variables capturing complementary policies and institutions.

Four country characteristics are tested to see whether they lead to economic activity around the project corridor—country size, terrain ruggedness, level of development (GDP per capita), and landlocked-ness. The results are relatively consistent across tables 2 and 3 (columns 1 and 2), with none of them having demonstrable relation to the economic activity that results from the corridor project. This could mean that these four characteristics had no bearing on the creation of WEBs because, for instance, country size may be irrelevant when international connectivity is improved; landlocked-ness may not matter much if landlocked countries do not reap significantly greater benefits from corridors than other countries; and higher initial level of development and better institutions could benefit treated and untreated locales about equally. And although it is measured at the local level, terrain ruggedness may be less relevant when, for instance, highways are built using technology such as tunnels and bridges to achieve the same regulated speed of travel across more and less rugged locations. Alternatively, this finding could imply that the projects supported by international development organizations are able to neutralize any differences that may have emerged from these country characteristics. In this sense, it could be that the support from international development organizations—involving convening power and technical assistance—helps level the playing field across country contexts.

Table 2: Regression Results Using Continuous Treatment Variables and Hexagons of 0-100 Kilometers

Variable	(1)	(2)	(3)	(4)	(5)	(6)
Post x Treatment	1.424	1.817	-2.079	-4.301	1.484	1.910
	(1.395)	(2.011)	(2.095)	(3.422)	(1.389)	(2.006)
Landlocked-ness	-0.316	-0.228	0.158	0.554	-0.333	-0.252
	(0.204)	(0.254)	(0.297)	(0.444)	(0.203)	(0.253)
Log land area (Ha.)	-0.0231	-0.0532	0.111	0.160	-0.0242	-0.0544
	(0.0580)	(0.0841)	(0.0881)	(0.142)	(0.0578)	(0.0839)
Terrain ruggedness index	-0.000203	-0.000323	0.000383	0.000622	-0.000234	-0.000357
	(0.000455)	(0.000475)	(0.000711)	(0.000729)	(0.000453)	(0.000472)
Log GDP per capita at appraisal (constant 2010 US$)	-0.121	-0.0809	-0.0522	0.178	-0.123	-0.0889
	(0.0858)	(0.0934)	(0.131)	(0.144)	(0.0853)	(0.0928)

Theory of change	0.150**	0.147**	0.165	0.131	0.145**	0.143*
	(0.0663)	(0.0732)	(0.104)	(0.113)	(0.0661)	(0.0729)
Private sector consultation	0.167	0.318**	0.439**	0.570**	0.142	0.293*
	(0.132)	(0.154)	(0.203)	(0.229)	(0.132)	(0.153)
Degree of private sector involvement	-0.385***	-0.319**	-0.832***	-0.747***	-0.381***	-0.316**
	(0.137)	(0.138)	(0.216)	(0.217)	(0.137)	(0.137)
Degree of connectivity increase	-0.00521	-0.0721	-0.0369	-0.174	-0.00835	-0.0733
	(0.0748)	(0.0816)	(0.113)	(0.125)	(0.0745)	(0.0813)
Investment at border	0.0176	0.0726	-0.417	-0.533	0.0283	0.0892
	(0.264)	(0.282)	(0.429)	(0.469)	(0.264)	(0.282)
Geographic scope	-0.127	-0.0888	-0.131	-0.199	-0.124	-0.0845
	(0.0932)	(0.0994)	(0.143)	(0.150)	(0.0929)	(0.0991)
Openness at approval [(Imports + Exports)/GDP]	-0.0623	-0.132	1.212*	0.965	-0.0599	-0.111
	(0.419)	(0.489)	(0.654)	(0.839)	(0.418)	(0.486)
Any DPO in past 5 years		0.0726		1.001***		0.0578
		(0.275)		(0.362)		(0.275)
Any DPO in past 5 years: Industry-trade-services		-0.175		-0.874		-0.135
		(0.343)		(0.560)		(0.342)
Any DPO in past 5 years: Public administration		-0.204		-0.194		-0.231
		(0.513)		(0.776)		(0.511)
Any DPO in past 5 years: Transport		-0.267		-0.138		-0.259
		(0.187)		(0.295)		(0.187)
Observations	40,572	40,572	17,813	17,813	40,426	40,426
R-squared	0.318	0.331	0.356	0.374	0.320	0.333
Sample	All	All	Exclude 20% at the nodes	Exclude 20% at the nodes	Exclude if Human Settlement Index > 2.5	Exclude if Human Settlement Index > 2.5
Specification	No DPOs	With DPOs	With DPOs	No DPOs	No DPOs	No DPOs

Note: Robust standard errors are in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Six design and implementation characteristics are tested to see whether they could significantly affect economic activity around the project corridor—quality of the theory of change, private sector consultation, private sector involvement, extent of increased connectivity, investment at the border, and geographic scope. The results are relatively consistent across tables 2 and 3 (columns 1 and 2) for four of the six characteristics—theory of change, private sector consultation, private sector involvement, and investment at the border.

The results indicate that having a well thought out theory of change is more likely to spur economic activity. A well-thought rationale for developing large pieces of infrastructure that can be effectively used by local businesses and the population is imperative to ensure that the investment does not end up being a white elephant.

The results also indicate that private sector consultations have a positive bearing on the WEBs, but private sector involvement in the operation and management of the infrastructure appears to have negative bearing on the WEBs resulting from the project. These results imply that although consulting with the private sector may translate into WEBs (perhaps through improved project design), the expected efficiency gains from private sector involvement have not so far translated into higher levels of economic activity around the corridor. Hence, country governments and international development organizations may need to rethink how they involve the private sector in implementation (operation or management) of corridors to fully achieve the potential benefits of such collaborations or partnerships.

In the same vein, investing at the border appears to have no significant bearing on economic activity. This result could indicate the need to implement trade-related, particularly customs, reforms to leverage the benefits of improved physical connectivity.

Similarly, the extent of increased connectivity and geographic scope have no significant bearing on economic activity. This means that a larger geographic scope (ranging from local, subnational/regional within the country, national, to international) is not likely to spur economic activity around the corridor alignment. This could be indicative of the inherent complexity in implementing projects over a large geographic area, possibly spanning more than one administrative jurisdiction. This finding is in line with the finding of no additional impact estimated when connectivity is created at the border. The same is true for the type of connectivity created (rehabilitation, capacity expansion, or greenfield).

Lastly, five variables capturing complementary policies and institutions are tested to see whether they help spur economic activity around the project corridor—trade openness at approval and four DPO-related variables (general as well as specific to transport). Trade openness does not have any discernable impact on greater economic activity around the transport corridor. Again, this could mean that trade openness has no bearing on the creation of WEBs, or that the projects supported by international development organizations are able to neutralize any differences that may have emerged from these characteristics. Similarly, reforms—approximated by the presence of World Bank DPOs—prior to the start of a project could lead to some positive impacts. However, the results demonstrate that the policy reforms we study are not associated with changes in local economic activity along the corridor that are different from the changes in other areas of the country.[17]

Table 3: Regression Results Using Discrete Treatment Variables and Hexagons of 0-20 and 80-100 Kilometers

Variable	(1)	(2)	(3)	(4)	(5)	(6)
Post x Treatment	1.236	1.515	-0.769	-3.006	1.288	1.606

[17] However, this does not imply that DPOs are ineffective. Because of their widespread (horizontal) nature, DPOs could be spurring economic activity equally between the treatment and control hexagons.

	(1)	(2)	(3)	(4)	(5)	(6)
	(1.303)	(1.879)	(1.952)	(3.038)	(1.298)	(1.875)
Landlocked-ness	-0.347*	-0.274	0.0898	0.296	-0.361*	-0.294
	(0.193)	(0.240)	(0.272)	(0.396)	(0.192)	(0.240)
Log land area (Ha.)	-0.0234	-0.0460	0.0708	0.130	-0.0243	-0.0475
	(0.0542)	(0.0790)	(0.0818)	(0.129)	(0.0540)	(0.0789)
Terrain ruggedness index	4.97e-05	1.17e-05	0.000448	0.000719	1.30e-05	-2.91e-05
	(0.00046)	(0.00048)	(0.000663)	(0.00068)	(0.000457)	(0.000477)
Log GDP per capita at appraisal	-0.0873	-0.0573	-0.116	0.0577	-0.0888	-0.0637
	(0.0800)	(0.0868)	(0.124)	(0.135)	(0.0795)	(0.0863)
Theory of change	0.163***	0.161**	0.172*	0.158	0.159***	0.157**
	(0.0608)	(0.0674)	(0.0946)	(0.104)	(0.0605)	(0.0671)
Private sector consultation	0.203*	0.320**	0.315*	0.412*	0.185	0.303**
	(0.123)	(0.143)	(0.185)	(0.214)	(0.122)	(0.142)
Degree of private sector involvement	-0.435***	-0.383***	-0.692***	-0.616***	-0.431***	-0.380***
	(0.128)	(0.128)	(0.196)	(0.196)	(0.127)	(0.128)
Degree of connectivity increase	-0.0571	-0.112	-0.0665	-0.191*	-0.0583	-0.112
	(0.0687)	(0.0753)	(0.103)	(0.115)	(0.0684)	(0.0750)
Investment at border	-0.0501	-0.0141	-0.494	-0.496	-0.0378	0.00369
	(0.248)	(0.270)	(0.397)	(0.426)	(0.247)	(0.269)
Geographic scope	-0.126	-0.0964	-0.117	-0.149	-0.126	-0.0945
	(0.0878)	(0.0932)	(0.135)	(0.140)	(0.0875)	(0.0928)
Openness at approval	0.0482	0.0288	1.111*	1.060	0.0489	0.0415
	(0.386)	(0.453)	(0.603)	(0.788)	(0.384)	(0.451)
Any DPO in past 5 years		0.0676		0.921***		0.0541
		(0.253)		(0.325)		(0.252)
DPO: Industry-trade-services		-0.0955		-0.460		-0.0636
		(0.335)		(0.521)		(0.333)
DPO: Public administration		-0.213		-0.469		-0.234
		(0.482)		(0.703)		(0.481)
DPO: Transport		-0.173		-0.132		-0.168
		(0.171)		(0.269)		(0.170)
Observations	16,248	16,248	7,165	7,165	16,166	16,166
R-squared	0.326	0.342	0.353	0.375	0.328	0.343
Sample	All	All	Exclude 20% at the nodes	Exclude 20% at the nodes	Exclude if Human Settlement Index > 2.5	Exclude if Human Settlement Index > 2.5
Specification	No DPOs	With DPOs	No DPOs	With DPOs	No DPOs	With DPOs

Note: Robust standard errors are in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

5.2. Robustness Tests

Several sensitivities are performed to test the robustness of our results. Because transport corridors are often conceived to connect large urban centers (booming centers of economic activity), excluding these end points limits the analysis to the areas along the corridor that were likely connected more arbitrarily (randomly). Columns 3 and 4 in tables 2 and 3 report the estimation results when 20 percent of the corridor area at the end nodes of the transport corridor is excluded. Moreover, it could be that some corridors are not envisioned to connect cities that happen to be at the ends of the corridor, but rather several cities, some of which are located at the ends of the corridor and some along the corridor alignment. To account for this possibility, the human settlement data prior to the start of project were used to exclude built-up urban centers. These results are reported in columns 5 and 6 in tables 2 and 3. The results across the various sensitivities are largely consistent, with a few exceptions. First, the robustness results hint that trade openness at appraisal could have a positive impact on local economic activity in non-nodal areas (column 3), and the impact of general policy reforms in non-nodal areas could also be positive (column 4). Second, the robustness results hint that a larger connectivity increase could negatively influence local economic activity (table 3, column 4), once again hinting at the need to balance ambition in project scope with the accompanying operational complexity. These nuances in the results could warrant future research.

6. Conclusion

This paper conducted a survey of large transport infrastructure (corridor) projects supported by the ADB, JICA, and World Bank. It used the survey data to catalog the project characteristics and relate them to success measures, focusing on a WEB—local economic activity. To this end, the paper used the difference-in-differences methodology, conditioning on country context, project design and implementation, and complementary policies and institutions. The underlying multivariate meta-regressions thus linked project characteristics to local economic activity measured through geocoded data on nightlights intensity.

The analysis found that some initial conditions and project characteristics play a significant role in determining whether increased connectivity through a transport corridor will spur economic activity around the corridor. Large transport infrastructure investments in countries that have direct access to the sea are more likely to spur economic activity. The size of the country, its terrain, and the level of development appear to have no significant influence.

Some project design characteristics can better stimulate local economic activity. For instance, having a well thought out rationale or theory of change for the project appears to generate significantly more economic activity in the surrounding areas. This is likely because such projects place a larger focus on designing the project in a way that fits the specific needs of its users, which could vary across locals and population groups. The evidence on private sector engagement and involvement suggests that although consulting the private sector on the project design could generate higher WEBs, involving the private sector in the implementation of the project has so far dampened the creation of WEBs. This finding hints at the intricacies that need to be understood by international development organizations and governments for effective engagement of the private sector in corridor projects for greater socioeconomic benefits. On complementary policies and reforms, further research is needed to reach robust conclusions, which would require better proxies than the World Bank DPOs used in the paper.

As the collection and public availability of spatial data on local development outcomes around the world progresses, more studies are needed to shed greater light on how the variation in project design and implementation—along with varying local conditions and complementary policies—could help transport corridor projects succeed and become truly transformational.

Annex 1: Data Description

A1.1 Variable Definitions

The initial conditions in the country are captured through the following four variables:

- Logarithm of land area. This is the logarithm of a country's area in 1,000 hectares.
- Terrain ruggedness index. This is measured by the average difference in elevation (measured in meters of elevation) for points 30 arc-seconds apart (that is, 926 meters on the equator or any meridian) and not covered by water.
- Landlocked-ness [0−1]. This is a dummy that is 1 if all countries involved in the project are landlocked, and 0 if they are not.
- Log gross domestic product (GDP) per capita at appraisal. This is the log of GDP per capita at the time the project is appraised (in constant 2010 US$).

Project design and characteristics are captured through six variables:

- Quality of theory of change. This is an expert rating of the theory of change, with ratings ranging from 1 to 5. The following objective criteria were used to create these rankings:
    - Rating = 1. Project objectives are limited to transport operating costs and times.
    - Rating = 2. The project documents mention some higher level of objectives (such as an increase in trade or economic growth) but are silent on the conditions needed to achieve these objectives (for example, competitive markets to translate reductions in transport operating costs and times into lower tariffs).
    - Rating = 3. In addition to (2), the project documents mention conditions in the transport sector needed to achieve the higher-level objectives.
    - Rating = 4. In addition to (3), the project documents mention conditions beyond the transport sector needed to achieve the higher-level objectives.
    - Rating = 5. In addition to (4), the project documents include an assessment of whether the conditions have been met and, if not, what actions will be taken to create them.
- Private sector consultation [0−1]. This is a dummy that is 1 if the private sector was consulted before, during, or after the project was designed, and 0 if the private sector was not consulted.
- Private sector involvement [0−1]. This is a dummy that captures private sector involvement in the operation or management of the transport infrastructure. The variable is 0 if no private sector actor is involved; it is 1 if the private sector is involved as a contractor, through a public-private partnership, or through transfer of ownership to the private sector.
- Degree of connectivity increase [1−3]. This variable captures the degree of increase in connectivity, ranging from 1, for the lowest increase in connectivity (rehabilitation of an existing link), to 2 (expanding the capacity of an existing link), to 3, for the highest increase in connectivity (greenfield projects).
- Investment at border [0−1]. This is a dummy that is 1 if the project makes any investment at a country border, and 0 if it does not.
- Geographic scope [1−4]. This variable captures the geographic scope of the investment, ranging from 1 (local), to 2 (subnational or regional within the country), to 3 (national), to 4 (international).

Complementary policies and institutions are captured through three variables:

- Openness at approval. This measure of trade openness consists of the sum of imports plus exports as a share of GDP.

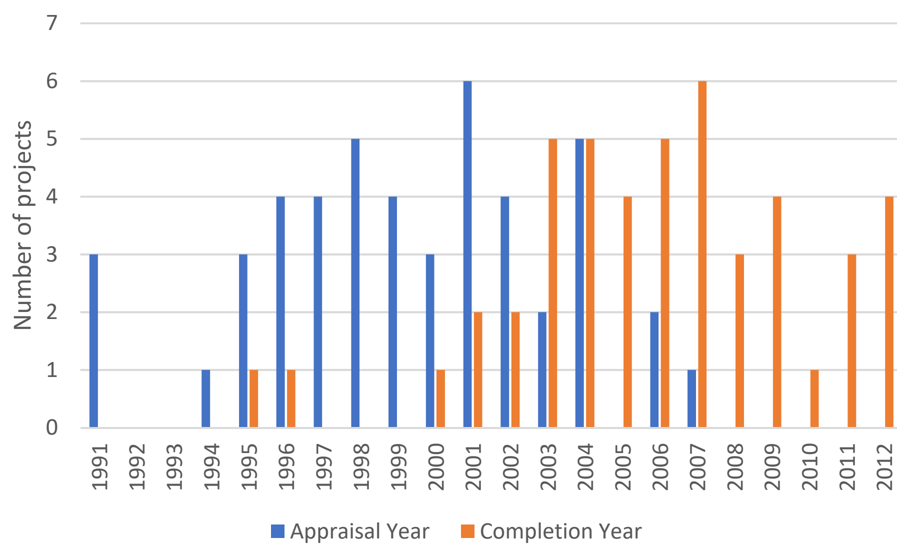
- DPOs. Dummies are included for whether in the five years before the project was approved, the World Bank had any Development Policy Operations (DPOs) in the country. Various dummies are used in relation to DPOs. The general dummy is 1 if any DPO was undertaken in the country in the past five years, and 0 otherwise.
- DPOs in various sectors. These are dummies for DPOs in transport, agriculture, the financial sector, and industry-trade-services.

A1.2 Data Summary

The data set is comprised of projects from 16 countries, namely, Argentina, Bolivia, Cambodia, China, India, Kazakhstan, the Lao People's Democratic Republic, Mali, Morocco, Mozambique, Nicaragua, Romania, Serbia, Tunisia, Uzbekistan, and Vietnam.

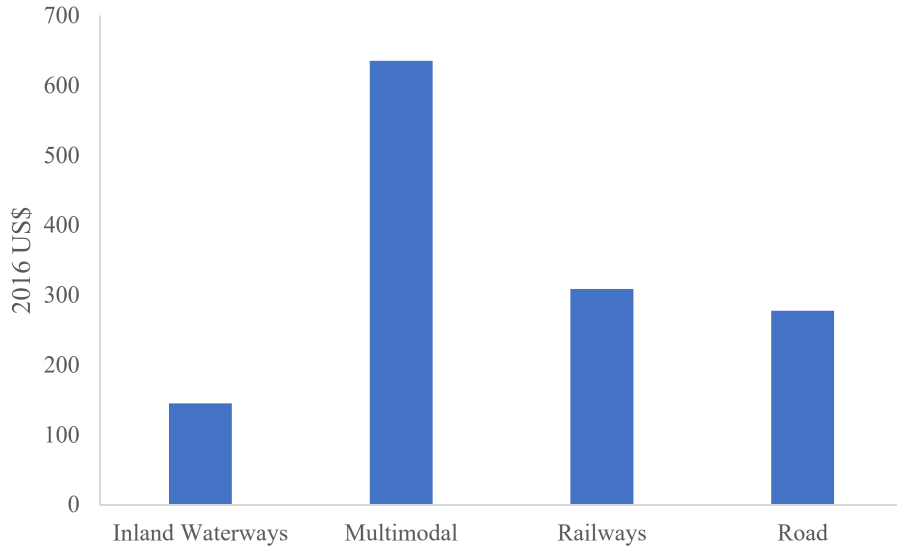
The earliest project in the sample was appraised in 1991, and the latest project in the sample was appraised in 2007. The appraisal and completion years for project completion are 1995 and 2012, respectively. It takes on average 6.5 years for a project to be completed (figure A1.1).

Figure A1.1: Appraisal and Completion Years for Projects



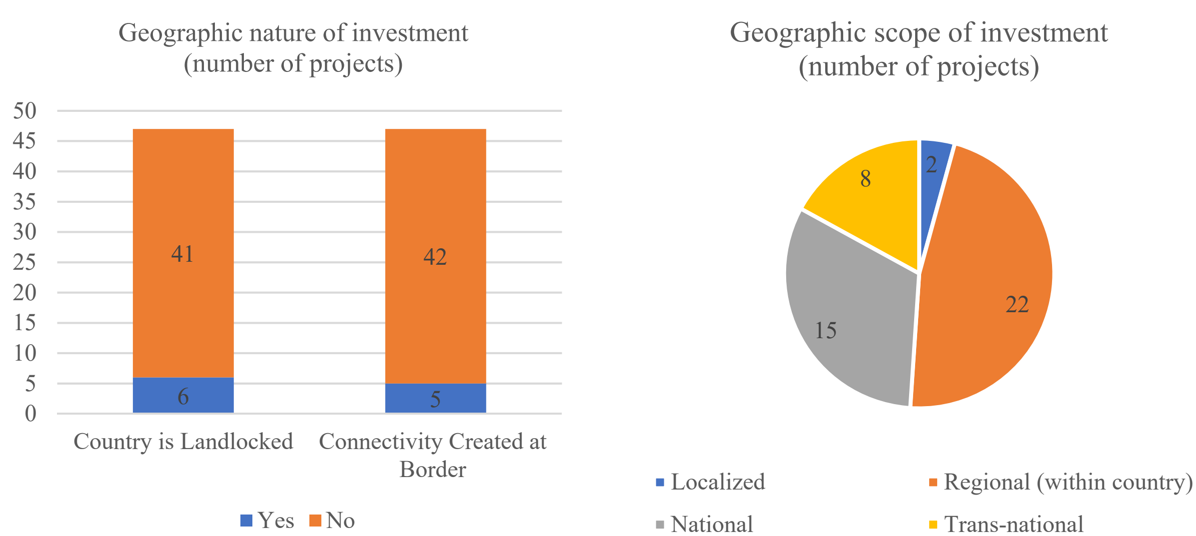
The average loan amount for the projects in the sample is US$293 million. Of these, the average loan size of multimodal projects within the sample is substantially higher than that of projects relating to a single mode. Although the loan sizes for road and railway projects are similar, the loan sizes for inland waterways projects are substantially lower (see figure A1.2).

Figure A1.2: Average Loan Size in US$ (2016 Values)



Among the 47 projects in the sample, only five create connectivity at a border and only six are in landlocked countries. For landlocked countries, connectivity at the border is a major concern (see figure A1.3). Of the six projects in landlocked countries, only two projects create connectivity at the border.

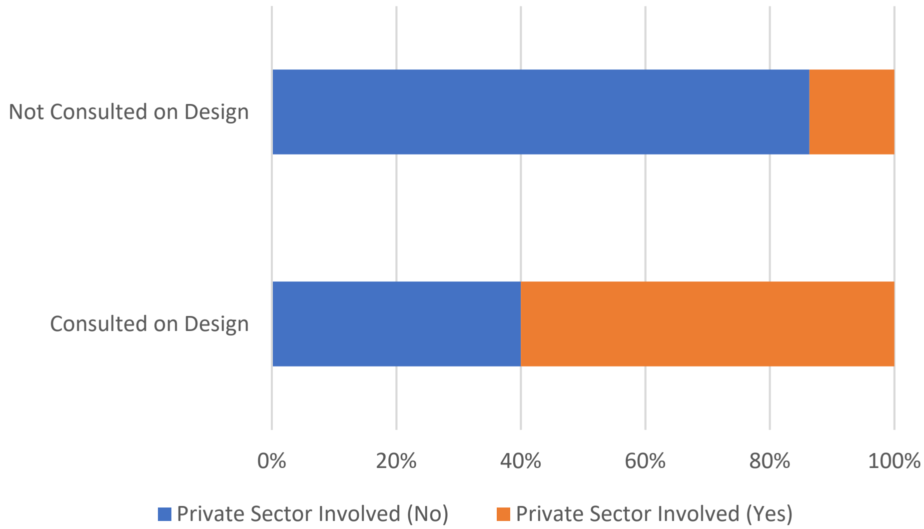
Figure A1.3: Characterization of Connectivity Created



In terms of the geographic scope of connectivity created, almost half the projects enhance regional connectivity within a country, and a third of the projects are national in their geographic scope. A fifth of the projects extend country boundaries, and a negligible share of the projects are localized in their scope.

In terms of the private sector, the majority of the projects (54 percent) consulted with the private sector before, during, or after the design of transport infrastructure. Far fewer (only 40 percent) engaged the private sector in the operation or management of the transport infrastructure (see figure A1.4).

Figure A1.4: Role of the Private Sector



Annex 2: Hexagon-Level Database

The methodology to create the hexagon-level database of nighttime lights and human settlements around transport corridors involves the following steps.

Step 1: Create a GIS layer of transportation corridors

We use a tabular data set, which indicates the latitude and longitude coordinates of major nodes along the corridors of interest, to create a GIS layer representing the spatial characteristics of each corridor (including extent, form, and length). Each corridor is divided into multiple segments (figure A2.1). For each segment, we record the construction starting and end dates. The GIS layer of the corridors does not represent the exact path of each corridor along the land; it only includes segments of straight lines that connect the known nodes, a beginning and an end point of a project's segment).

Step 2: Calculate buffer zones around each corridor

We calculate a buffer layer spanning 200 kilometers around each corridor (100 kilometers on each side of the corridor). The buffer layer consists of 10 rings around each side of the corridor, in intervals of 10 kilometers (a total of 20 rings around each corridor) (figure A2.1).

Step 3: Create a hexagonal tessellation grid around each corridor

We evaluate the wider economic benefits of transportation corridors by measuring changes in nighttime light luminosity around the corridors as a proxy for economic activity. To do this, rather than relying on the pixel as the unit of analysis, we calculate a Sum of Light (SOL) proxy, a well-established measure that is often used in the economic research literature to track economic development and evaluate spatial and temporal variations and social and economic dynamics. SOL is an aggregative measure that is calculated for geographical areas at different scales, for example, regions (Stathakis, Tselios, and Faraslis 2015), countries (Elvidge et al. 2014), and cities (Ma et al. 2012). Recently, studies have begun shifting from analysis at the level of the administrative unit toward analysis of artificial grid systems where each element in the grid is treated as an independent region of interest. Examples of such grids in practice include the Global Grid system (Theobald 2016) and the ISEA discrete global grids (DGGs) of Gong et al. (2013).

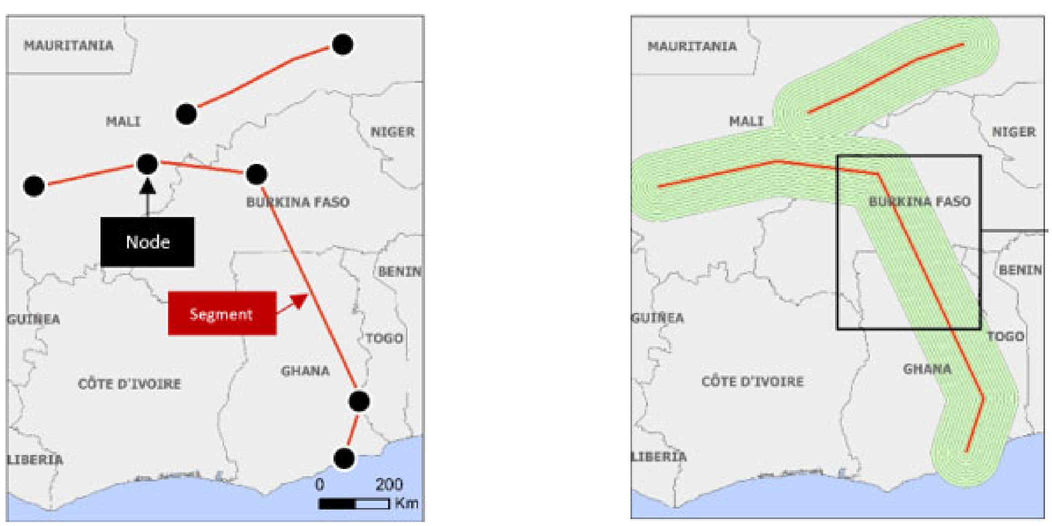
We use hexagons in an equal area hexagonal grid (or a hexagonal tessellation) as the unit of analysis. Each hexagon is approximately 20 kilometers in size from vertex to vertex, or approximately 260 square kilometers (figure A2.1). Each hexagon is identified by a unique ID. For each hexagon, we also calculate the distance between its center and the closest point along the corridor.

Hexagons are appropriate and efficient for management and analysis of geospatial data (Tong, Ben, and Wang 2010) and are increasingly popular as bases for discrete spatial simulations (Sahr, White, and Kimerling 2003). Hexagonal tessellation has been adopted by previous studies in the remote sensing domain (Potere 2009; Goldblatt et al. 2018). Hexagons are advantageous over square pixels because of their higher symmetry, sampling efficiency, equidistance, angular resolution, lower aliasing effect, and consistent connectivity (Wang and Ai 2018). Hex-cells in a hexagonal tessellation are arranged in a contiguous global lattice, which is the most compact arrangement of many equal circles. Hexagonal grids are advantageous because they are characterized by elements that do not have gaps or overlaps and the center-to-center distances between adjacent grid cells are approximately equal. Moreover, hex-cells have a topology that is symmetrical, invariant, and of equal area, and they can be recursively partitioned into smaller divisions of grids.

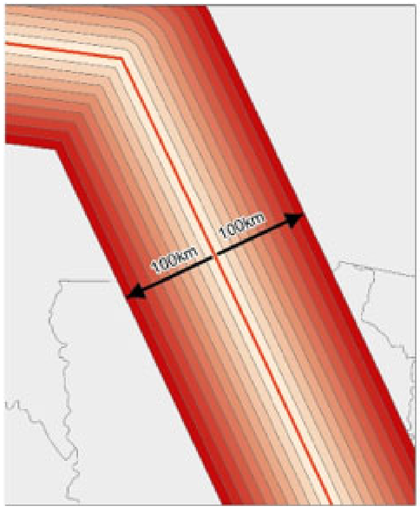
In this study, we use hex-cells that are approximately 20 kilometers from vertex to vertex. We select hex-cells that are within approximately 100 kilometers of each side of the transportation corridor (step 2). Previous studies utilize different sizes of hex-cells, which vary by application and domain. For example, Goldblatt et al. (2018) evaluates the optimal size of hexagons for classification of built-up land cover in three countries and finds variations in the hex-cell sizes between countries (ranging from 1 to 4 decimal-degrees from center to center). For other applications, for example, monitoring carbon sequestration with MODIS observations, an area of 390 square kilometers per hexagon has been found optimal (Kwon and Larsen 2013). In another study, Potere et al. (2009) evaluate the accuracy of eight global maps of built-up land cover by using an equal-area hexagonal DGG with a facet size of 0.132 square kilometers. Because in this study we evaluate temporal and spatial variations in SOL (the sum of the digital number values of all pixels in a hex-cell), as long as the size of the investigated units (hex-cells) is uniform, the size of the hex-cell should have minimal impact on the assessment.

Figure A2.1 Characterization of Corridors, Buffers, and Hexagons

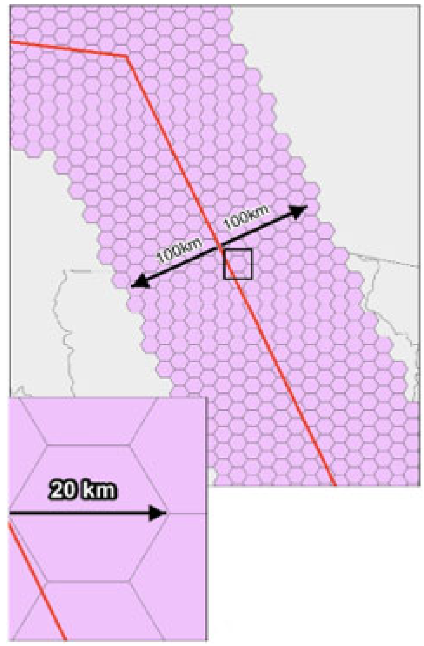
a. Nodes and segments | **b. Buffers**



c. Rings



d. Hexagons



Step 4: DMSP-OLD intercalibration

Defense Meteorological Satellite Program (DMSP) time series data consist of 33 annual products created since 1992 using data collected by six different satellites (table A2.1).

Table A2.1 DMSP-OLS Satellites

	F-10	F-12	F-14	F-15	F-16	F-18
1992	F101992					
1993	F101993					
1994	F101994	F121994				
1995		F121995				
1996		F121996				
1997		F121997	F141997			
1997		F121998	F141998			
1998		F121999	F141999			
1999			F142000			
2000			F142001	F152000		
2001			F142002	F152001		
2002			F142003	F152002		
2003				F152003		
2004				F152004	F162004	
2005				F152005	F162005	
2006				F152006	F162006	
2007				F152007	F162007	
2008					F162008	
2009					F162009	
2010						F182010
2011						F182011
2012						F182012

We estimate economic activity in the geographical extent of each hexagon using nighttime lights, as they are measured by the Defense Meteorological Satellite Program Operational Linescan System (DMSP-OLS) series of satellites. We use the *DMSP OLS: Nighttime Lights Time Series Version 4* product of the DMSP-OLS. Version 4 of the DMSP-OLS Nighttime Lights Time Series consists of cloud-free composites made using all the available archived DMSP-OLS smooth resolution data for calendar years. We analyze the *stable_lights* band, which contains the lights from cities, towns, and other sites with persistent lighting, including gas flares. Ephemeral events, such as fires, have been discarded. The background noise was identified and replaced with values of zero.

One of the limitations of DMSP-OLS is the lack of on-board calibration between satellites. The preflight calibration for the individual instruments is of little value, because the gain commands made to the instrument are not recorded in the data stream (Elvidge et al. 2014). We adopt a methodology developed by Elvidge et al. (2009) to intercalibrate the values of the satellites and allow a temporal analysis. This procedure relies on areas (known as reference areas) where little or no change in lighting has occurred over time. In their analysis, the authors find that the area of Sicily, Italy, has the most favorable characteristics to serve as a reference area: it consists of an even spread of data across the full dynamic range (0-63) and a clearly defined diagonal cluster of points. A second-order regression model is performed for each satellite, using F121999 satellite as the reference (this satellite had the highest digital values) to adjust all other satellite years to its data range. Because in some years multiple satellites have collected data (see table A2.1), for each year we select one satellite that we use for the analysis. The satellites we use are: F101992, F101993, F121995, F121996, F121997, F121998, F121999, F152000, F162008, F162009, F182010, F182011, and F182012. An intercalibration is applied based on the coefficients presented in table A2.2 (adopted from Elvidge et al. (2014)). The form of the calculation is:

$$y = c_0 + c_1 x + c_2 x^2 \tag{A2.1}$$

Table A2.1 Intercalibration Coefficients

Satellite	Year	c_0	c_1	c_2
F10	1992	-2.057	1.5903	-0.009
F10	1993	-1.0582	1.5983	-0.0093
F12	1994	-0.689	1.177	-0.0025
F12	1995	-0.0515	1.2293	-0.0038
F12	1996	-0.0959	1.2727	-0.004
F12	1997	-0.3321	1.1782	-0.0026
F12	1998	-0.0608	1.0648	-0.0013
F12	1999	0	1	0
F15	2000	0.1254	1.0452	-0.001
F15	2001	-0.7024	1.1081	-0.0012
F15	2002	0.0491	0.9568	0.001
F15	2003	0.2217	1.5122	-0.008
F16	2004	0.2853	1.1955	-0.0034
F16	2005	-0.0001	1.4159	-0.0063
F16	2006	0.1065	1.1371	-0.0016
F16	2007	0.6394	0.9114	0.0014
F16	2008	0.5564	0.9931	0

F16	2009	0.9492	1.0683	-0.0016
F18	2010	2.343	0.5102	0.0065
F18	2011	1.8956	0.7345	0.003
F18	2012	1.875	0.6203	0.0052

Step 5: Calculate the sum of light (SOL) measure per hexagon and per year (1992–2012)

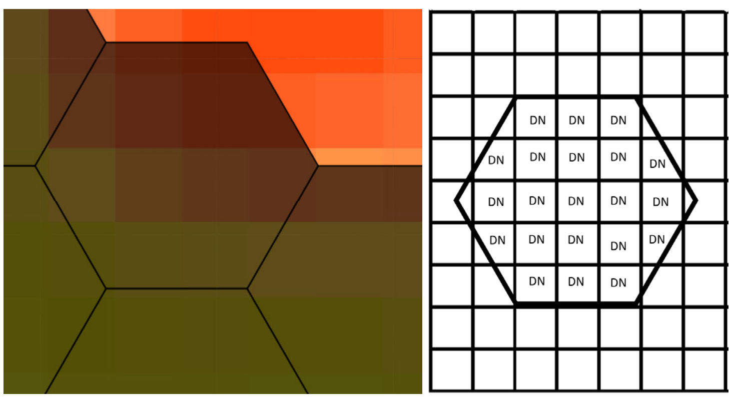
We overlay the hexagons with the DMSP-OLS satellite scenes of each year. Each hexagon consists of multiple DMSP-OLS pixels (figure A2.2). For each year, we calculate the SOL measure, as follows:

$$SOL_y = DN_{y1} + DN_{y2} + \cdots + DN_{yN}$$

Where SOL_y is the SOL in year y, and DN_{yi} is the decimal number value, or the light intensity of overlapping pixel i in a given hexagon, which ranges between 0 and 63.

A pixel is to be considered within a hexagon in this analysis if most of its area (that is, more than 50 percent) is within a hexagon.

Figure A2.2 Pixel Composition of Hexagons



We repeat these calculations for each year. The result is panel temporal data, which allows us to track annual changes in nighttime light emission in each hexagon.

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