Final report

International Growth Centre

Roads to trade

The welfare effects of connecting mines versus cities

Roberto Bonfatti
Yuan Gu
Steven Poelhekke

February 2017

When citing this paper, please use the title and the following reference number:
C-39304-SLE-1

DIRECTED BY
LSE
UNIVERSITY OF OXFORD

FUNDED BY
UKaid
from the British people

Final report for IGC Project Code: 39304

Roads to trade: the welfare effects of connecting mines versus cities

Yuan Gu

Vrije Universiteit Amsterdam, Tinbergen Institute

Roberto Bonfatti

University of Nottingham

Steven Poelhekke

Vrije Universiteit Amsterdam, Tinbergen Institute, and De Nederlandsche Bank[*]

February 15, 2017

[*]Corresponding author. Email: steven.poelhekke@vu.nl. Views expressed are those of the authors and do not necessarily reflect official positions of De Nederlandsche Bank nor of the Eurosystem of central banks.
Both authors are also affiliated with OxCarre and CESIfo.

1 Motivation

Should African countries build more transport infrastructure to export natural resources to overseas markets, or should they focus on improving internal connectivity between cities, and with cities in neighbouring countries? This is an important question, with no easy answer. On the one hand, Africa has a comparative advantage in primary commodities, and the first strategy may best serve her trade. Indeed, Africas networks were originally designed to export primary commodities, and Chinas recent investment seems to be reinforcing this pattern (Bonfatti and Poelhekke, 2015). On the other hand, to improve internal connectivity is a top priority of development agencies, on the premise that roads lead to more trade (i.e. Volpe Martincus and Blyde, 2013), and that more regional market integration is needed to foster sustainable growth.

To make an informed decision between these development strategies, it is important to develop a rigorous understanding of their economic impact. The aim of this project is to help to do so, by studying the role of natural resources in shaping the development of road infrastructure in West Africa from independence until today. When new mines start production, road improvements will be required to connect those mines to the port of shipment. Given scarce financial resources, policy makers may have to choose between investment in such connections, and investment in the improvement of roads connecting cities. Our first goal is to develop a measure of the extent to which actual road investment in West Africa focused on connecting mines versus cities. Next, we want to investigate the determinants of these investment decisions, and their impact on the spatial equilibrium of the economy. Finally, we want to compare the welfare consequences of these investment decisions to those of a benchmark optimal network expansion path. The ultimate goal is to learn lessons about what kind of transport infrastructure the African countries should focus on today.

In order to conduct this analysis, data was required on road construction, mine discovery, and city population growth in West Africa from independence until today. IGC funding was secured primarily to pay for a research assistant to help with the data collection and analysis, and in addition to cover for the dissemination of any preliminary results. As for the agreed contract timeline, 225 RA days, or roughly one year, were allocated to the data collection (from start of contract on Dec 1 2015 to Dec 1 2016), and the remaining contract period was allocated to initial data analysis (Dec 1 2016 to Feb 1 2017). Because the analysis proved very complex and time consuming, the PIs have not yet had the change to present results at conferences. For this reason, the small part of the budget which was allocated to travel expenses was returned to the IGC. As for informal understanding with the IGC, the PIs may be in contact in future to apply for travel funding on a conference by conference basis.

The data collection effort resulted in a comprehensive dataset on road paving, mine discovery and city population growth in 13 West African countries over a period of 47 years (1965-2012), divided into 18 sub-periods. The data had then to be elaborated to produce our measure of connection of mines versus cities. This required calculating two counterfactual networks, one based under the assumption that policy makers would primarily care about connecting mines to ports, and one based on the assumption that they would primarily care about connecting cities. Although the methodology to calculate these counterfactuals built on Burgess et al (2015), its actual implementation in the context of West Africa required the writing of a complex Phyton code, which automatically allocates kilometres of roads actually paved in each country-period to the alternative segments that would have been paved under the two counterfactuals. Having constructed our measure of connection of mines versus cities, we then started to study the determinants of these investment decisions.

In the rest of this report, we provide a full description of the outcome of the project. We begin in Section 2 by describing the dataset which we have put together. In Section 3, we describe the challenges faced in the construction of the mining and city counterfactuals. In Section 4, we explain how the counterfactuals are used to produce our measure of connection of mines versus cities, we provide summary statistics on our measure, and we discuss examples from road investment in Sierra Leone. Section 5 looks at possible determinants of the investment decisions captured by our measure. Finally, Section 6 discusses the next steps of this project.

2 Collection of the data

2.1 Roads

We have 18 Michelin maps which depict 13 West African countries' roads from 1965 to 2012. The West African countries include Benin, Burkina Faso, Côte d'Ivoire, Gambia, Ghana, Guinea, Guinea Bissau, Liberia, Mali, Niger, Senegal, Sierra Leone and Togo. The years include 1965, 1968, 1969, 1971, 1973, 1976, 1983, 1984, 1986, 1989, 1990, 1996, 1998, 2002, 2003, 2007, 2009,

2012. Figure 1 provides an example for Togo, showing two different years.

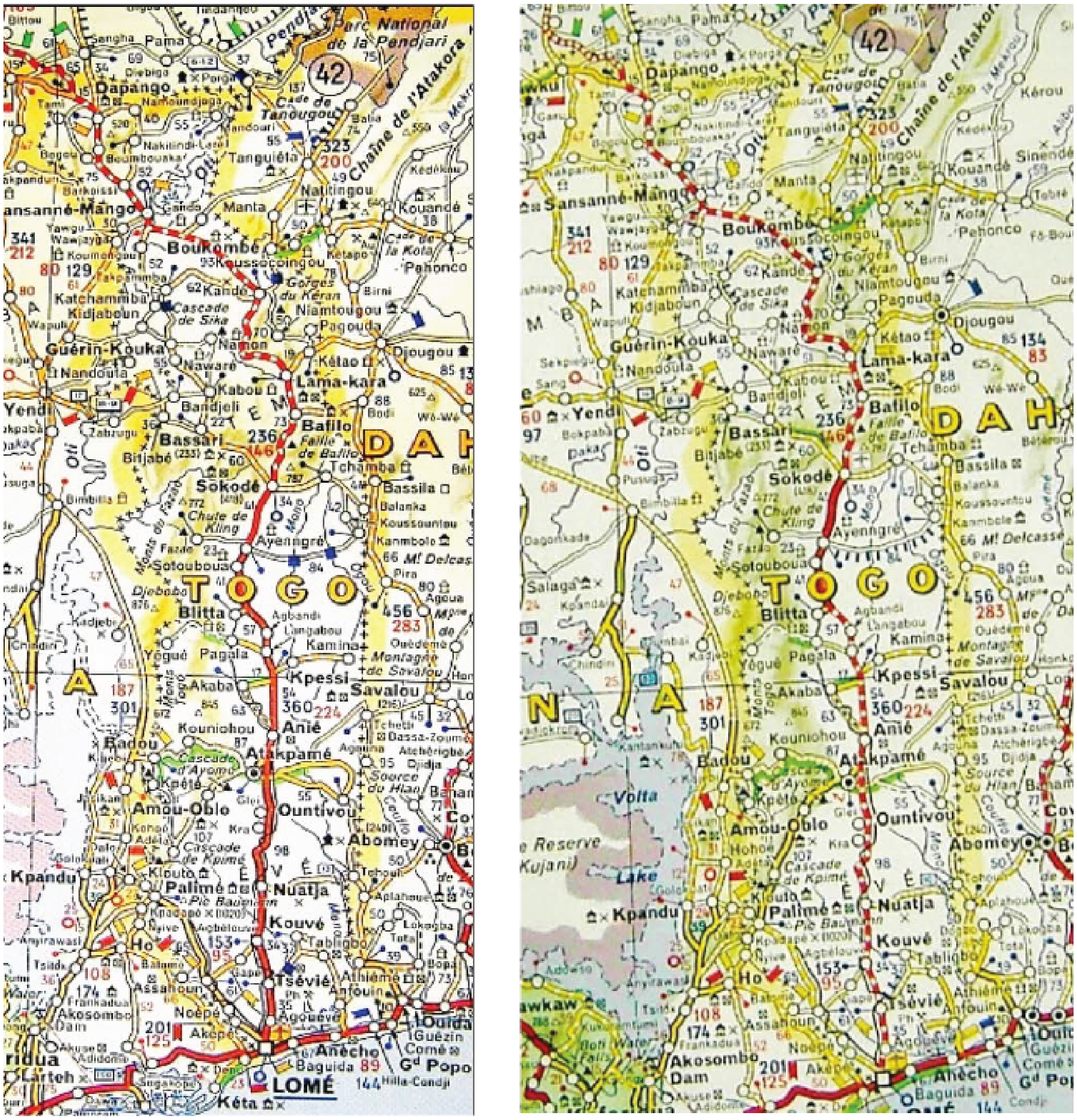


Figure 1: Michelin map detail for Togo in 1965 (left) and in 1968 (right)

The maps are scanned and the roads are manually digitized in ArcGIS platform. The world transport map from ArcGIS public online database is used as the base map, which is the latest update of world road information. The scanned Michelin maps are projected to the base map as graphs and we drew the road line by line. The digitized roads are geo-referenced, namely they have a predefined geographic coordinate system which locates them in the virtual space. For the network analysis described further down, we had to improve the quality of the digital map by making sure that all line segments connect. The Michelin maps record roads on a national level, unavoidably simplifying the twists and turns along the way. By using a high-resolution base map, we not only replicate Michelin maps but also manage to add on the precise shape of the roads, raising the resolution from 1:60,000 to 1:30,000 and solidifying the subsequent spatial analysis.

We choose the starting year at 1965 since Michelin maps change the legend at 1965, which makes the previous map unmatchable to the later ones. From 1965 onwards, Michelin maps have stuck to the same set of legend which lasts until today. The maps record the types and the surface condition of roads. For road types, the roads are classified as major roads, secondary roads or non-specified, with no further definition from Michelin. But from previous legends and the context, it is reasonable to interpret that road types refer to the regional importance of roads. Major roads are intercontinental roads; secondary roads are national roads and the unspecified roads are normal local roads. In terms of road surface condition, they are tagged as surfaced roads, improved roads, partially improved roads, earth roads, tracks and others. Michelin gives a much more elaborated description to its various categorization (see Table 1): Surfaced roads are the best roads paved with asphalt and concrete which are suitable for any vehicle and weather, the kind of roads where our interest mainly lies. Less than surfaced roads, improved roads are the ones unpaved but receive regular mechanical maintenance and suitable for high speeds in certain sections. Further down the line, partially improved roads are the ones whose resurfacing is more random and the structures like small bridges are temporary which may malfunction in bad weather. We also record worse roads like earth roads and tracks whose exact definition can be found in the table below. We stop at any roads below tracks, which we find less significant for transport.

To precisely describe the road condition, we generate two variables: road type(T) and road surface(S). Road type(T) takes the value 1, 2, 3 and 0, which indicates major roads, secondary roads, normal roads and nonexistence of roads. Road surface(S) takes the value of 1, 2, 3, 0, which indicates hard surfaced roads, improved roads, partially improved roads and tracks, whose definition can be check in Table 2 below. Though we have detailed information on road type and road surface, we are mostly interested in the dynamics of paved roads where $S = 1$ because it is standard to compare total length of paved roads among countries as an indicator of transport development. It is also convenient to cross reference with other research. We then categorize all interior roads as unpaved where $S \neq 1$. Future research may originate from the unused variation of roads in this project.

	Map Display	Map Key	Key Definitions
Road Type	red line	major road	/
	yellow line	secondary road	
	white line	/	
Road Surface	solid line	hard surfaced	asphalt, concrete, etc.
	dashed line	improved	suitable for high speeds in certain sections. Regularly maintained with mechanical equipment. River crosssings: permanent bridges or heavy capacity ferries.
	dotted line	partially improved	Improvement is mainly confined to the difficult sections. The state of the road depends largely on the length of time that has elapsed since the last grading and re-surfacing. Many small bridges and other structures are still of a temporary kind.
	faded line	earth roads	They are suitable for all types of vehicles but receive only summary maintenance.
	faded dashed line	track	suitable only for cross-country-vehicles and certain types of truck. Where there is no clear trail, a guide and navigation instruments are essential. It is most unwise for a single vehicle to journey on its own.

Table 1: Michelin map legend

Definition		**Road Type**			
		T=1	**T=2**	**T=3**	**T=0**
Road Surface	**S=1**	major road, hard surfaced	secondary road, hard surfaced	normal road, hard surfaced	/
	S=2	major road, improved surface	secondary road, improved surface	normal road, improved/partially improved/earth roads	/
	S=3	major road, partially improved surface	secondary road, partially improved surface	/	/
	S=0	major road, earth road or track	secondary road, earth road or track	marked track	road doesn't exist or deteriorates below track

Table 2: Road type and quality coding

It is interesting to look at the road dynamics of West Africa from 1965 to 2012, see Table 3. We can observe that roads are both upgrading and downgrading at different level. 90% of the paved roads from 1965 remain paved in 2012, while 10% have deteriorated, among which 1% completely vanish. Building roads out of nowhere is relatively rare. Paving normally happens to existing roads or tracks which is easier to upgrade. Compared to paved roads, unpaved roads are more prone to deterioration, suggesting the lack of investment in maintenance.

West Africa road quality dynamics 1965-2012							
Length (km)				**2012**			
		total		**no road**	**tracks**	**unpaved roads**	**paved roads**
1965	**no road**	16,678	**Transform to →**	719	4,938	8,985	2,036
	tracks	24,666		1,103	12,711	7,259	3,593
	unpaved roads	50,372		687	5,414	28,093	16,178
	paved roads	10,477		113	117	952	9,295

Table 3: Descriptive statistics on road quality changed

It is also enlightening to look at the country-level paved roads dynamics for the past four decades, see Figure 2. There is general trend of a paving jump in West African countries. For example, Côte d Ivoire increased paving almost six-fold from 900 km to 5,200 km, together with Senegal, Niger and Mali. Burkina Faso, Guinea, Togo, Benin are among the second layer with moderate amount of new road pavement, while Ghana, Sierra Leone, Guinea Bissau, Gambia and Liberia more or less stagnated in terms of total pavement length.

2.2 Cities

The data on cities was kindly shared by Hervé Gazel (Université Jean Moulin Lyon 3) of the Africapolis project.[1] It contains the location and population of cities in 33 countries for the years 1960, 1970, 1980, 1990, 2000 and 2010. Within our sample we observe 3,360 records on city location and historical population. We use the cities which exist from 1960.

[1]See: http://www.afd.fr/lang/en/home/publications/travaux-de-recherche/archives-anciennes-collections/NotesetEtudes/Africapolis

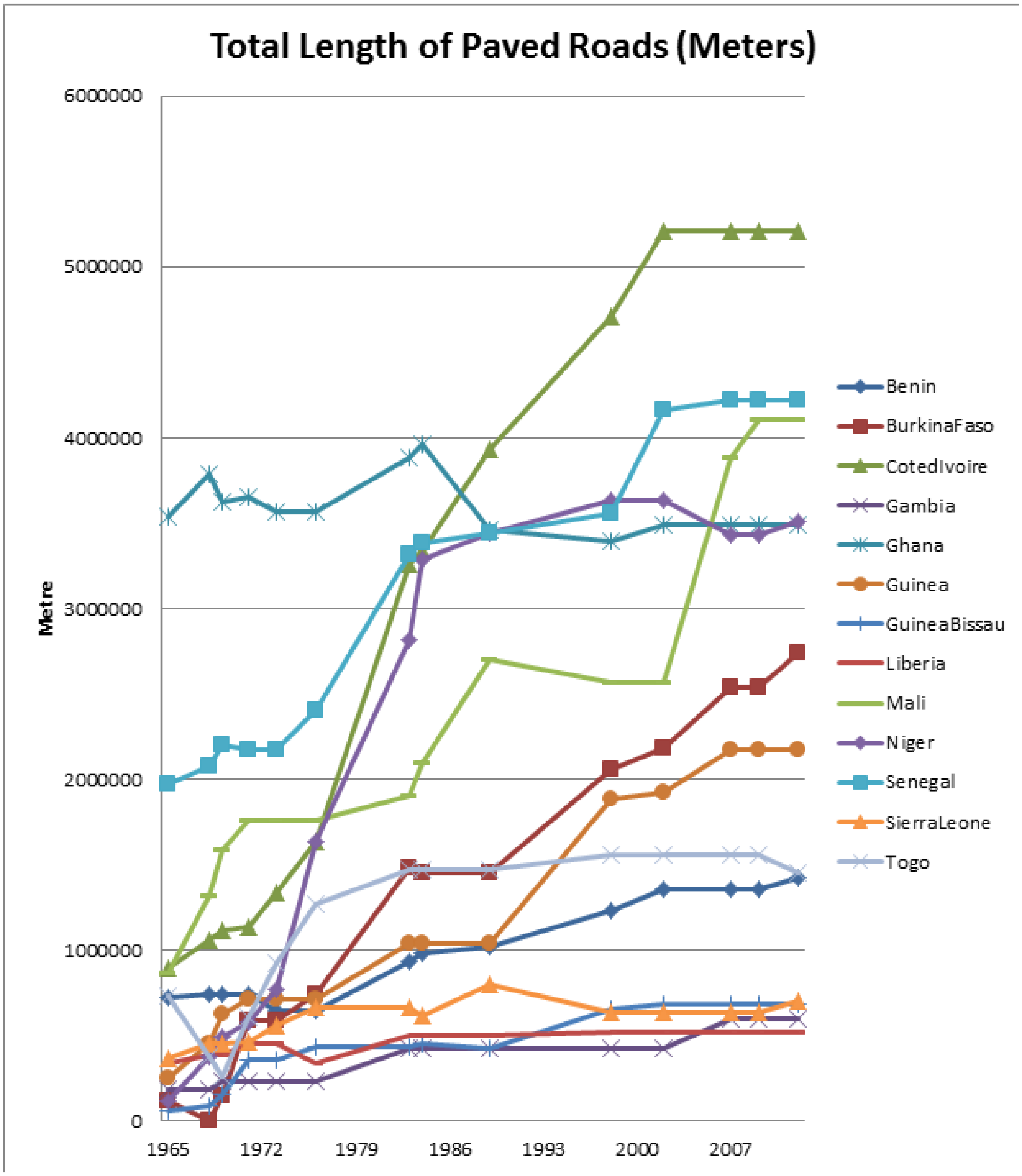


Figure 2: An example of road deterioration can be seen in Togo from 1965 to 1968. The long roads connecting Blitta and Lome used to be paved(solid red line) in 1965 but deteriorated into unpaved roads(dashed red line) in 1968.

2.3 Mines

Our mining data is the combination of three sources: MinEx Consulting, the Raw Material Data from InterraRMG(RMG) and Mineral Resources Data System(MRDS), providing us with 593 records on West African mines and 70% of which have exact discovery year.

We generate an indicator to measure mine size in all three mine databases, which mainly adopts the categorization in MinEx. We choose MinEx as the main source because it has the most complete data on the year of discovery. Missing dates are filled in using MRDS and RMG. MinEx has five tags for the size variable: supergiant, giant, major, moderate, minor. We group giant and supergiant together (there is only one supergiant among deposits discovered before 1965), to get four categories. They are weighted from 4 to 1: giant=4, major=3, moderate=2, minor=1. Big mines will have priority to road connection in our counter-factual road pavement. Very few of the deposits have other size measures which come from RMG and MRDS: for reference, we group 'Medium' into moderate, 'Small' into minor, and 'No' into missing, such that all mines adhere to the same size measure.

The mining database include various kinds of mines: bauxite, chromium, copper, gold, iron ore, manganese and others. We include all mines except diamond since they are unlikely to be transported in bulk ships. The unit value of the mines varies a lot. For the sake of simplicity, we do not weigh in mine value but only use mine size to rank counterfactual road connections for now.

2.4 Ports

We use the 2016 World Port Index(WPI) data on ports. The WPI is a public database which records ports around the globe, including West Africa ports. It provides the location, characteristics, shipping facilities and available services of many ports. We are mostly interested in the depth of the port since bulk transport requires deep water ports. WPI provide detailed quantified category to record water depth. We use 'Channel' and 'Cargo Pier' to measure water depth, which is defined in Table 4 below with letters A to Q.

According to Waters, Mayer and Kriebel (2000), figure 4.46, dry bulk ships from the 1950s onwards always needed at least 5 m draft. We therefore keep all the letters through the A and exclude ports with letters O, P and Q in either 'Channel' or 'Cargo Pier' depth. 'Anchorage'

WORLD PORT INDEX

FEET	a	76-over	e	56-60	j	36-40	n	16-20
	b	71-75	f	51-55	k	31-35	o	11-15
	c	66-70	g	46-51	l	26-30	p	6-10
	d	61-65	h	41-45	m	21-25	q	0-5
METERS	a	23.2-over	e	17.1-18.2	j	11.0-12.2	n	4.9-6.1
	b	21.6-22.9	f	15.5-16.8	k	9.4-10.7	o	3.4-4.6
	c	20.1-21.3	g	14.0-15.2	l	7.9-9.1	p	1.8-3.0
	d	18.6-19.8	h	12.5-13.7	m	6.4-7.6	q	0-1.5

Table 4: World port index depth coding

depth we do not consider, since mining stuff will be mostly loaded on the pier. We then group the remaining letters into 4 categories: a-d (the deepest ports, weight=4); e-g (second deepest ports, weight=3); h-k (weight=2); l-n (weight=1). Deeper ports will have priority to road connection in our counter-factual road pavement. We also drop 'Marine terminals' which are sea ports for oil.

We use all deep-water ports existing today to build our counterfactual network, on the logic that, even if some of them did not exist in 1965, we know that they could be built where they are today. Same logic that we have used for roads.

3 Construction of counterfactual road networks

First we calculate paving quota based on real paving record. For example, if Ghana paved 300 kilometers of roads and let 100 kilometers of roads deteriorate during 1970 to 1973, we will only count the 300 kilometers as paving quota. It is because the costs of paving and maintenance are most likely different. Deciding where to pave is different from holding back the money for maintenance, both of which may include more complicated social political concern that we want to capture. It is cleaner to stick to new paving only.

To assign the paving quota, we construct two set of counterfactuals: city-city counterfactuals and mine-port counterfactuals. Within each set of counterfactuals, we imply three sorting criteria:

distance, size and market potential, which imitates the objectives of the social planner at the starting year of 1965. The construction of the city-city counterfactuals follows exactly the method proposed by Burgess et al (2015), while the construction of the mine-port counterfactuals applies the logic of that method to the connection of mines and ports.

In the city-city counterfactuals, the social planner wants to connect cities to cities. 'Distance' indicates that the city pair close to each other will get paved first. 'Size' indicates that city pair with biggest 1960 population sum will get paved first. 'Market Potential' is the combination of both, indicating that city-pair with big population sum and short distance will get paved first.

Similarly, the mine-port counterfactuals represent the social planner's objective to connect mines to the nearest port. 'Distance' indicates that the mines closet to the port will get paved first. 'Size' indicates that big mine and deep ports will be connected first. 'Market Potential', being the combination of both, indicates that big mines and deep ports with short distance will get paved first. The details are shown in the table below.

Counterfactual paving			**Objective**	**Description**
1.1	city-city	Distance	Min Distance(city i, city j)	connect the city-pair with short distance first
1.2		Size	Max Population Sum(city i, city j)	connect the city-pair with big population sum first
1.3		Market Potential	Max Population Sum/Distance (city i, city j)	connect the city-pair with short distance and big population sum first
2.1	Mine-port	Distance	Min Distance(mine i, port j)	connect the mine and the port with short distance first
2.2		Size	Max Size Sum(mine i, port j)	connect the big mine and the deep port first
2.3		Market Potential	Max Size Sum/Distance(mine i, port j)	connect the big mine and the deep port with short distance first

Table 5: List of counterfactuals

The paving starts from the city with bigger population and ends at the city with smaller population based on 1960 city population. It is because bigger cities are more likely to be transport hubs where road construction are more economic. If the paving quota exhausts, the counter factual paving stops in the middle until new paving quota emerges.

In mine-port counterfactuals, the paving starts from the port and ends at the mine. The reason being that the roads connected to the port locate at the coast and branch out to inland road network, which makes it economical to start paving. Similarly, if the paving quota exhausts, the counter factual paving will stop in the middle until new paving quota emerges. Costal countries–Benin, Côte d'Ivoire, Gambia, Ghana, Guinea, Guinea Bissau, Liberia, Senegal, Sierra Leone and Togo– use their domestic ports. For the other three landlocked countries–Burkina Faso, Mali and Niger–we assume that they have access to all ports in West Africa and choose the optimal port based on counterfactual objectives.

The workflow of generating counterfactual roads is shown in Figure 3 below. First, we build a complete West African road network with ArcGIS network extension. We make use of the built-in python window to run a country-loop to draw the shortest route for every city-pair and mine-port connection. Export data into Stata where paving quotas are assigned to roads along the shortest routes based on various sorting objectives. Last but not least, reimport data back to ArcGIS to visualize the counterfactuals. We provide the Python code in the Technical Appendix.

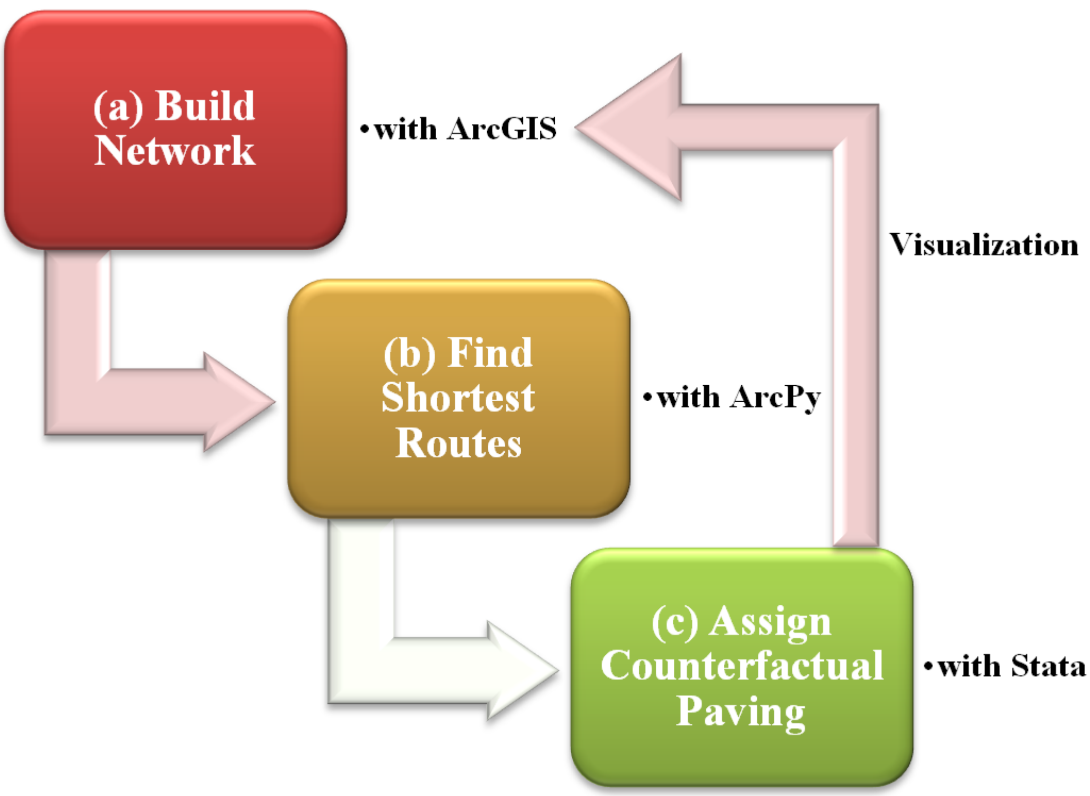


Figure 3: Process flow chart

4 Measuring the overlap between actual and counterfactual networks

To measure the overlap between the actual road network and the two counterfactuals we proceed in several steps.

First, we compare the network extension from year to year between the actual extension and the counterfactual that follows the principle of maximising market potential by prioritising nearby and large cities. In Figure 4 below, let area a represent the network that was in place in 1965. Assume now that it was extended to cover area $A = a + b + c + d$ by the year 1968. The actual additional paving has thus covered area $b + c + d$, which also provides us with the paving quota (the sum of road kilometers) that the country's budget allowed to be paved between 1965 and 1968.

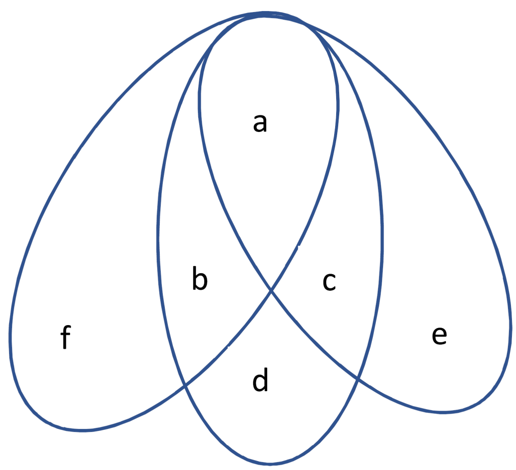


Figure 4: Overlap diagram

Let area $a + c + e$ represent the network that should have been completed by 1968 (taking as given the actual paving budget) if the market potential city counterfactual had been followed, because, presumably, there is a city in area e (that is larger than a city in area d) that should optimally have been connected first. The marginal paving should thus have covered area $c + e$. We now have c/A as the overlap between the actual new paving and the optimal new paving according to the market potential city counterfactual as a share of the total actual network by 1968. The country could have chosen to allocate this budget towards paving alternative roads.

Let area $a + b + f$ represent the network that should have been completed by 1968 if the mining counterfactual had been followed, because, presumably, there is a mine in area f that should optimally have been connected first to a port in area a to maximise natural resource export revenue. The marginal paving should thus have covered area $b + f$. We now have b/A as the overlap between the actual new paving and the optimal new paving according to the mining counterfactual as a share of the total actual network by 1968.

Our measure of relative bias R towards the city counterfactual is then the difference between b/A and c/A:

$$R = c/A - b/A \tag{1}$$

The bias R is bounded between -1 and 1, where 1 implies perfect overlap between the city counterfactual and the actual network ($c/A = 1$) and zero overlap between the mining counterfactual and the actual network ($b/A = 0$).

In the actual data, it happens in 44% of country-years that the quality of a segment of road deteriorates. At the median, 3% of the road network is no longer of paved quality in such an event. In other words, roads that were paved may change status and become unpaved one period later. The government can choose to repave these sections. We assume that repaving has the same marginal cost as paving a section of road that had never been paved before. Moreover, we assume that maintenance (making sure that a paved section is still paved in the next period) is without cost. This may seem like a strong assumption, but we have no information on the actual cost of road construction, which will likely depend a lot on the geography, but also on the market structure of the construction business in a given year. Since we cannot credibly know for each section of road the construction and maintenance costs in each year, we reasonably assume that paving is orders of magnitude more costly than maintenance. The effect of this assumption is that if we observe both new paving and repaving in a given year, we add both to the country's total paving budget in that year.

Finally, it can happen that a section of road is paved in reality in a period *later* than what would be prescribed by either counterfactual. In that case it may seem that there is no overlap in marginal terms. We therefor adjust the overlap measures to take into account the fact that in any period, the country's planner may choose to revert back to the original (possibly counterfactual) plan that prescribed paving of a section of road. Thus, if in 1972 we observe actual paving of a section of road that optimally should have been paved already by 1968, we still count this as overlap with that counterfactual program.

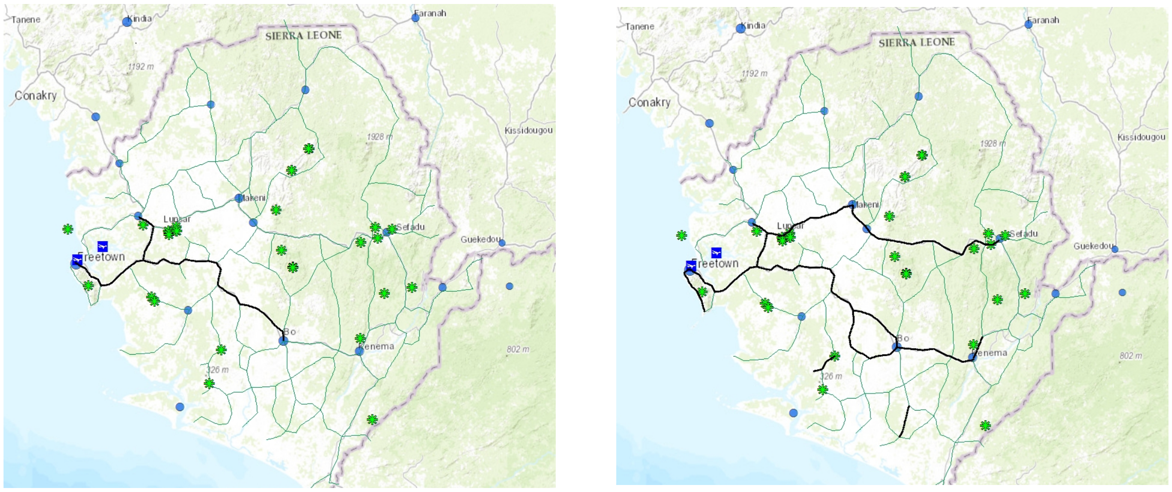
4.1 Examples of overlap: case of Sierra Leone

In keeping with the interest of the Sierra Leone IGC country office in this project, we provide some graphical examples of our measure of overlap for the case of Sierra Leone. Consider first Figure 5, which shows for 1965 (the start of our sample) and 2012 (the end of our sample) the actual road network in Sierra Leone. In total, Sierra Leone paved over 1,100 kilometers of road between those years, but due to frequent deterioration of the road quality the net increase has only been 440 kilometers. Also shown are the location of natural resource deposits in green asterisks and cities are denoted by blue circles, including those in neighboring countries that lie within 50 kilometer of the border. The network extends eastwards from the capital city and port of Freetown and appears to connect many of the deposits. At the same time, several cities are not connected and there are no paved connections with neighboring countries.

Figure 6 shows how this budget of road paving should have been allocated if the country had followed either of two possible counterfactual programs. The left figure shows the counterfactual that gives priority to natural resource deposits and the right figure the counterfactual that gives priority to cities. In both cases we show the 'market potential' version of the counterfactual. If no deterioration of roads had taken place (such as during civil war) then almost all deposits or all cities could have been connected to the network. Moreover, a country crossing would have been built to a city in neighboring Guinea to the North (by 1971 already).

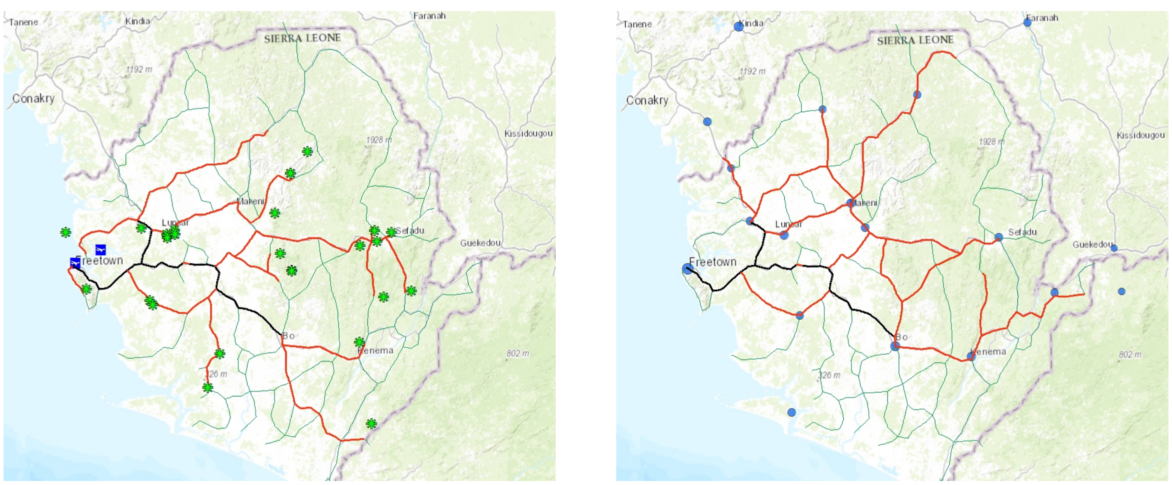
More detail on our measure of overlap of actual paving with either counterfactual can be shows by focussing on the years 1984 and 1986. Table 6 tells us that 158 kilometer of roads were paved between those years. Figure 7 shows that this effort was spread across the country: additions are circled in the right figure of Figure 7.[2] We can now compare these additions with the two counterfactuals in Figure 8. Only one section of newly paved road overlaps with the city counterfactual (in the center of the country, going south-west), while several other sections overlap with the mining counterfactual. This results in an overlap score of 0.16 with the city

[2]The cities are still given in blue dots and the natural resource deposits in green asterisks. Please note however, that some of the latter had not been discovered yet by 1986. These are nevertheless included in Figure 7, but not in Figure 8. The mining counterfactual uses the actual (exogenous) timing of natural resource discoveries.



1965 2012

Figure 5: Actual paved (thick black line) and unpaved (thin lines) road network in Sierra Leone



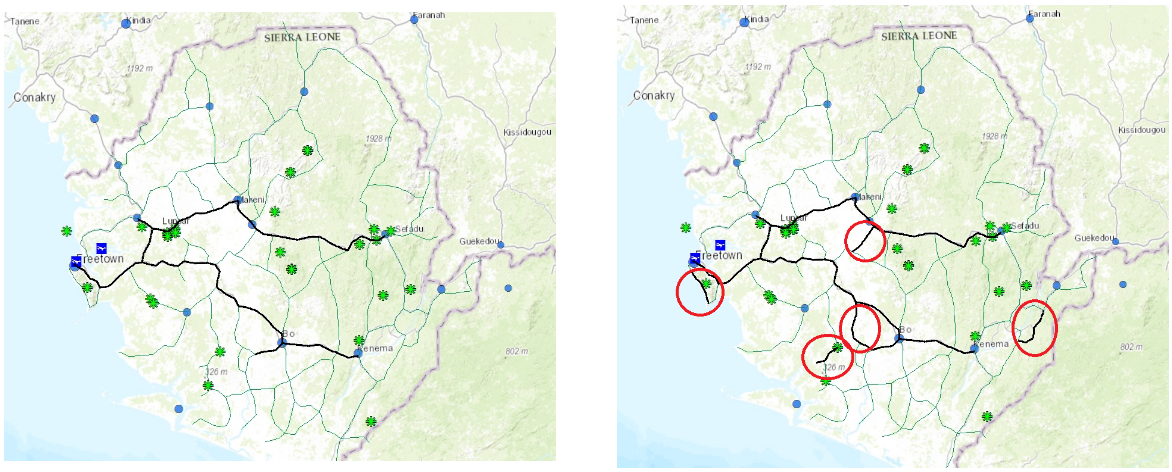
Mining market potential City market potential

Figure 6: Counterfactual paved road network in Sierra Leone by 2012 (red thick lines)

Table 6: Road paving by year in Sierra Leone

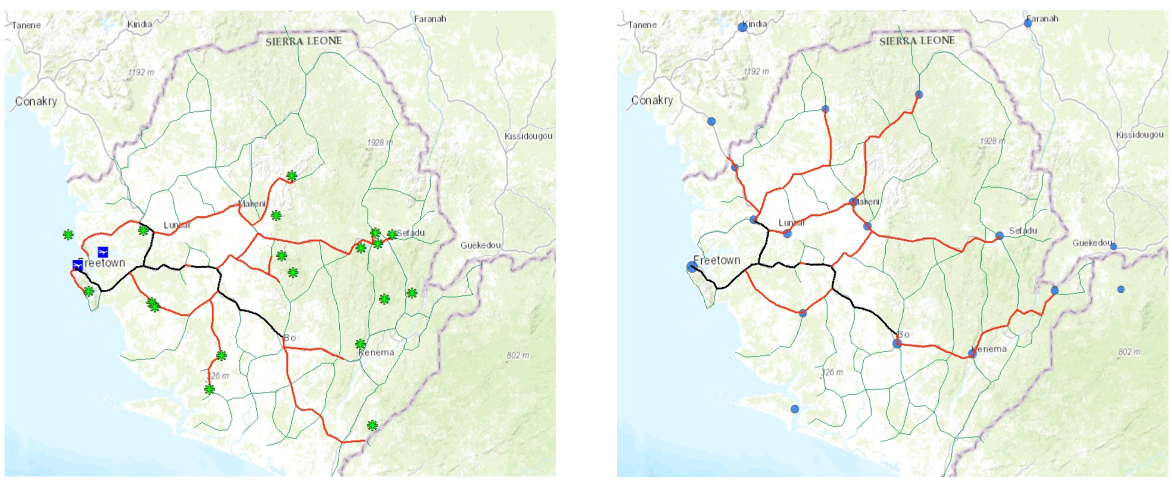
Year	Stock of paved roads	Paved since last period	Deteriorated since last period	Overlap with mining counterfactual	Overlap with city counterfactual	Difference (relative bias)
1965	271.048					
1968	478.356	254.684	-47.376	0.198	0	-0.198
1969	478.356	0	0	0	0	0
1971	460.395	110.522	-128.483	0.574	0.429	-0.146
1973	469.104	106.658	-97.949	0.664	0.935	0.271
1976	626.590	193.560	-36.074	0.512	0.555	0.044
1983	608.857	0	-17.732	0	0	0
1984	563.443	0	-45.414	0	0	0
1986	721.031	157.588	0	0.352	0.164	-0.189
1989	724.853	29.643	-25.821	0.730	0.652	-0.078
1990	750.674	25.821	0	1	1	0
1996	643.204	0	-107.470	0	0	0
1998	617.383	0	-25.820	0	0	0
2002	642.966	25.583	0	0	0	0
2003	599.913	25.821	-68.874	1	1	0
2007	668.787	68.874	0	0	0	0
2009	643.204	0	-25.583	0	0	0
2012	714.363	133.054	-61.894	0.808	0.808	0

counterfactual and 0.35 with the mining counterfactual. The difference then tells us that, between 1984 and 1986, Sierra Leone favoured the mining counterfactual (see also Table 6).



1984 1986

Figure 7: Actual paved (thick black line) and unpaved (thin lines) road network in Sierra Leone (Additions circled in red)



Mining market potential City market potential

Figure 8: Counterfactual paved road network in Sierra Leone by 1986 (red thick lines)

Table 7: Road paving characteristics, all country-years

variable	N	mean	s.d.	median	min	max
Paving (km)	221	136.92	225.08	51.52	0	1794.12
Deterioration (km)	221	-39.42	85.28	0	-759.17	0
Overlap with mining CF (b/A)	204	0.17	0.30	0	0	1
Overlap with city CF (c/A)	221	0.28	0.36	0.06	0	1
Relative bias to city CF (R)	204	0.13	0.34	0	-1	1

4.2 Descriptive statistics on overlap and relative bias

Table 7 shows the summary statistics for paving activity and the degree of overlap with either counterfactual. On average, road paving has more overlap with the city counterfactual than with the mining counterfactual. However, there is substantial variation and there are country-year observations in which paving has had full overlap with the city or with the mining counterfactual. It appears that the median country-year period has balanced both optimal programs, resulting in a median relative bias score of zero, but this is driven by periods in which no paving took place. Conditioning on country-years with positive paving the median is 0.06 (see Table 8). Table 9 shows by country the average annual paving activity and the degree of overlap with either counterfactual for country-years with positive paving. Table 10 shows the same variables but averaged across countries by year. For Gambia overlap is not defined, because it has no natural resource deposits. Ghana scores the highest in terms of overlap with both counterfactuals. However, in terms of relative bias towards the city counterfactual we see that Togo, Senegal, and Cote d'Ivoire lead, while Guinea, Sierra Leone and Niger have emphasized the mining counterfactual relatively more. Over the years we see that most roads were paved during the early 1980s and a remarkable apparent change in paving priority towards mines in 2003 and 2009.

Table 8: Road paving characteristics, country-years with positive paving activity

variable	N	mean	s.d.	median	min	max
Paving (km)	150	201.72	248.27	145.94	6.29	1794.12
Deterioration (km)	150	-46.27	96.15	-3.52	-759.17	0
Overlap with mining CF (b/A)	147	0.24	0.33	0.07	0	1
Overlap with city CF (c/A)	150	0.41	0.36	0.35	0	1
Relative bias to city CF (R)	147	0.18	0.39	0.06	-1	1

Table 9: Road paving characteristics by country, annual averages

Country	Paving (km)	Deterioration (km)	Overlap with mining CF (b/A)	Overlap with city CF (c/A)	Relative bias to city CF (R)
Benin	118.97	0.00	0.40	0.54	0.14
Burkina Faso	210.30	-12.75	0.20	0.34	0.14
Cote d'Ivoire	320.86	-42.74	0.09	0.32	0.23
Gambia	129.50	0.00	.	0.00	.
Ghana	199.40	-178.54	0.64	0.75	0.11
Guinea	189.41	-2.72	0.24	0.22	-0.03
Guinea Bissau	62.49	-9.93	0.18	0.31	0.13
Liberia	72.89	-5.06	0.29	0.40	0.11
Mali	307.95	-63.58	0.05	0.18	0.13
Niger	296.80	-18.72	0.17	0.25	0.08
Senegal	243.12	-61.10	0.21	0.57	0.37
Sierra Leone	102.89	-42.41	0.53	0.50	-0.03
Togo	141.73	-58.87	0.18	0.67	0.49
Total	201.72	-46.27	0.26	0.41	0.17

Note: the table shows annual average by country for country-years with positive paving.

Table 10: Road paving characteristics by year, country averages

Year	Paving (km)	Deterioration (km)	Overlap with mining CF (b/A)	Overlap with city CF (c/A)	Relative bias to city CF (R)
1965	.	.	.	.	.
1968	223.85	-88.02	0.04	0.10	0.06
1969	129.94	-27.69	0.17	0.25	0.12
1971	211.79	-69.32	0.21	0.28	0.07
1973	135.92	-42.13	0.19	0.33	0.14
1976	258.05	-30.24	0.33	0.37	0.03
1983	545.97	-19.49	0.31	0.40	0.13
1984	183.26	-34.00	0.10	0.42	0.33
1986	210.85	-43.74	0.23	0.34	0.11
1989	102.56	-128.58	0.28	0.48	0.20
1990	74.06	-28.57	0.35	0.59	0.23
1996	220.46	-44.08	0.43	0.50	0.07
1998	141.91	-42.21	0.20	0.56	0.36
2002	171.06	-49.90	0.22	0.61	0.38
2003	47.06	-16.50	0.60	0.41	-0.19
2007	251.24	-19.47	0.16	0.43	0.31
2009	109.22	-10.54	0.32	0.30	-0.02
2012	197.37	-74.48	0.42	0.87	0.45

Note: the table shows annual average paving by year compared to the previous year, for country-years with positive paving.

5 Determinants of the overlap

Having constructed our measure of relative bias towards the city counterfactual, we then started to study the determinants of the investment decisions captured by our measure. One first hypothesis is that countries should focus more on connecting mines in period of autocracy than in period of democracy. Intuitively, autocracies are likely to be less responsive to the broad needs of the population, particularly in the context of Africa where the governments capacity to tax the economy is very weak. In contrast, revenues generated through the export of resources are easily appropriated by autocrats, creating a strong incentive for them to provide the sort of transport infrastructure that facilitates such exports.

In Table 11, we look at the correlation between our measure (calculated based on the market potential principle) and two different measures of democracy. The first (columns 1-4) is the Polity IV autocracy/democracy index, which ranges between -10 for complete autocracies to 10 for high-quality democracies. The second (column 5) is the dichotomous measure by Acemoglu et al (2015), which classifies a country as a democracy if its Polity IV score is positive, Freedom House codes it as Free or Partially free, and a number of sources agree with these judgements. We average both of these measures across the multiple years which make up each of our 18 periods. Controlling for country fixed effects, results do indicate a positive correlation between democracy (lagged one period) and bias towards the city counterfactual, though this correlation is only statistically significant when democracy is measured using the Polity IV index (it is significant at the 15% level when we use the Acemoglu et al measure). The fact that democracy needs to be lagged one period to show a significant correlation could be explained with the fact that paving decision take time to be implemented, and Michelin maps are only updated every few years. Results are robust to controlling for year fixed effects, country specific trends, and trend interacted with country specific initial characteristics (the log of 1965 population, land area, urbanisation and GDP per capita).

A second hypotheses is that the amount of foreign aid and FDI that a country receives may be correlated with its road investment decisions. Both aid and FDI may pay for the improvement of roads, but may come with conditions in terms of what roads should be improved. For example, one could expect that aid could require governments to improve internal connectivity (that is, connect cities) with a view to facilitate development, whereas FDI might put more emphasis on

Table 11: Correlates with relative bias towards city counterfactuals

Dependent variable:	Relative bias towards city counterfactual						
	[1]	[2]	[3]	[4]	[5]	[6]	[7]
Democracy	-0.009	-0.015	-0.023*	-0.029*	-0.026		
	(0.009)	(0.014)	(0.013)	(0.015)	(0.139)		
Democracy (t-1)	0.027**	0.032*	0.023**	0.028**	0.231		
	(0.010)	(0.016)	(0.012)	(0.014)	(0.163)		
ln_Pop1965*trend				-0.006			
				(0.017)			
ln_Landarea1965*trend				-0.005			
				(0.019)			
urbanisation1965*trend				-0.224			
				(0.300)			
ln_GDPpc1965*trend				0.043			
				(0.048)			
ln_aid						-0.032	
						(0.032)	
ln_aid(t-1)						0.068*	
						(0.037)	
ln_FDI							-0.062
							(0.038)
ln_FDI(t-1)							0.097**
							(0.038)
Measure of democracy:	polity	polity	polity	polity	Acemog	-	-
country fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
year fixed effects		Yes					
country-specific trends			Yes				
Observations	123	123	123	94	132	136	97
R-squared	0.216	0.343	0.330	0.272	0.177	0.172	0.197

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

the connection of mines (particularly in Africa, where most FDI go to the extractive industries). In columns 6-7 of Table 11, we look at the correlation between our measure of relative bias towards the city counterfactual and total inflows of aid and FDI, both taken from the World Banks World Development Indicators and averaged within each sub period. As expected, we find a positive correlation between our measure and aid (lagged one period): countries who receive more aid tend to concentrate their road investment in connecting cities more than mines. Somewhat surprisingly, we also find a positive correlation between our measure and FDI (lagged on period). The fact that we once again only observe a correlation when aid and FDI are lagged one period is consistent with the view that investment decisions take time to translate into roads charted on Michelin maps.

6 Future work

Having completed the road data collection and having written a code that allows us to calculate counterfactual networks, the rest of the projects is articulated in several steps. First, we want to further study the determinants of road investment decisions in West Africa in 1965-2012, as captured by our measure of connection of mines versus cities. Preliminary results presented in Section 5 suggest some interesting correlations between political and external conditions and investment decisions: we think this deserves further attention.

Our second step will be to investigate the effect of investment decisions on the spatial equilibrium of the economy, and particularly on the economy's pattern of international trade, on the location of cities and economic activity, and on measures of individual welfare. Data on bilateral trade flows is readily available from a variety of sources, and data on cities is already incorporated in our datasets. The location of economic activity can be proxied using population density data available from the Gridded Population of the World (GPW) dataset, and from nighttime luminosity data available from the USA National Oceanic and Atmospheric Administration. Measures of welfare at the individual level can be found in a variety of household surveys that were run in the West African countries in the last two decades, such as USAID's DHS data (Perez-Heydrich et al., 2013). For the latter we intend to cooperate with Alexander Moradi at Sussex.

Our next task is to develop a model of regional and international trade, and transport infrastructure. We will model trade between domestic locations, regional locations, and the rest of the world, in which growth depend on the pattern of trade (since specialisation in manufactures generates more positive externalities than specialisation in raw materials), which in turn depends on available transport infrastructure. The model will clarify ways in which resource-related infrastructure may affect welfare, both statically (by expanding trade opportunities), and dynamically (by affecting the pattern of trade and thus growth). Using results from our previous step, we will calibrate the model to a sample of West African countries, and use it to identify expansion paths for the transport network after decolonisation.

Essential building blocks of the model are that the optimal network will change following the discovery of the resource. These will be shaped by two opposite forces. On one hand, static gains from trade considerations advice to spend more of the budget on connecting the resource to the coast and to overseas markets. On the other, dynamic gains from trade considerations suggest to do so with moderation since to shift the budget away from connections between domestic and/or regional locations will disproportionately penalise regional trade relations along which domestic locations may have a comparative advantage in manufactures; in turn, this will damage learning by doing and growth. Using the calibrated model, we will compare the actual network of infrastructure to counterfactuals. For example, we can compare the welfare effect of the actual investment path to that of our counterfactual network in which primary emphasis is given to connecting cities. Such counterfactual analysis assumes a constant budget for road paving (or at least, it fixes the number of kilometres of roads that are being paved). In addition, we could evaluate the welfare effect of a budget expansion, by using our methodology to expand the counterfactual in accordance with the increased budget, and using then the model to calculate the impact of this on welfare. This second approach may give a sense of the return to aid that is tied to the improvement of the road network in a country.

References

[1] Acemoglu, Daron, Suresh Naidu, Pascual Restrepo and James A. Robinson (2015). "Democracy Does Cause Growth", *mimeo.*

[2] Bonfatti, Roberto and Steven Poelhekke. "From Mine to Coast: Transport Infrastructure and the Direction of Trade in Developing Countries", Revision of CESifo WP 4170.

[3] Burgess, Robin, Remi Jedwab, Edward Miguel, Ameet Morjaria and Gerard Padr i Miquel (2015). "The Value of Democracy: Evidence from Road Building in Kenya", *American Economic Review*, Vol. 105, No. 6, pp. 1817-51.

[4] David L. Kriebel, Robert H. Mayer, and Jennifer K. Waters. 2000. Shipping Trends Analysis for Impacts of Navigation Trends on Channel Usage and Design. Draft Final Report for Institute for Water Resources U.S. Army Corps of Engineers.

[5] Perez-Heydrich, C., Joshua L. Warren, Clara R. Burgert and Michael E. Emch (2013). "Guidelines on the Use of DHS GPS Data", USAID Spatial Analysis Reports No. 8, September 2013.

[6] Volpe, Martincus C. and J. Blyde (2013), "Shaky roads and trembling exports: Assessing the trade effects of domestic infrastructure using a natural experiment", *Journal of International Economics*, Vol. 90, No. 1.

A Technical Appendix: Build Network with ArcGIS

1. import Michelin maps to road data Add data, choose photo, add as raster, do not create pyramid

2. locate Michelin map to the correct location Editor toolbar, customize, choose 'georeferencing', 'fit to display',use 'add control points' in georeferencing toolbar, 'update georeferencing'

3. draw new roads referring to Michelin map Do it country by country, use 'World Transportation' and 'Frontiers des pays d'Afrique country borders' of Africa' as reference maps. They are public maps which can be added in ArcMap. Use 1:500,000 in World Transportation map when the small roads are shown normally. Different traces show up at 1:300:000. Start from 2012 since it has the most extensive road network. Compare maps retrospectively, downgrade or delete roads dating back in time. The work ends at 1965.

4. Combine all countries' map and clean the data use "integrate", 300 meters, to link the polylines together use "trim", 100 meters, to clean the tiny branches use "feature vertices to points"+ select point type "Dangle" to create a layer of dangling points use "select layer by location" to select the lines containing dangling points use "extend", 10 km, on the selected lines to connect the misconnected road ends use "integrate" and "trim" (trim 3,000 meters) 'extend' (5km, both lines can extend) 'integrate'(2km) again to clean the tiny branches use "feature vertices to points"+ select point type "Dangle" to create a layer of dangling points. Check dangling points one by one (especially on country border), connect end points if necessary based on Michelin Maps 2012.

5. Generate network with ArcGIS network extension

6. Import cities.xls(ArcMap can only import 2003 Excel files) display XY data, change coordinate system to "Geographic Coordinate System: Name: GCS WGS 1984", generate points export as cities.shp file

7. Similarly, import mine and port data to prepare for spatial analysis in the next steps.

B Technical Appendix: Find shortest routes with ArcPy

B.1 Find shortest routes between city pairs

```
import arcpy, os
from arcpy import env

# Set the workspace
arcpy.env.workspace = "C:\Users\ygu200\Dropbox\A_161121\WestAfrica.gdb"

# arcpy.env.workspace = "D:\dropbox\A_161121\WestAfrica.gdb"
env.overwriteOutput = True

# Define export location
exportLocation = "C:\Users\ygu200\Dropbox\A_161121\Results"
# exportLocation = "D:\dropbox\A_161121\Results"

# Create country loop ['BEN','BKF','IVC','GHA','GUI','LIR','MLI','NER','SEN','SIL','GMB','GNB','TGO']
# Create country loop ['BKF','MLI','NER']
countries = ['BEN','BKF','IVC','GHA','GUI','LIR','MLI','NER','SEN','SIL','GMB','GNB','TGO']

for CNT in countries:

        # Make a layer from the Roads.shp feature class
        arcpy.MakeFeatureLayer_management("Roads", "Roads_lyr")
        print "make_roads_layer"

        # select CNT roads
        arcpy.SelectLayerByAttribute_management("Roads_lyr", "NEW_SELECTION", "CNTNAME3_=_'" + CNT + "'")
        print "select_CNT_roads"

        # Write the selected features to a new featureclass
        arcpy.CopyFeatures_management("Roads_lyr", CNT)
        print "make_CNT_roads_copy"

        # Split line at vertices
        arcpy.SplitLine_management(CNT, CNT + "_split")
        print "split_lines_at_vertices"

        env.overwriteOutput = True
        # Generate Points Along Lines for every 1km
        arcpy.GeneratePointsAlongLines_management(CNT + "_split", CNT + "_points", "DISTANCE", "1000_Meters", "", "NO_END_POINTS")
```

```
print "generate points along roads for every 1km"

env.overwriteOutput = True
# Process: Split Line at Point for every 1km roads, Search Radios = 20 Meters
arcpy.SplitLineAtPoint_management(CNT + "_split", CNT + "_points", CNT + "_split_1km", "20 Meters")
print "split roads at points"

# Process: Feature To Line
arcpy.FeatureToLine_management(CNT + "_split_1km", CNT + "_roads", "", "ATTRIBUTES")
print "save as CNT_roads"

# ExportXYv_stats (Input_Feature_Class, Value_Field, Delimiter, Output_ASCII_File, Add_Field_Names_to_Output)
Value_Field = ["OBJECTID", "CNTNAME3", "COUNTRY_NA", "F1965S","F1968S", "F1969S",
 "F1971S", "F1973S", "F1976S", "F1983S", "F1984S", "F1986S", "F1989S", "F1990S",
 "F1996S", "F1998S", "F2002S", "F2003S", "F2007S", "F2009S", "F2012S", "Shape_Length"]
Output_ASCII_File = os.path.join(exportLocation, CNT + "_roads" + ".txt")

# Process: Export Feature Attribute to ASCII...
arcpy.ExportXYv_stats(CNT + "_roads", Value_Field, "SEMI-COLON", Output_ASCII_File, "ADD_FIELD_NAMES")
print "Export to CNT_roads.txt"

#finish in 4 mins

# define local variables
expression_country = "ISO = '" + CNT + "'"
expression_citysize = "OBJECTID > 50"
print "define local variables"

# Make a layer from the feature class
# Syntax: MakeFeatureLayer_management (in_features, out_layerr, {where_clause}, {workspace}, {field_info})
arcpy.MakeFeatureLayer_management("cities_1960", "cities_1960_layer")
print "make feature layer of all 1960 cities"

# select CNT cities
arcpy.SelectLayerByAttribute_management("cities_1960_layer", "new_selection", expression_country)
print "select CNT cities"

# Select CNT origin cities
# Write the selected features to a new featureclass
# Syntax: CopyFeatures_management (in_features, out_feature_class, {config_keyword}, {spatial_grid_1}, {spatial_grid_2}, {spatial_grid_3})
arcpy.CopyFeatures_management("cities_1960_layer", CNT + "_cities_origin")
print "save as CNT_cities_origin"
```

```python
# Sort origin cities by 1960 population from large to small and write to a new feature class
arcpy.Sort_management(CNT + "_cities_origin", CNT + "_cities_origin_sort", [["PT1960_7", "DESCENDING"]])
print "sort_CNT_cities_origin_in_decending_order"

# Execute MakeTableView to open the sorted city table
arcpy.MakeTableView_management(CNT + "_cities_origin_sort", "tempTableView")

# Execute SelectLayerByAttribute to choose the 50th largest cities onwards, which will be deleted
arcpy.SelectLayerByAttribute_management("tempTableView", "NEW_SELECTION", expression_citysize)
print "select_origin_cities_smaller_than_50th_in_size"

# Execute GetCount and if some features have been selected, then execute
#  DeleteRows to remove the selected rows.
if int(arcpy.GetCount_management("tempTableView").getOutput(0)) > 0:
    arcpy.DeleteRows_management("tempTableView")
print "delete_origin_cities_smaller_than_50th_in_size"
arcpy.CopyFeatures_management(CNT + "_cities_origin_sort", CNT + "_cities_origin_50")
print "save_as_CNT_cities_origin_50"

# Select CNT destination cities
arcpy.SelectLayerByLocation_management("cities_1960_layer", "intersect", CNT + "_buffer", 0, "new_selection")
print "select_CNT_cities_destination"

# Write the selected features to a new featureclass
arcpy.CopyFeatures_management("cities_1960_layer", CNT + "_cities_destination")
print "save_CNT_cities_destination"

# ExportXYv_stats (Input_Feature_Class, Value_Field, Delimiter, Output_ASCII_File, Add_Field_Names_to_Output)
Output_ASCII_File = os.path.join(exportLocation, CNT + "_cities_destination" + ".txt")
print "define_location_to_export_CNT_cities_destination.txt"

# Process: Export Feature Attribute to ASCII...
arcpy.ExportXYv_stats(CNT + "_cities_destination", ["OBJECTID", "ID_INT", "PT1960_7"], "SEMI-COLON", Output_ASCII_File, "ADD_FIELD_NAMES")
print "export_CNT_cities_destination.txt"

# Sort destination cities by 1960 population from large to small and write to a new feature class
arcpy.Sort_management(CNT + "_cities_destination", CNT + "_cities_destination_sort", [["PT1960_7", "DESCENDING"]])
print "sort_CNT_cities_destination_in_decending_order"

# Execute MakeTableView to open the sorted city table
arcpy.MakeTableView_management(CNT + "_cities_destination_sort", "tempTableView")

# Execute SelectLayerByAttribute to choose the cities smaller than 50th in size, which will be deleted later
```

```
# Notice: the foreign neighbouring cities remain.
arcpy.SelectLayerByAttribute_management("tempTableView", "NEW_SELECTION", expression_citysize)
print "select_destination_cities_smaller_than_50th_in_size"

# Execute GetCount and if some features have been selected, then execute
#  DeleteRows to remove the selected rows.
if int(arcpy.GetCount_management("tempTableView").getOutput(0)) > 0:
    arcpy.DeleteRows_management("tempTableView")
print "delete_destination_cities_smaller_than_50th_in_size"
arcpy.CopyFeatures_management(CNT + "_cities_destination_sort", CNT + "_cities_destination_50")
print "save_as_CNT_cities_destination_50"
print "end"
# finish in 2 mins

#Check out the Network Analyst extension license
arcpy.CheckOutExtension("Network")

#Set local variables
network = os.path.join("RoadNetwork", "RoadNetwork_ND")
impedance = "Length"
facilities1 = CNT + "_cities_destination"
incidents1 = CNT + "_cities_origin"
CNT_routes1 = CNT + "_routes"


# Create a new closest facility analysis layer. Find the 30 closest facilites.
# "TRAVEL_TO" means that the direction of travel is from incidents to facilities.
ClosestFacility_Object = arcpy.na.MakeClosestFacilityLayer(network, "ClosestFacility",
                                                          impedance, "TRAVEL_TO",
                                                          "", 50)
print "Make_closest_facility_object"

#Get the layer object from the result object. The closest facility layer can
#now be referenced using the layer object.
ClosestFacility_Layer = ClosestFacility_Object.getOutput(0)
print "Get_closest_facility_layer"


#Get the names of all the sublayers within the closest facility layer.
sublayer_names = arcpy.na.GetNAClassNames(ClosestFacility_Layer)
print "Get_closest_facility_sublayer_names"
```

```
#Stores the layer names that we will use later
Facilities_Sublayer = sublayer_names["Facilities"]

Incidents_Sublayer = sublayer_names["Incidents"]

#Get the routes sublayer from the route layer
Routes_Sublayer = arcpy.mapping.ListLayers(ClosestFacility_Layer, sublayer_names["CFRoutes"])[0]


#set the search radius as 10 km
searchTolerance = "10000_Meters"



#Load the cities_destinations as Facilities. Map the Name property from the ID_INT field
#using field mappings
field_mappings_facilities = arcpy.na.NAClassFieldMappings(ClosestFacility_Layer, Facilities_Sublayer)
field_mappings_facilities["Name"].mappedFieldName = "ID_INT"
print "field_mapping_facilities"
arcpy.na.AddLocations(ClosestFacility_Layer, Facilities_Sublayer,
                        facilities1, field_mappings_facilities, searchTolerance)
print "add_facility_locations"


#Load the cities_origins as Incidents. Map the Name property from the ID_INT field
#using field mappings
field_mappings_incidents = arcpy.na.NAClassFieldMappings(ClosestFacility_Layer,
                                                          Incidents_Sublayer)
field_mappings_incidents["Name"].mappedFieldName = "ID_INT"
print "field_mapping_incidents"
arcpy.na.AddLocations(ClosestFacility_Layer, Incidents_Sublayer, incidents1,
                       field_mappings_incidents, searchTolerance)
print "add_incidents_locations"


#Solve the closest facility layer
arcpy.na.Solve(ClosestFacility_Layer)
print "Solve"


# Write the selected features to a new featureclass
arcpy.CopyFeatures_management(Routes_Sublayer, CNT_routes1)
print "Save_the_routes"
```

```
        # Process: Export Feature Attribute to ASCII...
        Output_ASCII_File = os.path.join(exportLocation, CNT_routes1 + ".txt")
        arcpy.ExportXYv_stats(CNT_routes1, ["OBJECTID", "Name", "Total_Length"], "SEMI-COLON", Output_ASCII_File, "ADD_FIELD_NAMES")
        print "Export as txt file"

# Note: ignore WARNING 000642: Problems reading 107 of 3210 total records.
# WARNING 001158: Features with NULL field values (only includes first 30): OBJECTID = 1, 31, 61, 91, 121, 151, 181, 211, 241, 271, 301, 331, 361, 391, 421, 4
# These are the route from a city to itself. Thus the route fields are Null, which generate a warning message.

for CNT in countries:

        # Set local variables
        in_features = CNT + "_roads"
        in_routes = CNT + "_routes_M"
        route_id_field = "Name"
        radius_or_tolerance = "1 Meters"
        out_table = CNT + "_Roads_Along_Routes"
        out_event_properties = "RID LINE FMEAS TMEAS"
        print "set local variables"



        arcpy.LocateFeaturesAlongRoutes_lr(in_features, in_routes, route_id_field,
                                                              radius_or_tolerance, out_table,
                                                              out_event_properties,"FIRST", "DISTANCE",
                                                              "ZERO", "NO_FIELDS",
                                                              "M_DIRECTON")
        print "Locate feature along routes"

        #finish in 14 mins.

        exportFile = os.path.join(exportLocation, out_table + ".txt")
        arcpy.CopyRows_management(out_table, exportFile)
        print "Export as txt file"
```

B.2 Find shortest routes from mine to port

```
import arcpy, os
from arcpy import env

# Set the workspace
arcpy.env.workspace = "C:\Users\ygu200\Dropbox\A_161121\WestAfrica.gdb"
# arcpy.env.workspace = "D:\dropbox\A_161121\WestAfrica.gdb"
env.overwriteOutput = True

# Define export location
exportLocation = "C:\Users\ygu200\Dropbox\A_161121\Results"
# exportLocation = "D:\dropbox\A_161121\Results"

# Create country loop
CNT = "TGO"

# Define local variables
Ports = "WPI_deep"
Ports_Layer = "Ports_Layer"
Port_Country = "COUNTRY_=_'" + CNT +"'"
Port_Save_A_Copy = CNT + "_Ports"

arcpy.MakeFeatureLayer_management(Ports, Ports_Layer)
print "make_feature_layer_of_ports"
# select
arcpy.SelectLayerByAttribute_management(Ports_Layer, "new_selection", Port_Country)
print "select_ports_of_the_country"
# Syntax: CopyFeatures_management (in_features, out_feature_class, {config_keyword}, {spatial_grid_1}, {spatial_grid_2}, {spatial_grid_3})
arcpy.CopyFeatures_management(Ports_Layer, Port_Save_A_Copy)
print "save_a_copy_of_the_ports"

# Do the same for mines
Mines = "mines_bulks"
Mines_Layer = "Mines_Layer"
Mines_Country = "wbcode_=_'" + CNT + "'"
Mines_Save_A_Copy = CNT + "_Mines"

arcpy.MakeFeatureLayer_management(Mines, Mines_Layer)
print "make_feature_layer_of_mines"
arcpy.SelectLayerByAttribute_management(Mines_Layer, "new_selection", Mines_Country)
print "select_mines_of_the_country"
arcpy.CopyFeatures_management(Mines_Layer, Mines_Save_A_Copy)
```

```
print "save a copy of the mines"


#Check out the Network Analyst extension license
arcpy.CheckOutExtension("Network")

#Set local variables
network = os.path.join("RoadNetwork", "RoadNetwork_ND")


facilities = CNT + "_Ports"
incidents = CNT + "_Mines"
impedance = "Length"
routes = CNT + "_Mines_Routes"
Value_Field = ["OBJECTID", "Name", "Total_Length"]

# Create a new closest facility analysis layer. Find the N closest facilites.
# "TRAVEL_TO" means that the direction of travel is from incidents to facilities.
ClosestFacility_Object = arcpy.na.MakeClosestFacilityLayer(network, "ClosestFacility",
                                                           impedance, "TRAVEL_TO",
                                                           "", 1)
print "Make closest facility object"

#Get the layer object from the result object. The closest facility layer can
#now be referenced using the layer object.
ClosestFacility_Layer = ClosestFacility_Object.getOutput(0)
print "Get closest facility layer"


#Get the names of all the sublayers within the closest facility layer.
sublayer_names = arcpy.na.GetNAClassNames(ClosestFacility_Layer)
print "Get closest facility sublayer names"


#Stores the layer names that we will use later
Facilities_Sublayer = sublayer_names["Facilities"]

Incidents_Sublayer = sublayer_names["Incidents"]

#Get the routes sublayer from the route layer
Routes_Sublayer = arcpy.mapping.ListLayers(ClosestFacility_Layer, sublayer_names["CFRoutes"])[0]
```

```
#set the search radius as 10 km
searchTolerance = "15000_Meters"


#Load the cities_destinations as Facilities. Map the Name property from the PORT_NAME field
#using field mappings
field_mappings_facilities = arcpy.na.NAClassFieldMappings(ClosestFacility_Layer, Facilities_Sublayer)
field_mappings_facilities["Name"].mappedFieldName = "PORT_NAME"
print "field_mapping_facilities"
arcpy.na.AddLocations(ClosestFacility_Layer, Facilities_Sublayer,
                      facilities, field_mappings_facilities, searchTolerance)
print "add_facility_locations"


#Load the cities_origins as Incidents. Map the Name property from the ID_INT field
#using field mappings
field_mappings_incidents = arcpy.na.NAClassFieldMappings(ClosestFacility_Layer,
                                                         Incidents_Sublayer)
field_mappings_incidents["Name"].mappedFieldName = "mine_id"
print "field_mapping_incidents"
arcpy.na.AddLocations(ClosestFacility_Layer, Incidents_Sublayer, incidents,
                      field_mappings_incidents, searchTolerance)
print "add_incidents_locations"


#Solve the closest facility layer
arcpy.na.Solve(ClosestFacility_Layer)
print "Solve"


# Write the selected features to a new featureclass
arcpy.CopyFeatures_management(Routes_Sublayer, routes)
print "Save_the_routes"

# Process: Export Feature Attribute to ASCII...
Output_ASCII_File = os.path.join(exportLocation, routes + ".txt")
arcpy.ExportXYv_stats(routes, Value_Field, "SEMI-COLON", Output_ASCII_File, "ADD_FIELD_NAMES")
print "Export_as_txt_file"
# Note: ignore WARNING 000642: Problems reading 107 of 3210 total records.
# WARNING 001158: Features with NULL field values (only includes first 30): OBJECTID = 1, 31, 61, 91, 121, 151, 181, 211, 241, 271, 301, 331, 361, 391, 421, 4
# These are the route from a city to itself. Thus the route fields are Null, which generate a warning message.
```

```
# Set local variables
in_features = CNT + "_roads"
in_routes = CNT + "_Mines_Routes_M"
route_id_field = "Name"
radius_or_tolerance = "1_Meters"
out_table = CNT + "_Mines_Roads_Along_Routes"
out_event_properties = "RID_LINE_FMEAS_TMEAS"
print "set_local_variables"

arcpy.LocateFeaturesAlongRoutes_lr(in_features, in_routes, route_id_field,
                                   radius_or_tolerance, out_table,
                                   out_event_properties,"FIRST", "DISTANCE",
                                   "ZERO", "NO_FIELDS",
                                   "M_DIRECTON")
print "Locate_feature_along_routes"

# Export the table to result folder
exportFile = os.path.join(exportLocation, out_table + ".txt")
arcpy.CopyRows_management(out_table, exportFile)
print "Export_as_txt_file"
```

The International Growth Centre (IGC) aims to promote sustainable growth in developing countries by providing demand-led policy advice based on frontier research.

Find out more about our work on our website
www.theigc.org

For media or communications enquiries, please contact
mail@theigc.org

Subscribe to our newsletter and topic updates
www.theigc.org/newsletter

Follow us on Twitter
@the_igc

Contact us
International Growth Centre,
London School of Economic and Political Science,
Houghton Street,
London WC2A 2AE

IGC
International Growth Centre

DIRECTED BY
LSE
UNIVERSITY OF OXFORD

FUNDED BY
UKaid from the British people

Designed by soapbox.co.uk