103695

Transport, Economic Growth, and Deforestation in the Democratic Republic of Congo

A Spatial Analysis

Acknowledgements

This report was prepared by a team led by Richard Damania comprising (in alphabetical order) Alvaro Federico Barra, Mathilde Burnouf and Jason Daniel Russ.

The strategic support of Ahmadou Moustapha Ndiaye (Country Director, DRC) and Yisgedullish Amde (Country Program Coordinator, DRC) are gratefully acknowledged. The team are also grateful to Benoit Bosquet (Practice Manager, Environment and Natural Resources) for his guidance, and advice. Special gratitude is due to Jean Christophe Carret (Sector Leader, DRC) for his encouragement and assistance at every stage of this report's development, including as a peer reviewer. The support of Mohammed Dalil Essakali (Senior Infrastructure Economist, Transport & ICT) for advice, support and help in data gathering and as a reviewer is also acknowledged. Nagaraja Rao Harshadeep (Harsh) (Global Lead (Watersheds), Environment and Natural Resources) provided extremely helpful comments and assistance.

During preparation of this report several agencies of the Government of DRC provided incisive comments and support. Notable are the contributions of the Prime Minister's Economic Council, the Infrastructure Unit, Sustainable Development MECNT, Cellular Infrastructure, National REDD Coordination.

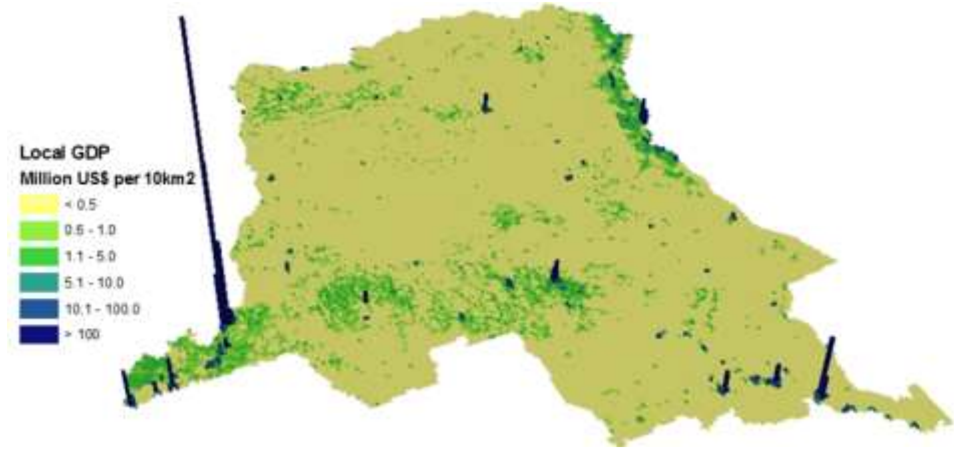
The FAO - DIAF, USAID, African Wildlife Foundation (AWF), Wildlife Conservation Society (WCS), World Resource Institute (WRI), Observatory for Central African Forests (OFAC), Observatoire Satellitale des Forêts d'Afrique Centrale (OSFAC), World Wildlife Fund (WWF), as well as stakeholders from the University of Kinshasa, ERAIFT all provided advice and comments on earlier versions of the study.

Executive Summary

Motivation

1. The natural endowment of the Democratic Republic of Congo (DRC), in the form of land, minerals, and forests, is unparalleled. The right mix of policies has the potential to unleash incentives that could transform the economy perhaps even to middle-income status. The agricultural sector generates around 40 percent of total income and employs 60 percent of the workforce. Mining accounts for 12 percent of GDP, and some estimates put the DRC's mineral wealth at US$24 trillion. Perhaps the country's best known natural asset is its vast forest estate. Home to over 145 million hectares of rain forests, the DRC has the second largest forest endowment in the word, and contains over 60% of the total forest area in the Congo Basin. These forests are of global importance, as they represent the second largest carbon sink in the world, and have considerable potential to generate income for the DRC through the REDD+ mechanism. Locally too, forests are of paramount importance. Up to 40% of individuals living in forested provinces of the DRC rely on hunting, forest products and fishing as their main source of food (Bahwere 2008).

2. However GDP (wealth) in DRC is geographically concentrated. The figure on the right illustrates that aside from the area around Kinshasa, the capital, significant peaks in income can be seen around Lubumbashi, the mining capital of DRC with enormous deposits of copper and cobalt, Mbuji-Mayi, an area rich in diamonds, and Kivu, which has large deposits of gold and other rare-earth metals.

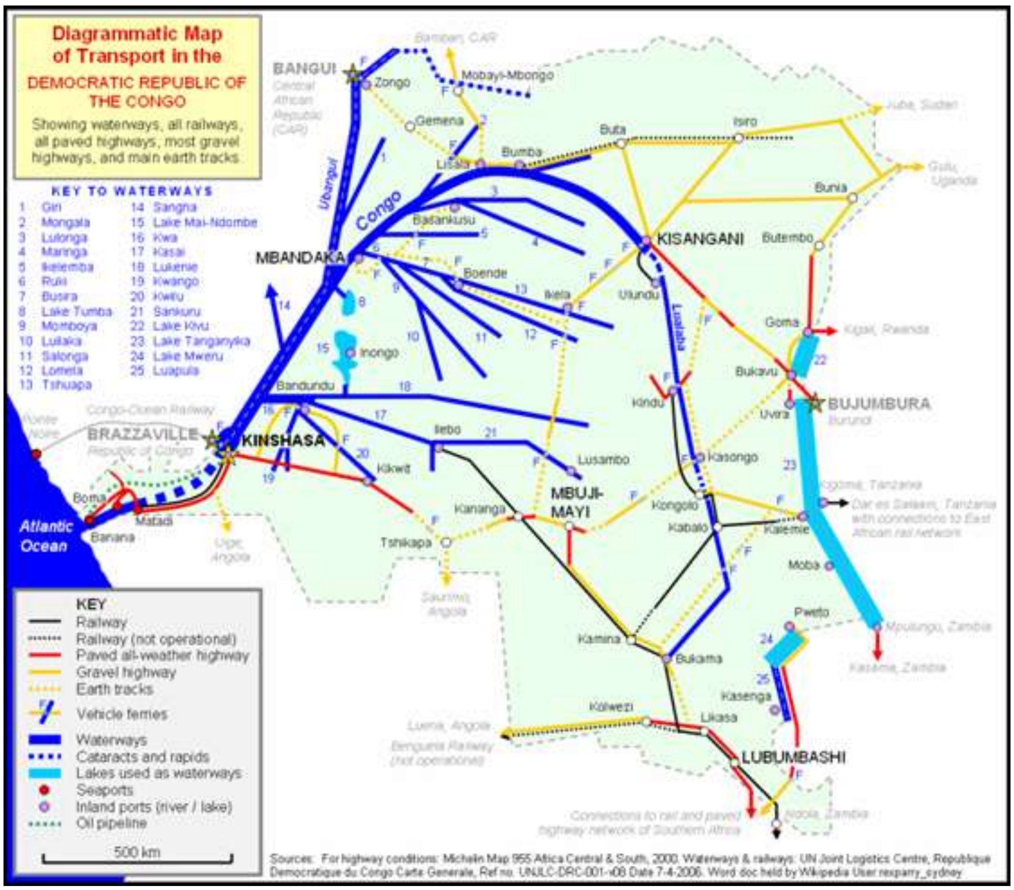


3. Given the vast distances and extreme variations in the spatial distribution of GDP, connecting regions that flourish with those that lag (relatively) could provide a significant boost to economic growth. There is thus an urgent need for improving inter-provincial as well as intra-provincial connectivity to promote trade and economic cohesion.

4. The objective of this report is to present new tools to prioritize infrastructure investments and guide their location. It recognizes that investment needs far outstrip available resources, so there is a need for prioritization and objective quantification of impacts. Accordingly the report illustrates techniques for identifying the benefits of investments at a highly disaggregated

spatial scale and recognizes that there are costs and externalities that also need to be considered, especially in the DRC. The approach is illustrated in the context of transportation infrastructure, and can be applied with modifications to other sectoral investments too.

5. Transport infrastructure in the DRC is amongst the sparsest and most dilapidated in the world. In many parts of the country, traveling to the capital, Kinshasa, by road is impossible and many of the provincial capitals are unconnected to Kinshasa. Despite being bequeathed with one of the largest river networks in the world, river transport is often hampered by high levels of silting, long wait times at ports due to poor infrastructure, and uneven governance.



6. While roads and infrastructure bring many benefits and are necessary for development, they also generate externalities and impose costs—environmental, social and economic. Roads often catalyze a process of deforestation and land conversion. So there is a need to plan and establish procedures that minimize the risks of deforestation in order to preserve the potential revenues that could be earned through REDD+ (the Reducing Emissions from Deforestation and Forest Degradation) and other initiatives. There may also be less recognized, localized economic costs that emerge as roads encourage growth in areas of high economic potential at the cost of areas

with a competitive and comparative disadvantage. Such spatial sorting is an inevitable and necessary consequence of economic transition based on promoting spatial productive efficiency.

Approach

7. Infrastructure investments in long-lived assets, such as roads, have the potential to shape the development possibilities of the DRC for generations to come. This suggests the need for careful planning and decision making tools that take account of the wide range of direct and induced impacts that might eventuate, in order to maximize the full range of net benefits from these costly investments. Accordingly this report presents new information and tools that can be used by policy makers for broad planning purposes to determine where investments yield the highest net returns and how damage to valuable natural assets could be avoided. It develops a preemptive planning approach based upon economic analysis consider impacts at the very outset of the planning process.

8. This work considerably advances the information that is available to planners, and provides methodologies that could be used to make more informed decisions to identify trade-offs and maximize net welfare benefits. The approach draws from the state-of the art across a variety of disciplines – spatial (GIS) analysis, spatial econometrics, economic theory, and conservation biology – to create a framework and set of tools that can guide the location and level of investments by estimating benefits and environmental costs at a highly disaggregated spatial scale.

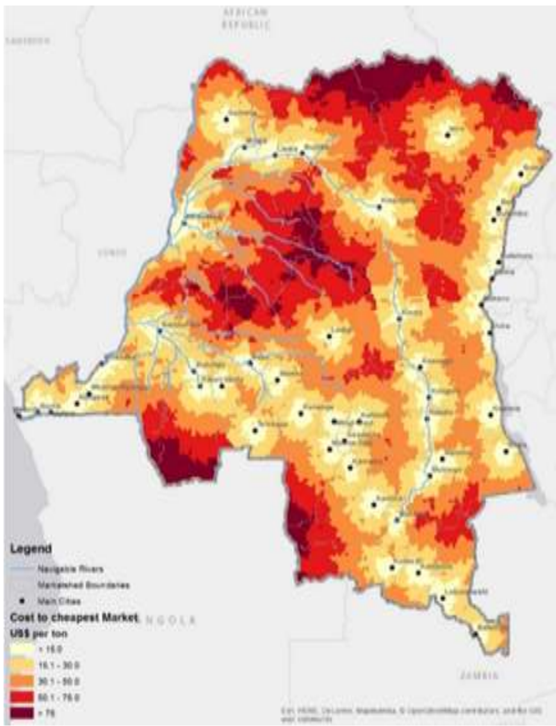
9. The analysis proceeds in several related phases that combine economic assessments with geospatial analysis. First, transport costs are estimated using GIS techniques. Next a variety of econometric procedures are used to determine the economic effects of changing transport costs. The estimated elasticity measure provides a broad indication of the benefits that would accrue in each location by reducing transport costs. Second highly disaggregated spatial data is used to estimate the effects of roads on forest cover. A novel metric of biodiversity is also developed to identify forests of high (and low) value, recognizing that not all forests are of identical ecological significance. Next, the two spatial estimates are combined to simulate the effects of different policies. Finally, this provides a series of maps that identify hotspots where risks are high and benefits relatively low, regions where risks are low and benefits high, and regions where there are large trade-offs between economic and ecological goals.

Costs of travel

10. In the first stage a geospatial model is developed which identifies costs and bottlenecks to travel. It simulates how individuals and traded goods are moved around. The Congolese transport system is intrinsically multi-modal with the River Congo as its spine. The left image (below) shows the costs of transporting goods to the cheapest market from every location

within the DRC (a market is defined as a city of at least 50,000 residents), using a multi-modal model with access to both roads and rivers.

11. The image on the right (below) shows the difference in costs between a uni-modal, model with **only** roads, and the multi-modal model with land and river transport included. It thus shows the areas that are most likely to use, and benefit from, the river for transport to reach the nearest market.



It is clear from the map that, aside from some isolated areas in the northwest part of the country, rivers are used relatively infrequently for local transport. Specifically, 14% of DRC individuals live in areas where it would be cost effective to use river transport for any portion of their trip to the local market. Further, these individuals live in areas which only account for approximately 7% of the country's GDP, implying that investments in river transport will not have a significant impact on *local market* transport, given the current economic geography of the country. The implication is that the road network is likely much more cost effective for *shorter distance local transport*. This is a well-established result and reflects the fact that river transport is typically most economic for low-value and high-volume goods that need to be transported over longer distances.

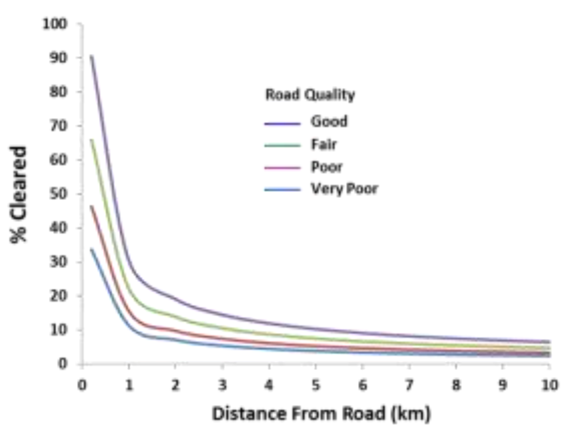
12. On the other hand when Kinshasa is the desired destination, approximately 80% of DRC's population would prefer to utilize river travel, at least in part (figure on right). These individuals live in areas that accounts for nearly 60% of DRC's GDP. The northern part of the DRC is particularly dependent on river transport for reaching Kinshasa, which is not surprising when one considers that much of this region has no direct road access to Kinshasa.

Economic Benefits

13. Having estimated transport costs from each location the report uses state-of-the-art econometric methods to determine the economic effects of reducing local transport costs.[1] The results suggest that that there would be significant benefits to decreasing local transportation costs, especially in the highest cost, more densely populated regions. Specifically, *a 10% reduction in local transportation costs would lead to, on average, a 0.46% increase in local GDP*. A related paper (World Bank (2015)) shows that in the DRC, reducing transport costs could have a significant, positive impact on wealth accumulation and poverty reduction.

Ecological Implications

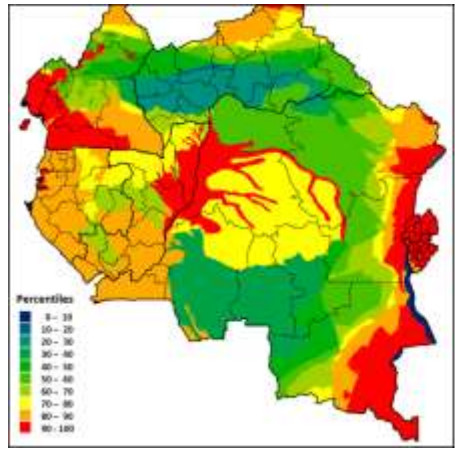
14. In the next step the report examines changes in forest cover induced by roads. The estimates indicate significant effects of road upgrading on the intensity and extent of forest clearing in well-defined corridors. Predicted effects of deforestation around improved road corridors vary widely with prior road conditions and locational economics, but increases in deforestation of 10-20% are typical.



15. Two patterns are noteworthy (see figure on left). First, upgrading roads from very poor to good condition produces near-complete deforestation within a narrow corridor (of about 1-1.5 km radius) straddling the road. Second, the impact is non-linear and deforestation intensity falls very rapidly as distance from the road increases. Most of the

[1] The approach uses cross-sectional data on local GDP, transport costs, and several control variables, to predict how changes in transport cost effect local GDP.

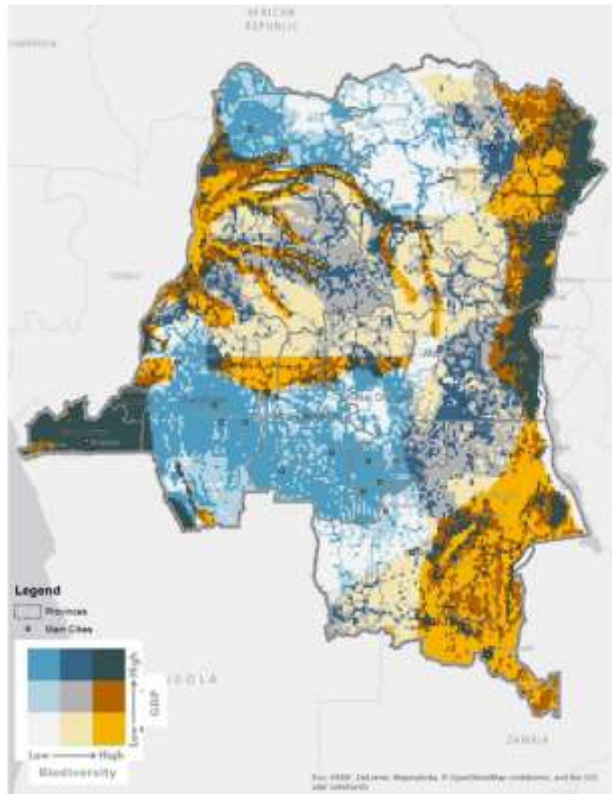
deforestation occurs within about a 2km radius of the road as shown in the adjoining figure. This is a useful result for planning the location of roads and suggests that *small changes to location could have significant environmental benefits.*



16. Since not all forest land is of uniform ecological value, nor is it of uniform economic value the report also develops a novel metric to identify areas that are of high ecological value and at higher risk of degradation. A high-resolution map of ecological vulnerability is developed that combines information on species as well as ecosystems including measures of geographic vulnerability, extinction risk and other aspects of the ecosystem captured through a measure of biomes developed by WWF. The figure to the right ranks regions from the most important (red) to least significant (blue), based on a composite index that satisfies desirable properties. Overall the results suggest that the siting of infrastructure needs to consider effects on deforestation and biodiversity loss at the very outset of the planning process. Analysis is also presented which clearly shows that sequential decision making whereby location decisions occur first, followed by an environmental impact assessment can lead to economically less favorable outcomes that can be avoided through careful upstream planning.

Identifying trade-offs, win-wins and low impacts

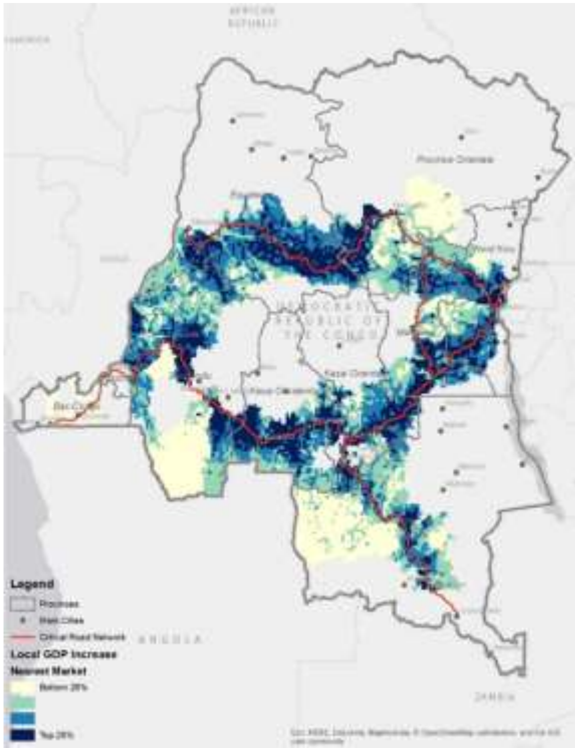
17. The report demonstrates how these results could be used to guide planning decisions. It is instructive to begin by visualizing the spatial distribution of the economy and ecology of the DRC. To do this, the intersection of local GDP and the composite species-ecoregion index, are shown in a combined map (right). The results suggest that quite often, the regions of DRC that are most important economically also tend to contain the highest levels of sensitive biodiversity (*dark blue and dark brown*). The most important ecological areas, according to the index, are along DRC's eastern and southeastern border, the Congo River and its tributaries, and much of the provinces of Bas Congo and Kinshasa. These also tend to be areas of higher population density and economic activity, with the notable exception of much of the eastern portion of Katanga province. Significant risks to any development plan are indicated suggesting the need for effective policies and safeguards. On the other hand there also zones where there is high GDP and low ecological endowments (*light blue)* and vice-versa (*light orange*). The obvious implication is that careful planning and proactive approaches can avoid areas of sensitivity, prioritize areas where conservation management is most needed, and encourage accelerated construction elsewhere.

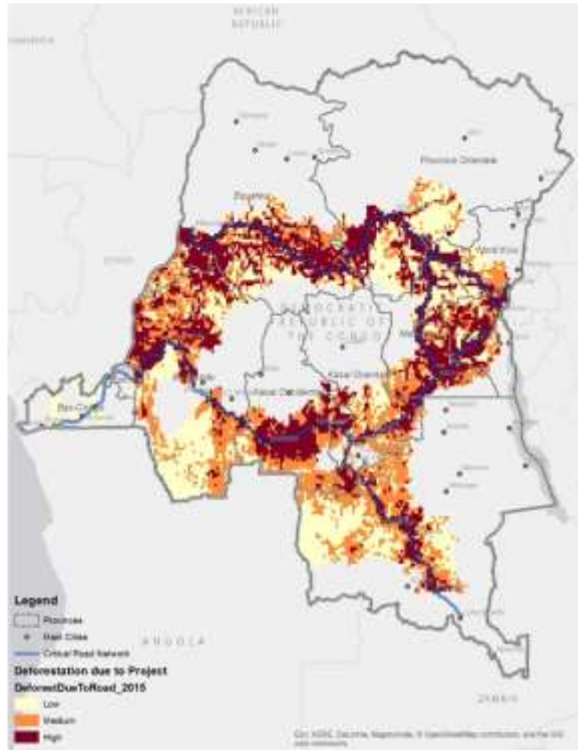


18. How might these results be used as a practical guide to decision making? As an illustration the report presents simulations for potential welfare benefits, as well as deforestation, which would result from the completion of proposed road investment projects which *connect major urban centers to Kinshasa with high quality roads.* The aggregate increase in local GDP is estimated to be approximately US$ 18.1 million per year. This is a lower bound estimate. [2] In a similar manner, simulations were done which estimate the total deforestation due to the major urban center road improvement project. The estimated additional deforestation due to this project predicts that much of the additional deforestation will occur near the major cities of Katanga, Kisangani, Maniema, as well as much of South Kivu and Maniema provinces. A comparison of GDP and forest loss is presented in the figures below. For further policy guidance it is useful to

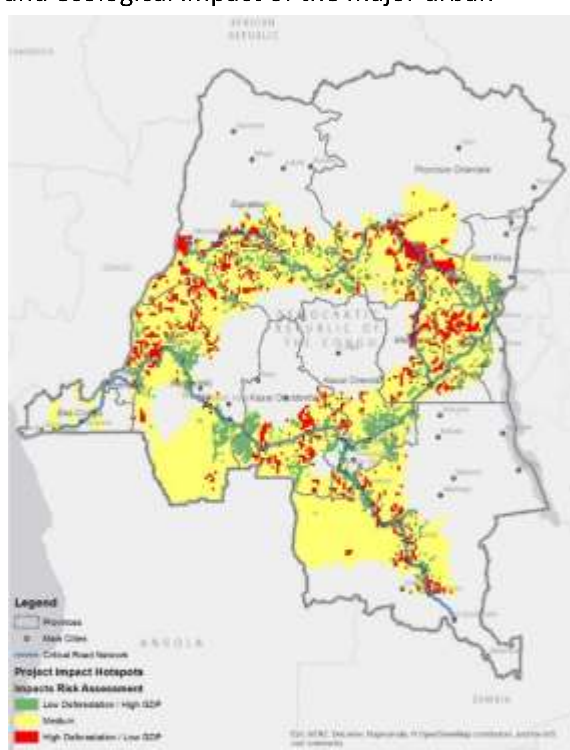
[2] Keeping in mind that this is estimated using a partial equilibrium framework, and that these benefits are only a subset of the total benefits to reducing transportation costs (other benefits include those stemming from improved transport between cities, increased access to multiple cities rather than solely the cheapest one, and better access to ports), this estimate is likely a very conservative, minimum benefit.

combine these to identify high potential areas, the high risks and areas where there will be complex trade-offs.





19. In order to get a clearer picture of the economic and ecological impact of the major urban center road network improvement project, as a first step, changes in local GDP and deforestation are overlaid to identify areas which would see the most benefits, or face the highest risks of loss.
    - Areas in green are 'pure benefit' regions, where local GDP gains are very significant, and deforestation increases are very low.
    - Red areas are the riskiest regions, which are estimated to have very low local GDP gains, but significant deforestation as a result of the project. These are the regions which would be most beneficial to protect, given that there would be little lost in terms of economic activity, and there is a significant risk to deforestation.



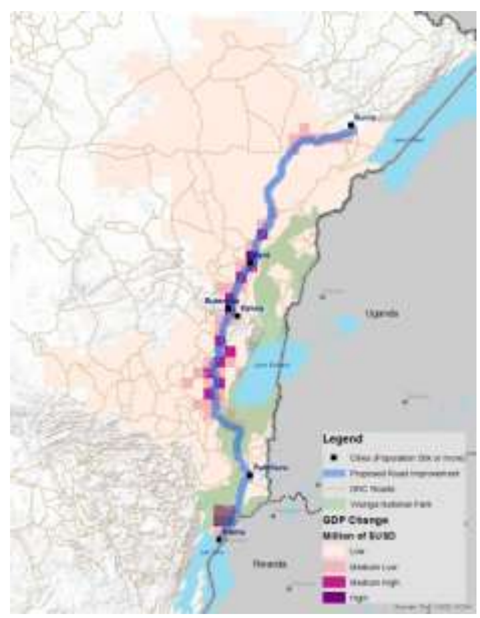
- The intermediate zone is in yellow.

Interestingly a policy implication is that estimated areas of high concern are relatively few and well defined, on the other hand the trade-off zones and low hazard areas seem larger, suggesting scope for considerable win-wins for the economy and the environment.

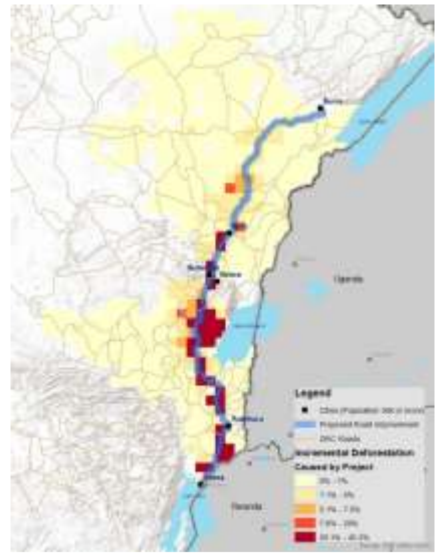
20. To illustrate the utility of this approach at finer spatial scales the report uses the same techniques to examine the costs and benefits of a much smaller road improvement project, situated around Virunga National Park. This project would improve a 525 km road which connects the city of Goma, situated just south of Virunga National Park, between the park and Lake Kivu, to Bunia, approximately 100 km north of the park, near Lake Albert. Despite being a very populated area (approximately 4.5 million Congolese live within a small area around the road), the current condition of the road is quite poor, and in many areas, impassable.

21. The surrounding area has significant deposits of mineral wealth including gold and the rare-earth mineral coltan. The land also contains very fertile soils, with theoretical maximum yields that are orders of magnitude greater than current agricultural yields. This road thus appears to be a major candidate for significant investments to spur economic activity. Nevertheless, road infrastructure development in this region may come with deep trade-offs. The land around the potential road project is heavily forested, and includes one of the world's most important national parks. Virunga National Park was established in 1924 and was the first designated national park in Africa. Environmental factors aside, Virunga National Park has the potential to become one of the greatest tourist attractions on the continent if the conflict and security issues in eastern DRC could be resolved. Destroying this natural capital would be much more than an environmental calamity – it would extinguish a significant source of future income for the country's impoverished inhabitants.

22. Given these immense tradeoffs that come with this project, this is an example of a project that would benefit from the analysis developed in this report. The benefits, in terms of the increase in local GDP, are calculated at the pixel level, and aggregated to arrive at a final range of $7.29 million-$31.9 million per year above the baseline, depending on whether one uses a local elasticity, or the national elasticity calculated in Box 2 of Chapter 2. The figure on the right shows a distribution of these benefits. Note that they are clustered around the road because the local GDP increase is the intersection of the baseline local GDP and the percentage change in transport costs, both of which are highly clustered around the road themselves. Multiplying these two together magnifies this clustering even further.

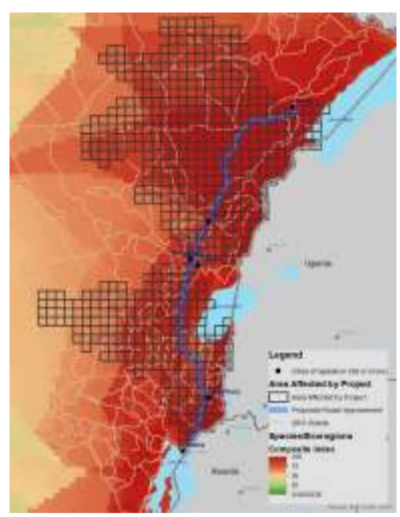


23. Using the methodology described in this report, the predicted additional deforestation due to the Virunga National Park road improvement project is now estimated, to see which regions are most at risk. The next figure shows the estimated annual deforestation that would occur due to the road improvement project. The biggest risk to deforestation are those regions which have already shown a propensity to be deforested, and which are nearest to the population centers and the improved road. This simulation shows that the areas that would be most stressed are those near Lake Edward, the corridor between Goma and Rutshuru, and the corridor from Katwa, to Butembo, to Beni. To a much lesser extent, additional deforestation may also occur to the west and northwest of Bunia, and to the northwest of Goma.



24. As a final point, the estimated additional deforestation due to the project is layered on top of the current biodiversity index to see which threatened areas have the most biodiversity, and are therefore worth the most to protect. This composite map is shown below. The grid cells outlined in black are those in which deforestation is predicted to increase because of the project. Although this does not distinguish by the intensity of deforestation, it allows one to compare the gradient of biodiversity within the areas affected, to see which areas are ecologically most important. It is clear that some of the regions with the highest ecological value also coincide with the regions predicted to experience the highest rate of deforestation from the project.

25. The important conclusion from this is that the Virunga National Park road project poses a very significant risk to the forests and to high value biodiversity in the region. Before undertaking such a project, stakeholders should carefully compare the estimated benefits with these costs, to ensure the tradeoffs are worthwhile and decide on whether and what mitigation strategies are needed. Indeed as this report highlights, a small deviation of this road may make an immense difference in generating more economic benefits while safeguarding vulnerable areas. The tools developed here allow for such assessments to occur before a major investment in project appraisal and design occurs.



Conclusions

26. Overall the results suggests that the siting of infrastructure needs to consider impacts at the very outset of the planning process. This report presents both new data and new techniques that can be used to identify areas of opportunity, risk and potential for REDD+ financing.

27. Such upstream planning has been rendered both feasible and cost effective with the availability of geo-referenced information on forest cover and economic data. This report provides the data and easily comprehensible maps for such an exercise. The maps provide a simple visual tool that summarize a computationally intensive exercise. The report demonstrates a procedure for prioritizing investments and identifying hazards, win-wins, and areas where difficult trade-offs may need to occur. The data made available as a result of this exercise could provide valuable information for policies such as REDD prioritization, the location of growth poles, agricultural zones, and so on. The approach is perhaps a timely contribution for DRC since much investments is likely to occur in the next few decades. Finally an important caveat is in order. The results presented here are contingent upon the available data which is imperfect and limited, so caution needs to be exercised and the results need to be combined with adequate ground-truthing to confirm the accuracy of the results.

Contents

Acknowledgements 2
Executive Summary 3
Chapter 1: Overview of the Report 16
  Context and Rational 16
  Natural Resources, Infrastructure, and Development 17
  Structure of the Report 20
Chapter 2: A Snapshot of DRC's Transportation System 21
  The Current State of the Transport Network 22
    An overview 22
    Local Transport to the Nearest Market 24
    Transport to Kinshasa 26
  Two Transport Network Improvement Proposals 27
    Improving Access to River Ports 28
    Major Urban Center Road Network 29
  Benefits to Road Improvement 30
  Concluding Remarks 32
Chapter 3: Roads, Forests and the Biodiversity of DRC 33
  Motivation 33
  Approach 34
  Results on Forest Clearing 35
  Gradients of Biodiversity Impacts 38
  The Stakes for Vulnerable Areas 42
  Concluding Remarks and Extensions 44
Annex 1 Econometric Results 46
  Annex 2 Modeling the Economics of Road Improvement and Deforestation 47
Chapter 4: Economic and Ecological Impact of Prospective Road Investments 51
  Major Urban Center Road Network Improvement 51
    Estimated Benefits: Increases in Local GDP 53
    Estimated Deforestation: Forest Cover Loss 54
    Visualizing Opportunities and Safeguarding Against Risks 58
  Virunga National Park Road Improvement Project 61
    Estimated Benefits: Increase in Local GDP 64

Estimated Deforestation: Forest Cover Loss ... 68
Chapter 5: Summary and Conclusions ... 71
Modeling Transport Cost in DRC and its effects in the Economy ... 71
References ... 74

Chapter 1: Overview of the Report

Context and Rational

The purpose of this study is to demonstrate several techniques which can be used to evaluate pathways to sustainable growth in the Democratic Republic of Congo (DRC) via infrastructure improvement. Decades of conflict and neglect have left the DRC's transport infrastructure amongst the sparsest and most dilapidated in the world. Even by the standards of other low income countries, road infrastructure seems deficient (see table 1). In many parts of the country, traveling to the capital, Kinshasa, by road is impossible, making air travel the only way to move around the country. And despite having one of the largest river networks in the world, river transport is often hampered by high levels of silting and long wait times at ports due to poor infrastructure (Ulimwengu 2009). This transportation infrastructure deficit reinforces national, provincial, and within-city isolation, causing not just economic problems, but also making it difficult to forge economic and social cohesion.

While it is acknowledged that improving infrastructure is by no means a panacea, it is well established that the DRC's infrastructure deficit is a significant constraint to growth. However, determining the optimal location of infrastructure investments is rendered complex in the context of the DRC given its geography and socio-economic structure. First, given the vast distances and extreme variations in the spatial distribution of GDP (Figure 1) there is an urgent need for improving inter-provincial as well as intra-provincial connectivity to promote trade and economic cohesion. Connecting regions that flourish with those that lag (relatively) could provide a significant boost to economic growth. Second, the challenge of connectivity is greatly assisted by the DRC's vast river network. It is frequently used as a means of transportation, connecting areas that are otherwise unconnected by roads. But this potentially useful mode of transport remains more expensive than it should be (World Bank 2014). Third, DRC has an exceptional endowment of forests that are potentially put at risk from infrastructure improvements and expansion. Given the very high global and local value of the forests, minimizing the potential for their destruction must be a top priority. Finally, frequent conflict which pervades the eastern portion of the country can potentially limit or negate entirely any infrastructure investments made there, and must be accounted for.

Table 1. Road Transport in DRC

Indicator	Units	Low Income Country Average	DRC
Paved Road Density	km/1,000 km^2 of land	16	1
Unpaved Road Density	km/1,000 km^2 of land	68	14
Paved Road Traffic	Average annual daily traffic	1,028	257
Unpaved Road Traffic	Average annual daily traffic	55	20
Perceived Transport Quality	% firms identifying as major business constraint	23	30

Source: The Democratic Republic of Congo's Infrastructure: A Continental Perspective, March 2010

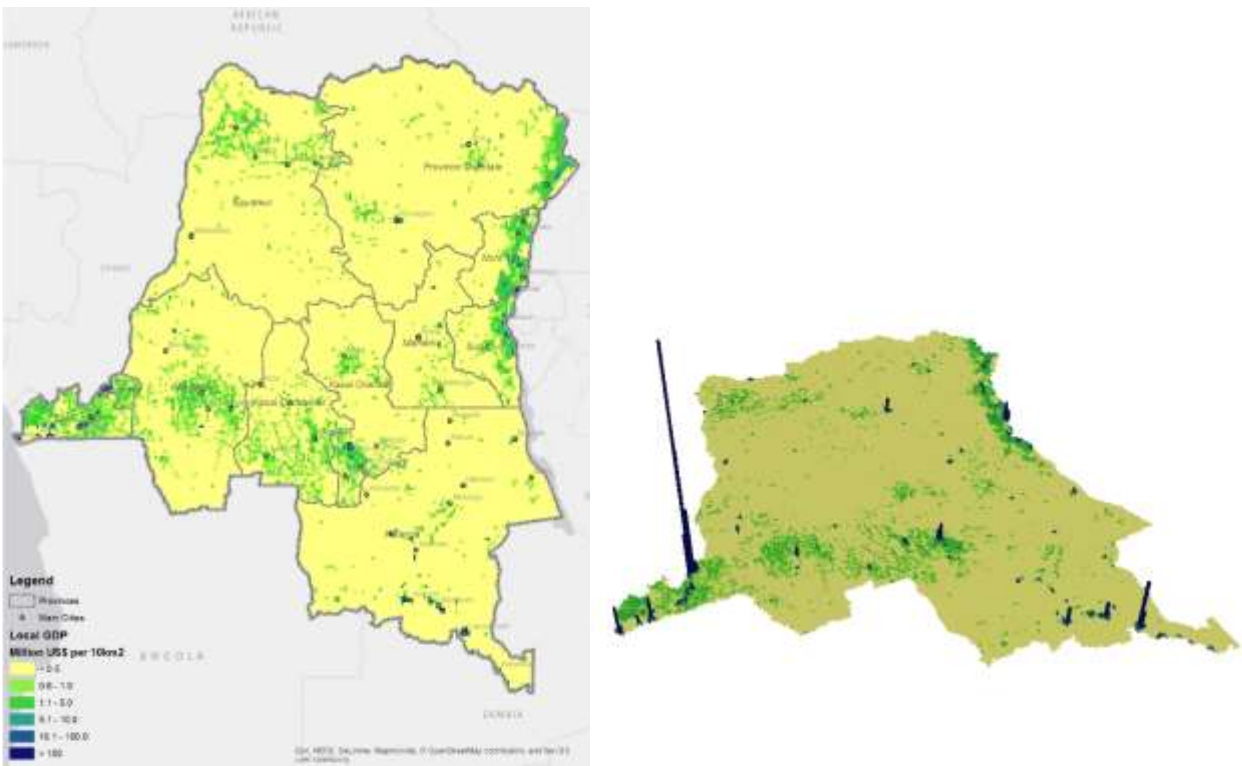
Natural Resources, Infrastructure, and Development

Despite being one of the poorest countries in the region, the DRC contains vast economic potential within its borders. The DRC's natural resource endowment, in the form of land, minerals, and forests, is unparalleled. The agricultural sector, which is overwhelmingly the most important sector for employment, generates around 40 percent of total income and employs 60 percent of the workforce. Nevertheless, agricultural productivity (output per worker) has declined dramatically since independence in 1960 (Block 2010). This has led to a steep reduction in agricultural exports, a decline in food availability leading to over 70% of the population being food insecure, and nearly one-fourth of the population being chronically malnourished (Ulimwengu 2009).

Despite this historical decline, sustainable expansion of the agricultural industry remains achievable. Currently, only 10 percent of arable land is farmed, and only 13,000 hectares are irrigated against a potential of four million hectares. With over 22.5 million ha of low population density, uncultivated, unprotected, nonforested land, there is considerable room for expansion with putting little pressure on forests (Deininger et al. 2011). With proper management and stewardship of the land, the DRC could become the breadbasket of Africa and feed upwards of one billion people. There is strong evidence showing that reducing travel times to markets has a significant effect on agricultural production. Dorosh et al (2010) showed a strong, plausibly causal effect between these variables using data from all of sub-Saharan Africa. Ulimwengu et al (2009), in a similar study, focused solely on the DRC and found that reducing travel time to the nearest city of 50,000 residents by 10% increases crop production by 4.4%.

Mining, another pivotal sector in the DRC's economy, also presents tremendous opportunities for development. Currently accounting for 12 percent of GDP, some estimates put the DRC's mineral wealth at US$24 trillion, a figure that is especially high considering that two thirds of the population subsist on less than US$1 per day (Block 2010). Indeed, much of the DRC's current income is clustered around large mining sites. Figure 1 shows the spatial distribution of GDP. Aside from the area around Kinshasa, the capital, significant peaks in income can be seen around Lubumbashi, the mining capital of DRC with enormous deposits of copper and cobalt, Mbuji-Mayi, an area rich in diamonds, and Kivu, which has large deposits of gold and other rare-earth metals. DRC's economic success is influenced heavily by this sector.

Figure 1: Local GDP in DRC, 2006

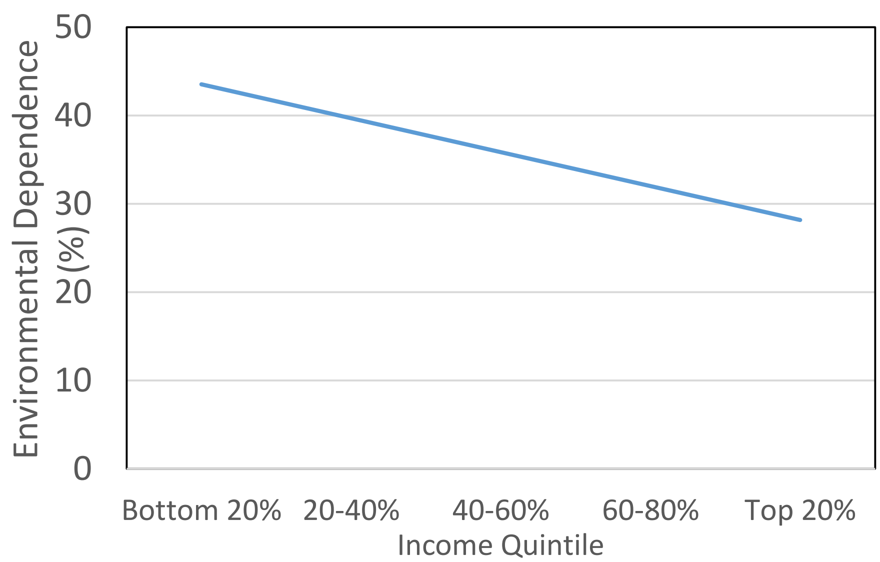


Source: Authors' calculations. Data is from Ghosh et al (2010)
Figure on the left shows local GDP for DRC from 2006, as estimated by Ghosh et al (2010). Figure on right shows the same data in 3-dimensional format to illustrate the extreme spatial inequalities.

The familiar resource-curse challenges coupled with low investment and lack of infrastructure have prevented the DRC from fully taking advantage of its mineral wealth. While tapping mineral reserves offers the prospect of poverty alleviation and growth, it also comes with risks. Much of the DRC's mineral deposits are located in the eastern part of the country. These mines are geographically isolated from the rest of the country, and are located in areas which are subject to frequent conflict from local militias. Indeed, the very presence of the mineral deposits is both a cause for these conflicts, and also generates the economic windfall necessary to perpetuate them. Improving transport infrastructure near these mines, while necessary to spur economic growth, will therefore also come with the risk of fueling these conflicts, both by facilitating the movement of resources out of the region, and reducing travel costs of rebel groups (see Ali et al. 2015). When analyzing the impacts of future road construction, this study accounts for this possibility by factoring in the effects of recent conflicts.

Finally, perhaps the DRC's most valuable natural resource is its forests. Home to over 145 million hectares of rain forests, DRC has the second largest forest endowment in the word, and contains over 60% of the total forest area in the Congo Basin. These forests are of great global importance, as they represent the second largest carbon sink in the world, and are of tremendous biodiversity value. In terms of local welfare, the forests are also of paramount importance. Up to 40% of individuals living in forested provinces of the DRC rely on hunting, gathering, and fishing as their main source of food (Bahwere 2008). Recent data from CIFOR's Poverty Environment Network (PEN) shows that environmental dependence (i.e. the share of income that households derive from environmental sources) is as high as 45% for the DRC's poorest families, and tends to decline as incomes increase (see Figure 2). This implies that the most vulnerable households in the DRC could have a large share of their incomes jeopardized if the forests are not properly managed and protected.

Figure 2: Environmental Income Dependence by Income Quintile



Environmental dependence is the ratio of environmental derived income to total household income
Ratio is calculated for each income quintile and best fit line is shown
Source: Authors' calculations. Data from CIFOR's Poverty Environment Network (PEN) survey. See Angelsen (2014) for more details on this survey.

While the deforestation rate in the DRC is currently the highest of the Congo basin, at around 0.22% annually between 2000 and 2005 (Growth 2013), it is still low compared to South America and

Southeast Asia, whose net deforestation rates are, respectively, 2 and 4 times higher. The DRC's relatively low deforestation rates cannot be entirely attributed to successful public policy, however. Deforestation and degradation in the DRC has been limited by a combination of various factors—conflict, political instability, and poor infrastructure—creating a kind of "passive protection" of the forest. A vast literature has shown that deforestation tends to occur near roads.[3] Therefore, the location of new road construction or improvement in the DRC must be chosen carefully so that, for a unit cost, it maximizes net welfare benefits. This includes both increasing economic benefits in terms of increased GDP from reduced transport costs and increased connectivity, and also minimizing costs in terms of deforestation and biodiversity loss.

Structure of the Report

This report attempts to take a holistic approach to evaluating the impact of road network improvement. Chapter 2 gives an overview of the current state of DRC's transport system. Using a geospatial model, the critical portions of the system are identified, and the economic benefits from reducing local transportation costs are estimated. Chapter 3 then examines the potential for deforestation that could occur from infrastructure investments. Estimates of total forest loss are explored, as well as possible biodiversity impacts that this may have on the local biome. Chapter 4 then combines these two analyses by simulating the effects of two road improvement projects: one connecting major urban centers to Kinshasa and another dealing with a road improvement project in the East of the country. Estimates for the economic benefits due to local transport cost reductions, as well as costs in the form of additional forest depletion are provided. The results of these simulations are meant to give policy makers one additional tool to help them prioritize infrastructure investment projects. Chapter 5 then concludes.

In sum this report presents both new information and new tools that can be used by policy makers for broad planning purposes to determine where investments yield the highest net returns and how damage to valuable natural assets could be avoided. As such this work considerably advances the information that is available to planners, suggests sophisticated methodologies that could be used to guide decisions, and provides a more informed foundation upon which to deliberate and decide upon issues that inevitably involve trade-offs when financial resources are limited.

[3] Several notable papers include Cropper et al (2001) in Thailand, Chomitz and Gray (1996) in Belize, and Gaveau et al (2009) in Indonesia.

Chapter 2: A Snapshot of DRC's Transportation System

The Congolese transport system is a multimodal system with the Congo River as its spine. Much of the DRC relies on a combination of both roads and rivers to transport people and goods around the country. In some parts of the country, including much of Equator province, roads have deteriorated so much, or in some cases, never existed, making river transport the only means of travel. Several railway lines connect Kinshasa with Kasai and Katanga provinces. However, the service on these lines is often unpredictable and slow, making the shipment of perishable goods along them a dubious and uncertain endeavor. Much of the current transport system was established during the DRC's colonial period, and was developed for the purpose of rapidly exporting raw materials (mainly rubber, ivory, minerals, and timber) from the country's interior. The system gave little regard to socio-economic integration of the Congolese territory.

With over 25,000 km of waterways, the DRC has one of the largest networks of navigable routes in the world. Better use of the river and lake transport could be one of the keys to economic development and poverty alleviation, chiefly because it is cheap, and serves most of the interior portion of the country, which has high agricultural potential. It also complements, or in some cases, substitutes for road infrastructure in the other major regions of the Congo. Kisangani, the third largest city, and Mbandaka, the capital of the important province of Equateur, are connected to the capital, Kinshasa, only by river transport.

The exploitation of river and lake transport, which until 1971 was virtually the monopoly of public enterprises, is now dominated by numerous formal and informal private operators. The largest port in the country is in Kinshasa, which handles around 2 million tonnes of cargo per year. For comparison, this single port caries more than triple the volume transported by the national railway, Société Nationale des Chemins de Fer du Congo (SNCC). River transport is essential for the development of agriculture, which has become the center of the economic development strategy of the Government since it would allow the opening up of DRC's immense rural areas.

In this chapter, several analyses are performed which attempt to identify the most crucial parts of the DRC's transportation network by analyzing the effectiveness of roads and rivers as transportation modes to the local markets and to Kinshasa. It is found, generally, that while roads are important for local transport to a nearby city, the overall road network is far too incomplete for longer distance transport to the capital. For transport over long distances, the river system is vital. This is because, even with the current poor state of port infrastructure, traffic is still able to traverse the rivers for much of the year. Thus, the river has become a last resort in many areas, where the more infrastructure-intensive transportation networks of roads or railways have broken down, or never existed. Finally a methodology for estimating some of the economic benefits from road construction is demonstrated.

The Current State of the Transport Network

An overview

A geospatial model is developed which identifies costs and bottlenecks to travel. It simulates how individuals and traded goods can move around the DRC. The model takes the road and river network (including both location and quality information), land topography, and population data as inputs, and makes several plausible assumptions about how local farmers, traders, and other economic agents will move around the country, given these inputs. The culmination is an algorithm which estimates the transport routes that a cost minimizer would take to ship products to market, to and from any location within the DRC. The assessment ultimately identifies the existing portions of the road network which are both most crucial to the current network, and also most in need of rehabilitation. Box 1 provides more information on the geospatial model.

Box 1: Geospatial Model

The analysis done in this chapter is based on the findings of a geospatial model constructed to simulate how products and people move around the DRC. A geospatial model was chosen over other means of analysis, such as household surveys, because it allows for analysis in every part of the country, not just where the surveyed are located. It also allows for a richer analysis given that only limited household survey data exists for the DRC.

The construction of this model involves two steps. First, a dataset on the transportation network is compiled. This involved collecting data on the road and river network, and the location of ports. Next, assumptions are made about how people and products will move around this network. These two steps are discussed below, followed by a section describing the caveats of using this model.

Transportation Network

The foundation of the geospatial model is that it allows for the determination of the cost of traveling between any two points within the DRC. Once that is determined, transportation routes can easily be calculated under the assumption that agents will minimize transportation costs. The first step in doing this is taking account of what type of transportation infrastructure exists, and of what quality and condition it is in.

For this study, various sources were used to collect this data. Road location data was obtained from Delorme, a company which specializes in GPS mapping software and has one of those most thorough road networks available for DRC. The quality of the roads was obtained from the African Infrastructure Country Diagnostic (AICD) which contains attribute information, such as the width of each road, whether it is paved or unpaved, and in what condition it is in. Data on which rivers are navigable was obtained from FAO and DRC's Ministère des Infrastructures, Travaux publics et Reconstruction (MITPR), and the location of ports along the river was obtained from UN's Joint Logistic Centre.

Model Assumptions

Once the transportation network is constructed, informed assumptions are made about the cost of moving around the network. For the road network, the Highway Development and Management Model (HDM-4) was used to estimate the cost. This is a model that is commonly used by engineers, which takes into account the roughness of the terrain, quality and condition of the road, as well as country level factors (such as the price of fuel, average quality of the fleet, the price of a used truck, and wages), to determine the unit cost of traveling along every segment of the road network (for more details see Ali et al forthcoming). Information on the cost of traveling along the river and the cost of loading products onto boats was obtained from World Bank (2014).

Now that the costs of moving people and products around DRC are known, the likely transport routes used by the Congolese can be simulated. The points of origin for the analysis were created by dividing DRC's territory in more than 27,000 cells of approximately 10 by 10 kms, with origin points given at each cell's centroid. Transport cost to the local market is then estimated by calculating every possible transport route from every cell centroid to every possible market, and selecting the cheapest route/market combination as the most likely route/destination. A market is defined in this report as a city of 50,000 or more residents. This threshold was chosen at it identifies all major, and smaller cities in DRC, and is also consistent with much of the transport literature in Africa. Outputs from this model are used as inputs into a statistical analysis, as is described in Box 2.

Model Caveats

While it is believed that this model simulates how people and products move around DRC as accurately as possible, some shortcomings must be acknowledged. First, the model does not factor in the cost of delays at ports, or along the roads or rivers. Transport in the DRC, especially along the river, can take significantly longer than one might expect because of dilapidated infrastructure (such as roads that are washed away during the rainy season), river silting (which can make segments of some rivers impassable, especially during the dry season), or other human factors (such as low capacity and skills at shipyards, or port operators having little information on supply and demand for transport, and thus not making optimal staffing decisions) (World Bank 2014). Without proper estimates of the opportunity cost of time, the model likely underestimates the true cost of using the river, which is relatively cheap in a pecuniary sense, but costs a significant amount of time. At the same time, cost estimates of using the roads also only include pecuniary costs, however, time delays along the roads are significantly lower on average than time delays from using the river.

Finally, while the model includes the two most common methods of transport—roads and rivers—these are not the only methods for transporting people or products around DRC. Several railroad lines do exist in DRC. However, these mostly service small portions of the country, mainly in the Kasai and Katanga provinces, and are notoriously unreliable. Air travel is also used quite commonly to fly in between provinces in DRC. Due to its cost, however, this is not a viable option for most Congolese citizens (World Bank 2013).

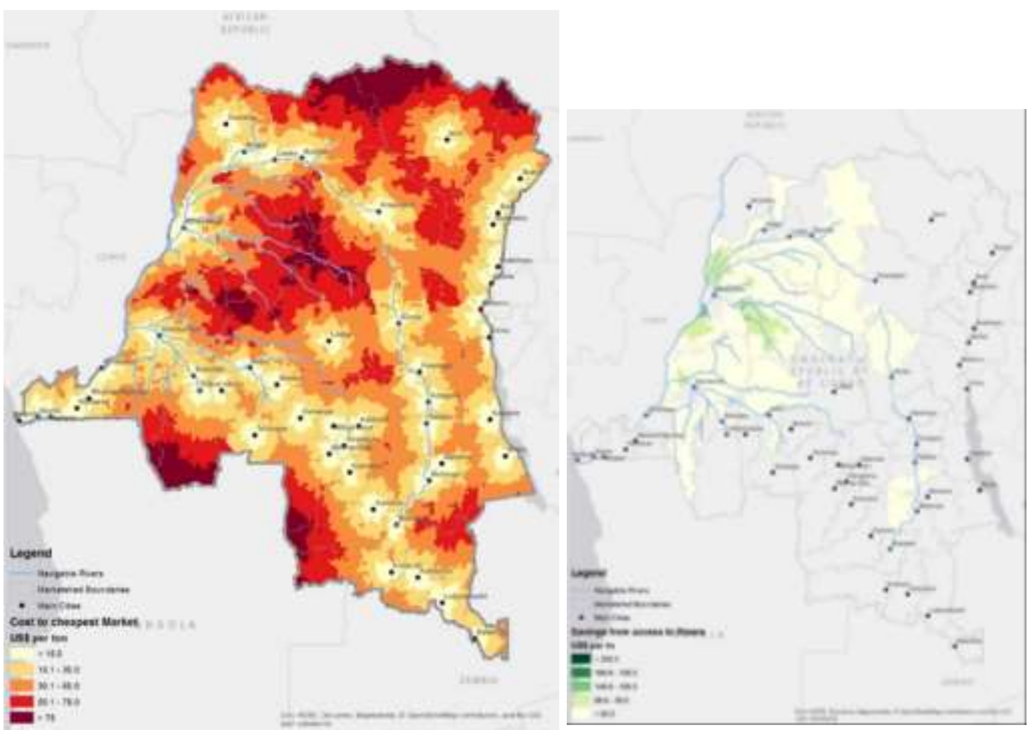
As stated, this model includes two modes of transportation, transport using road infrastructure, and using rivers. The third type of ground transportation used in the DRC, railways, is excluded because it only serves very local areas and provides services that can be sporadic, and hence of limited economic reliability.

Local Transport to the Nearest Market

There are several reasons why improving access to local markets would be beneficial. These include increased opportunities and lower costs for farmers to sell their crops, increased access to productive inputs, and increased access to local services such as schools and hospitals, amongst many others. Given the importance of local trade to rural farmers, it is natural to begin with an analysis of local transport to the nearest market.

Two images are shown in Figure 1. The image on the left shows the costs of transporting goods to the cheapest market from every location within the DRC (a market is defined as a city of at least 50,000 residents), using a multi-modal model with access to both roads and rivers.[4] The image on the right shows the difference in costs between a uni-modal, road only model, and the multi-modal model, and thus shows the areas that are most likely to use and benefit from using the river for transport. It is clear from these maps that, aside from some isolated areas in the northwest part of the country, rivers are used relatively infrequently for local transport. Specifically, only 14% of DRC individuals live in areas where it would be cost effective to use river transport for any portion of their trip to the local market. Further, these individuals live in areas which only account for approximately 7% of the country's GDP, implying that investments in river transport will not have a significant impact on local market transport, given the current economic geography of the country. Given these facts, it is evident that the road network is likely much more important for local transport than is river transport.

Figure 1: Transport cost to cheapest market



[4] Note that it is assumed that 1 tonne of goods are shipped in a large truck, or river barge. If more or fewer goods are shipped, the cost would change accordingly. However, it is not the actual cost that is important for this analysis, but the relative costs between different locations, so this assumption is made merely for comparative purposes.

Image on left shows the transport cost to the cheapest market for every region within DRC, given a multi-modal (road and river) model. Image on right shows the difference in transport costs between this multi-modal model, and a uni-modal, roads only, model, and thus shows the regions where river transport is most important.
Source: Authors' calculations

Transport to Kinshasa

Transport costs to the national capital, Kinshasa are summarized in Figure 2. Having access to Kinshasa is important for connectivity and social cohesion. Not only does the capital contain over 10% of the country's population, but it is also a center of wealth and economic activity, making it a vital demand center for rural farmers and other traders to ship their products.

Given the long distance between most of the country and Kinshasa, and the fact that DRC's road network is fractured, travel along rivers becomes important to the overall Kinshasa-transport network. Figure 2 (left image) shows the cost of transporting goods to Kinshasa, utilizing both roads and rivers in the most efficient manner. As is expected, the cost tends to increase as one moves away from Kinshasa, and also tends to be lower in the northwestern part of the country, which is heavily serviced by tributaries of the Congo River. The map on the right shows the transport cost difference between the multi-modal model and the uni-modal, roads only model.

Access to river transport is, as always, more important for longer distance travel and for goods with a relatively low value to bulk ratio. Hence there is a significant difference between the mode of transport that is important for travel to local markets, and those used for transport to Kinshasa. When minimizing travel costs, the geospatial model indicates that approximately 80% of DRC's population would prefer to utilize river travel, at least in part, in order to transport goods to Kinshasa. Estimates suggest that approximately 80% of DRC's population would prefer to utilize the river for at least some fraction of the journey to Kinshasa. Moreover these individuals live in areas that account for nearly 60% of DRC's GDP. Relative to the 14% of individuals and 7% of GDP that are in areas which use rivers to transport goods to the local market, it is clear that the river is much more important for long distance transport to Kinshasa.

While cost savings to local market transport are quite low and isolated only to areas right along the river, as shown in Figure 1, cost savings to Kinshasa transport are much greater and achieved throughout nearly the entire country, save the southern part of the country which is mostly outside of the Congo River basin. The northern part of the DRC is particularly dependent on river transport for reaching Kinshasa, which is not at all surprising when one considers that much of this region has no direct road access to Kinshasa.

Figure 2: Transport cost to Kinshasa

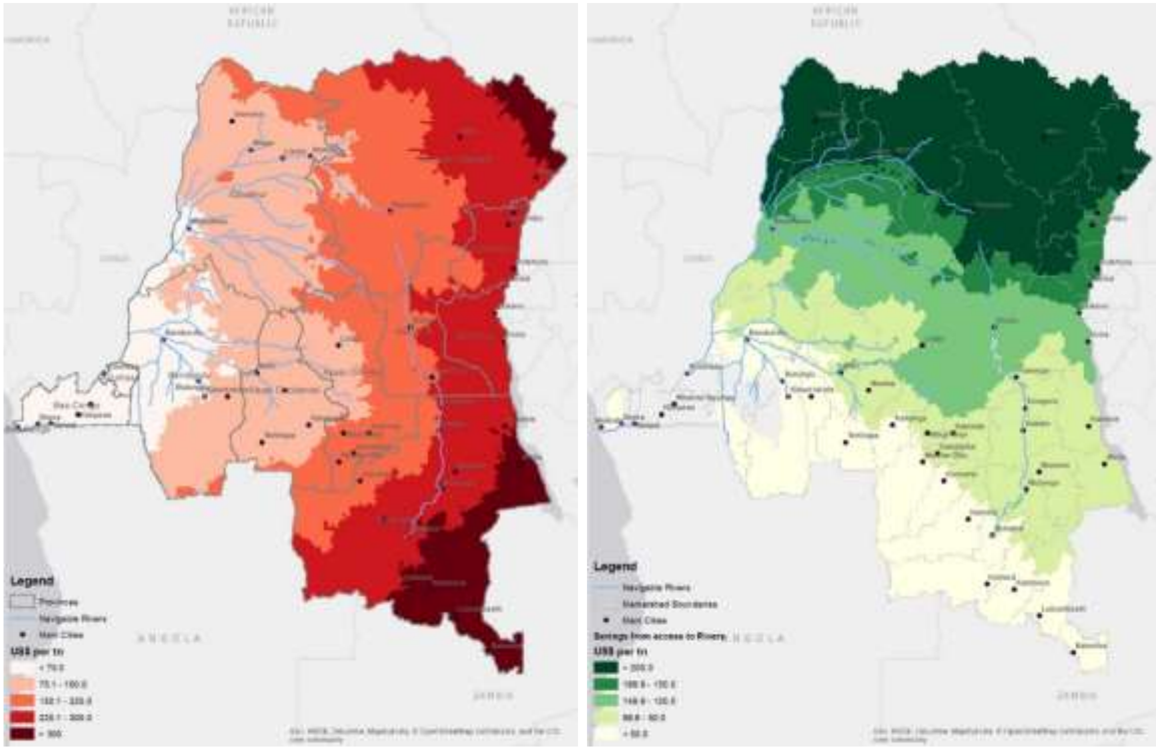


Image on left shows the transport cost to Kinshasa for every region within DRC, given a multi-modal (road and river) model. Image on right shows the difference in transport costs between this multi-modal model, and a uni-modal, roads only, model, and thus shows the regions where river transport is most important.
Source: Authors' calculations

Two Transport Network Improvement Proposals

The Congo River and its tributaries act as a backbone for shipping goods to Kinshasa. Facilitating access to the river's ports which can connect the Congolese to the capital may therefore be a short-term priority for any infrastructure improvement program. For individuals who do not live directly on a navigable and connected river, or live in an area which does not have a river port, the road network becomes an important first leg of the journey, to connect them to a port, and eventually, Kinshasa.

For long-term growth and integration, however, improving access to river ports is insufficient. The volumes of freight transported over rivers are already significant and continue to grow. This mode of transportation though remains unreliable, and much more expensive than it should be. As an example, a trip from Kisangani to Kinshasa over river can take up to two weeks (World Bank 2014). For this reason, in addition to a competitive inland waterway transport system, there is a need for a complementary efficient road system, which is demanded by segments of the market for which waterway transport is not a viable option (for example, passenger transport, transport of light weight, high value goods, or highly perishable goods). Connecting the entire country with a fully integrated road network should therefore be an important priority. In order to do this, a major urban center road network is proposed, which connects 11 major urban centers throughout the country with the national capital, Kinshasa.

Improving Access to River Ports

When considering the road network leading to ports, some roads will be more important than others. Figure 3 displays roads that connect large population agglomerations[5], such as Kisangani, Lubumbashi, and the provinces of North and South Kivu, to the river network. Collectively, these roads improve connectivity for up to 60% of the population. Focusing on infrastructure which improves these routes, as well as infrastructure at the ports at which they end, will likely have a large positive impact on connectivity, relative to other transport projects.

[5] When considering the road network leading to ports, some roads will be more important than others. Improving those which service the most amount of people is likely to have the biggest impact in the short term by not only improving connectivity to the local markets where the ports are located but also to Kinshasa via the multimodal network . These roads were identified by calculating the optimal road to get to the nearest port for each portion of the country, and selecting the sections of road from DRC's network which have the potential to be traversed by the largest population. When determining the number of people serviced by each road/port, the model assumes that all DRC residents are equally as likely to transport goods. Without information on who is most likely to use the roads—data which in all likelihood does not exist—assuming uniform road usage is necessary.

Figure 3: Critical roads for the port network

Source: Authors' calculations

Major Urban Center Road Network

In the coming years, one of the key priorities of the government of DRC is to connect major urban centers with well maintained, high quality roads. Figure 4 identifies the primary roads that would need to be improved or completed in order to ensure that these urban centers were connected, while minimizing the size of this network. This network includes 6,500 kms of road. To put this number in context, this is nearly as long as the entire Sahel, from Dakar, Senegal, to Khartoum, Sudan. Additionally, only 20% of the roads that are a part of this major urban center road network are currently paved, and 75% of them are currently in poor condition. While it would require a tremendous infrastructure investment to connect these urban centers to Kinshasa, and may not be feasible at the moment, any long term infrastructure plan should consider this an important priority for improving national cohesion. In chapter 4, a simulation of the geolocation of the benefits of this potential project is presented.

Figure 4: Major urban center road network

Estimating Benefits to Road Improvement

In the final section of this chapter, a methodology is laid-out which uses regression analysis to determine the economic effects of reducing local transport costs along roads. The approach follows World Bank (2015) and Ali et al (forthcoming) by using cross-sectional data on local GDP, transport costs, and several control variables, to predict how changes in transport cost effect local GDP. See Box 2 for a more thorough explanation of this model.

The results from the regressions show that there would be significant benefits to decreasing local transportation costs, especially in the highest cost, more densely populated regions. Specifically, a 10% reduction in local transportation costs would lead to, on average, a 0.46% increase in local GDP. Ali et al (2015) also shows that in the DRC, reducing transport costs could have a significant, positive impact on wealth accumulation and poverty reduction.

There are several ways one could reduce road transport costs. The most obvious, and likely the most costly way, would be to build new roads and bridges. However, in the context of the major urban center road network proposal, discussed in the prior section, new road construction is only a very small part of the overall project. While some vital gaps in the road network are missing, much of the network is already in place. Instead, much of the network will need to be improved from poor or fair condition, to good condition. According to the HDM-4 model used in this analysis, transforming a road from poor to good condition, could reduce the cost of traveling along it by nearly 50%. It may also have the additional benefit of ensuring that the road is passable all year round, and not just in the dry season, the benefits from which are not quantified by this model.

Box 2: Transport costs effect on economic activity

In order to determine the effect of transport costs on economic activity, this report relies on regression analysis. The analysis follows very closely the approach taken by Ali et al (forthcoming) and Ali et al (2015). The entire DRC is divided up into gridcells of approximate size 10km x 10km. Each gridcell is a unit of observation in the following model:

$$\ln(Y_i) = \beta_0 + \beta_1 \ln(TM_i) + X_i'\gamma + \varepsilon_i \qquad (1)$$

where Y_i denotes the local GDP, according to Ghosh (2010), in gridcell i. TM_i is the transport cost to the local market, and X_i is a vector of regional controls. Those controls include ln(population), ln(population)^2, ln(cassava potential yield), ln(cassava potential yield)^2, ln(distance to nearest mine), and a measure of conflict near the gridcell and the local market. To account for the endogeneity of both market cost and the conflict variables, this report follows Ali (2015) and takes an instrumental variable approach (see Ali (2015) for details on the instrumental variables used and a discussion of the conflict measures).

The results are given in Table 1 below. Because all variables are in log form, the estimated coefficients can be interpreted as elasticities. The results in the 2SLS model (column 2) show that a 10% decline in transport costs to the local market would lead to a 0.46% increase in local GDP. Additionally, the regression shows that high conflict near the cell and the market reduce local GDP, GDP is higher near mines, GDP tends to increase with population size, and there is an increasing, but concave relationship between agricultural land suitability (proxied by the potential cassava yield of the land) and local GDP.

Table 1: Economic Effects of Transport Cost to Local Market

Dependent Variable: Local GDP (2010)	(1) OLS	(2) 2SLS
ln(Cost to market)	-0.016***	-0.046***
	(0.0047)	(0.012)

Indicator: High Conflict Cell	0.020***	-0.250***
	(0.0072)	(0.079)
Indicator: High Conflict Market	-0.023***	-0.175***
	(0.0066)	(0.02)
ln(Distance to nearest mine)	-0.067***	-0.024***
	(0.006)	(0.0094)
ln(Population)	0.528***	0.528***
	(0.0031)	(0.0032)
ln(Population)^2	0.036***	0.036***
	(0.00027)	(0.00029)
ln(Cassava potential yield)	0.240***	0.197***
	(0.03)	(0.04)
ln(Cassava potential yield)^2	-0.019***	-0.016***
	(0.0026)	(0.0028)
N	26,535	25,523

Standard errors in parentheses
*** significant at 1% level, ** significant at 5% level, * significant at 10% level

Concluding Remarks

The analysis above highlights several key points. The current road network is insufficient for long distance travel throughout the DRC. For travel to Kinshasa from most parts of the country (or, likewise, travel from Kinshasa to most points within the country) a multimodal approach which utilizes both roads and rivers is often necessary. For transport to local markets, the optimal route typically only utilizes roads, with river transport barely used. Two projects were proposed above. The first one focuses on improving access to ports, in order to improve long distance transport in the short term. Recognizing that relying solely on the river for transport is not a sustainable, long-term solution, another project is proposed which seeks to connect major urban centers with Kinshasa using a fully integrated road network. In Chapter 4, this project is revisited and, using the results of the regression analysis performed in this chapter, the economic benefits to such a project are estimated.

Chapter 3: Roads, Forests and the Biodiversity of DRC

Motivation

The DRC, the largest country in Sub-Saharan Africa, is endowed with the second largest rain forests in the world. The iconic Congo forests are a trove of economic value – some monetizable and much that is not. The forests of the Basin are home to about 30 million people with over 100 ethnic groups and remain a crucial livelihood asset, often generating more income for the poor than that obtained from farming (Angelsen et al 2014). Forests also perform valuable ecological services at local, regional, and global levels. Local and regional services include maintenance of the hydrological cycle and important flood control in a high-rainfall region. They harbor between 30 to 40 gigatons of carbon, which is equal to 8 percent of the world's forest carbon, the equivalent of 3–5 years of world emissions of CO2 equivalent.

The carbon sequestered by the forests gives DRC the potential to leverage considerable financial resources that are being made available through the REDD+ (Reducing Emissions from Deforestation and Forest Degradation) initiative. The initial DRC National Program which helped launch and structure the country's national REDD+ strategy, has transitioned into the full National Program (Readiness Plan). When fully implemented REDD+ has the potential to create new opportunities that provide incentives for improved stewardship of the forests and the carbon that they sequester, and as a consequence, the innumerable other benefits such as climate regulation, livelihood support, and biodiversity protection.

DRC has the resources and potential to become one of the richest countries in the region. The country's comparative advantage clearly derives from its immense endowment of natural resources – forests, minerals and water resources. Prudent economic management therefore calls for proper stewardship of its natural assets to assure sustainable and equitable economic growth. But harnessing the growth potential of these endowments is not without challenges. It calls for carefully weighing the country's natural capital and the services it provides against other potential land uses. Going forward one of the greatest challenges for the DRC is to determine the location of roads. As noted earlier, the country's transport infrastructure is severely deficient even by the standards of other low-income countries. It is therefore no surprise that road construction and rehabilitation remains a high priority of both the Government of DRC and the major development partners.

However, while roads may bring benefits and are vital for commercializing agriculture, they are often also the precursors to deforestation. A common response to such threats is the creation of protected areas that prevent or severely restrict intrusive structures within demarcated areas. Often such strategies fail to protect critical natural assets for several reasons. First, governments may seek to minimize economic opportunity costs by siting protected areas in remote regions with low agricultural potential that may not coincide with the areas of highest ecological values (such as climate regulation, biodiversity or watershed benefits). Second, attempts to restrict road improvements in protected areas with strong agricultural or mineral potential may fail because economic interests invariably overwhelm the limited resources of conservation interests. The vast literature on the political economy of environmental policy suggests two reasons why this might be so. First, the benefits of land conversion are concentrated, while the environmental costs are diffused. Collective action problems render lobbying by environmental groups more difficult. Second, the benefits from land conversion are monetary, while the costs are typically non-pecuniary and emerge in the future, creating a further asymmetry in bargaining ability. The result is higher levels of land conversion and environmental loss than may be either economically optimal or desired by constituencies.

Approach

This chapter seeks to mitigate such conflicts by developing a high-resolution spatial econometric model of road improvement impacts that includes both ecological risks and the economics of forest clearing. The objective is to provide a methodology for prospective assessments that can inform infrastructure planning at the outset. By understanding impacts of a road or other infrastructure (positive or otherwise), better decisions can be made on ways to locate roads that maximize benefits and minimize costs. The focus of this chapter is on the physical impacts of roads on forests, with the previous chapter dealing with the monetary benefits. No attempt is made to value environmental services in large measure due to the high imprecision of estimates and also because there is little consensus on the validity of approaches used to elicit important, unmarketed services provided by the ecosystem.

To guide the empirical analysis a theoretical model of land use change is developed (see Annex 2). The analysis provides a key insight. Decisions on road improvement projects are typically made sequentially. Initially the location of a road is determined and this is followed by an EIA (Environmental Impact Assessment) that seeks to identify and mitigate forest clearing by strengthening environmental management. The analysis shows why infrastructure planning in such a sequential decision regime may actually reduce welfare, because it increases deforestation and the associated ecological and social impacts beyond what is economically desirable. The model, together with a body of empirical evidence, suggests that such reactive approaches are inadequate in situations encountered in DRC and will be less effective at adequately influencing outcomes. Instead, siting decisions and impacts need to be considered simultaneously.

Put simply the sequencing needs to be altered. The EIA process needs to occur together with siting plans. Such upstream planning has been rendered both feasible and cost effective with the availability of geo-referenced information on forest cover and economic data. This chapter provides the data and easily comprehended maps for such an exercise. The maps provide a simple visual tool that summarize a computationally intensive exercise. The following chapter demonstrates a procedure for identifying hazards, win-wins and areas where difficult trade-offs may need to occur. The data made available as a result of this exercise could provide valuable information for policies such as REDD prioritization, the location of growth poles, agricultural zones, and so on. The data and approach are perhaps timely and valuable with much development and the need for determining trade-offs likely to occur in the next few decades.

Results on Forest Clearing

The assessment begins by mapping changes in forest cover and correlating these with geographic and socio-economic variables. The analysis uses the most recent and comprehensive high-resolution data on forest cover from Hansen, et al. (2013). The data are available at a 30m spatial resolution for 2000-2012 that are converted for tractability into 2.7 km grid cells. The econometric estimates are remarkably robust and stable across different statistical specifications in the regressions. Details are provided in Annex 1.

The results suggest that forest clearing intensity declines on average with: (i) distance from roads, (ii) closeness to protected areas and (iii) less accessible terrain (e.g. higher elevation). It increases on average with (iv) improvements in road conditions, (v) the agricultural value of land (opportunity cost), (vi) closeness to population agglomerations (i.e., urban centers) and (vi) conflict intensity.

Two patterns illustrated in Figure 1 are noteworthy. First, upgrading roads from very poor to good condition produces near-complete deforestation within a narrow corridor (of about 1-1.5 km radius) straddling the road. Second, the impact is non-linear and deforestation intensity falls very rapidly as distance from the road increases. Most of the deforestation occurs within about a 2km radius of the road. This may be a useful result for planning and siting of roads in areas of high ecological sensitivity. It suggests that a relatively small detour may be sufficient to protect natural assets of significance.

Figure 1: Effect of road quality on forest clearing intensity

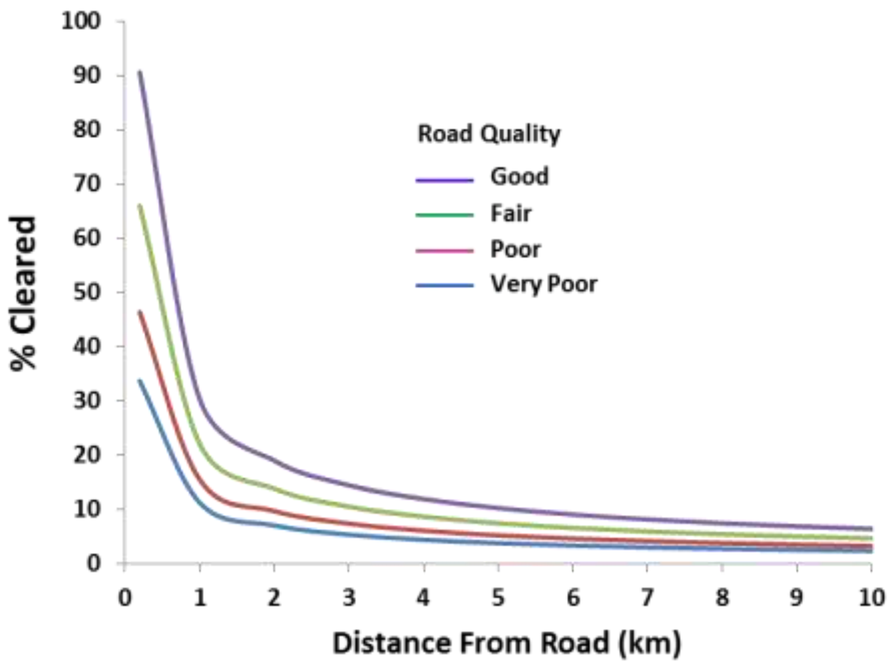


Figure 2 applies the analysis to Eastern DRC and provides an illustration of the extent of clearing that might occur with upgrading. The left panel shows the current deforestation (percent cleared) along the major existing roads. The right panel performs a hypothetical experiment whereby all of the roads are improved from their current state to a "good" condition. Factors such as current road condition, distance from urban center and elevation determine the intensity of clearing and the eventual amount of forest cover along any segment. Increases in deforestation of 10-20% are typical, with significant extensions along many corridors, depending upon local conditions. Intensive clearing is more pervasive nearer to urban centers (where population density and economic activity is concentrated) and in relatively narrow corridors.

Figure 2: Eastern DRC: Change in percent clearing along roads without and with upgrading

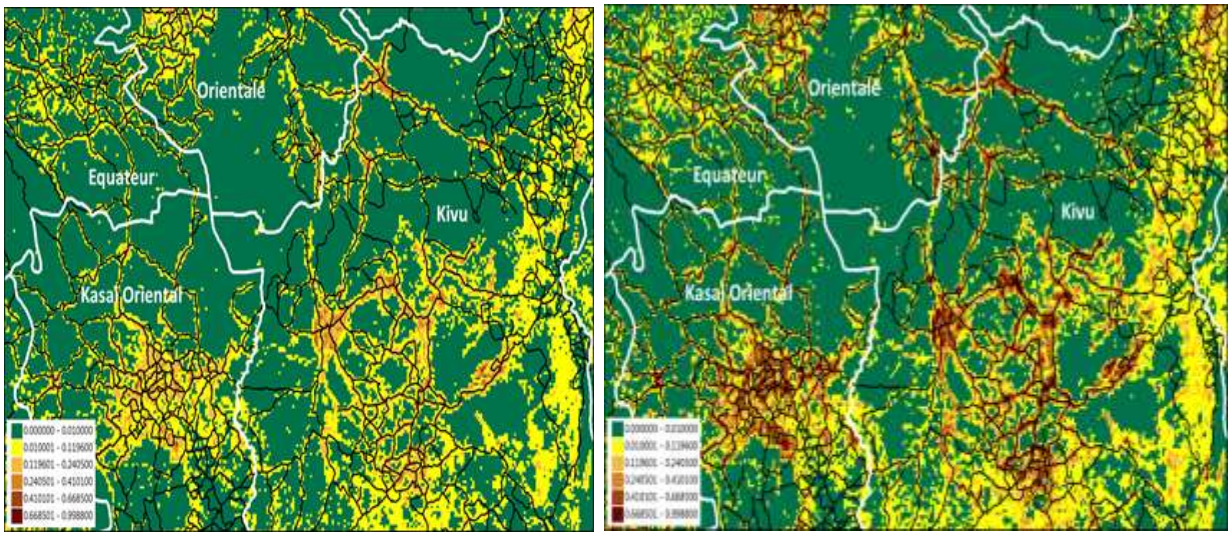
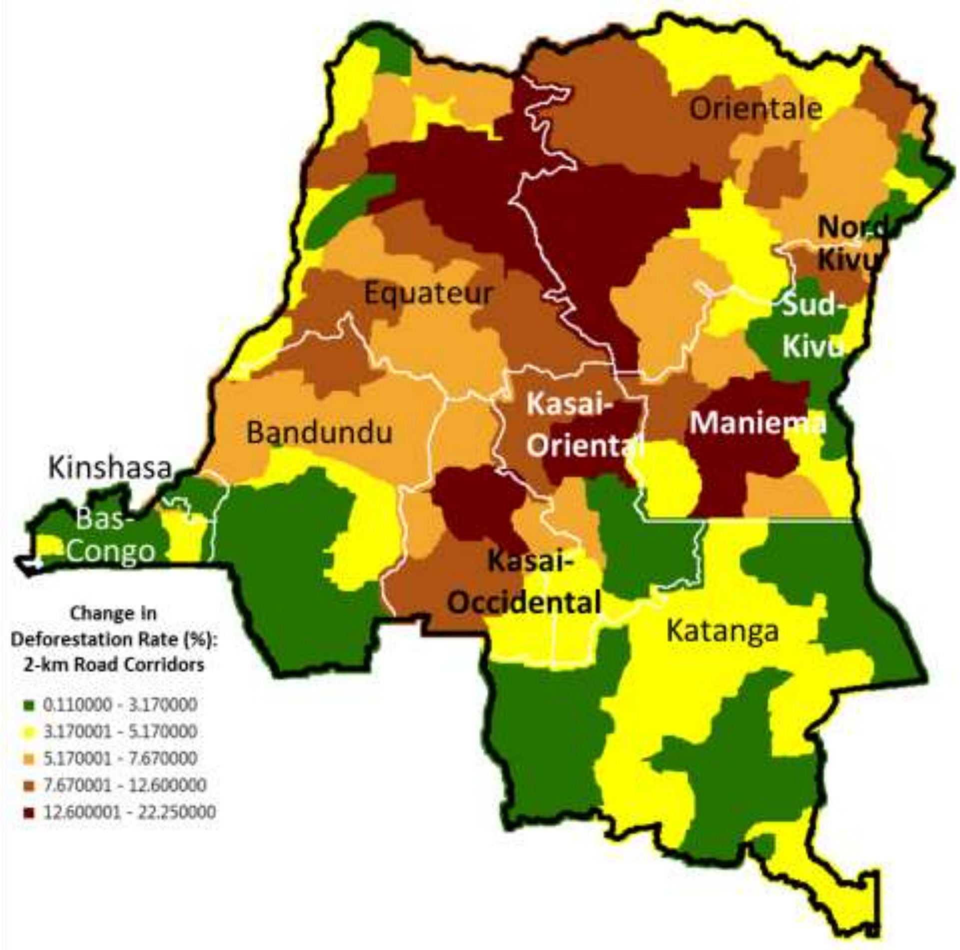


Figure 3 extends the analysis across the country. It is meant to be illustrative and displays changes in mean deforestation rates produced by road upgrading to good condition that would allow speeds of around 60 kmph. It should be noted however that these spatial averages conceal very wide variations within each cluster.

The heaviest impacts (increases of 12.6% to 22.3%) are evident in west Orientale, east Equateur, central Kasai-Occidental, northeast Kasai-Oriental and central Maniema. Adjacent areas in all five provinces also have significant impacts (7.7% to 12.6%). The greatest impacts are concentrated in relatively isolated rain forest areas with poor roads, since market access for these areas would be most improved by upgrading. Overall, the results indicate that 10-20% increases in deforestation would be common after upgrading in rain forest road corridors.

Figure 3: Changes in road corridor deforestation with generalized upgrading



Gradients of Biodiversity Impacts

Not all forest land is of uniform ecological value, nor is it of uniform economic value. This section develops a variety of metrics to identify areas that are of high ecological value and at higher risk of degradation. Spatial analysis of carbon stocks in the Congo and biodiversity habitats has largely confirmed that there are significant overlaps: Areas that store large amounts of biomass carbon may coincide with areas of biodiversity significance.[6] There is therefore an opportunity to realize and monetize many of these multiple benefits through the REDD+ process. This correlation suggests that it is important for the DRC to identify and appropriately manage areas that generate multiple gains in order to maximize both the monetary and non-monetary benefits from the forests.

[6] Musampa Kaungandu, C Mane, Lola Amani, P Betzky, C Ravilious, L Miles (2012) Mapping potential biodiversity benefits from REDD+. The DRC. Prepared by UNEP-WCMC, Ministry of Environment DRC and Satellite Observatory for Central African Forests

Efforts to develop a single index of ecological value remain elusive and beset with difficulties of enumeration and measurement. Nor is there a consensus on the weighting of different risks and species. To address these issues this study develops a "gradient approach" that combines information on species as well as ecosystems. This approach has practical policy merit. Some road corridors will be built in areas of modest ecological concern, while others pass through areas of higher value. An ecological gradient strategy can be used to minimize ecological damage by favoring road improvements in areas of modest concentration.[7]

There are several components of the biodiversity gradient. Species density provides critical information for developing ecogradients, but at least three other elements are needed:

- Geographic vulnerability, which can be proxied by endemicity: the proportion of each species' range that lies within each grid cell. Species that reside in very few grid cells may be particularly vulnerable to habitat encroachment.
- The other is extinction risk that adds the insights of the international scientific community. Recent work by Mooers, et al. (2008) has explicitly modeled the relationship between extinction probability and the risk indicator that is provided for each species in the IUCN.[8]
- And finally there is a need to incorporate other aspects of the ecosystem captured through a measure of biomes developed by WWF.

Endemicity is measured by the percentage of each species' range that is found in each grid cell. Total endemicity for each grid cell -- the sum of its species endemicity measures -- assigns higher values to cells inhabited by species whose ranges are relatively limited. By implication, forest clearing in higher-value cells may be particularly destructive for remaining critical habitat. Species differ in vulnerability for many reasons that are not captured by our endemicity measure. To incorporate these factors, the threat status code assigned to each species by the IUCN is used with extinction probabilities using the methodology of Mooers, et al. (2008). Table 1 tabulates conversions from Red List codes to normalized species weights, using four probability assignments. Three employ IUCN estimates to derive measures of extinction probability over the next 50, 100 and 500 years. The fourth draws on recent

[7]A composite gradient is developed that includes measures of endemicity, extinction risk (from IUCN) and phylogenetic significance and extinction probabilities (from Isaac 2007). Each index generates a different set of priorities.

[8] The IUCN's current classification categories are Critically Endangered, Endangered, Vulnerable, Near Threatened and Least Concern.

work by Isaac, et al. (2007), who combine a direct extinction risk measure with a measure of each species' isolation on a phylogenetic tree.[9] Each measure provides different priorities and information. For instance a spatial grid containing very diverse species, all in the "Least Concern" category, would be given a relatively low weight by the IUCN measure. But by the Isaacs measure it would be deemed more important due to the elevated genetic diversity of species, even when none are critically endangered.

Table 1: Normalized species aggregation weights[a]

		Normalized Extinction Probabilities			
			IUCN: Future Years		
IUCN Code	Status	Isaac[b]	50	100	500
CR	Critically Endangered	1.00000	1.00000	1.00000	1.00000
EN	Endangered	0.50000	0.43299	0.66770	0.99600
VU	Vulnerable	0.25000	0.05155	0.10010	0.39000
NT	Near Threatened	0.12500	0.00412	0.01000	0.02000
LC	Least Concern	0.06250	0.00005	0.00010	0.00050
	Rounded Weight Ratios				
	CR:EN	2	2	1	1
	CR:VU	4	19	10	3
	CR:NT	8	243	100	50
	CR:LC	16	20,000	10,000	2,000

[a] Data source: Mooers, et al. (2008).
[b] From calculations by Mooers, et al., based on Isaac, et al. (2007).

An ecogradient measure based on species vulnerability alone provides an incomplete accounting of ecological values and functions. A more comprehensive measure would need to incorporate biomes. Using the World Wildlife Fund (WWF) classification of ecoregions[10] a vulnerability

---

[9] A phylogenetic tree is a branching tree diagram that traces the evolutionary descent of different species from a common ancestor. Species in sparse (isolated) branches of a phylogenetic tree are relatively unique, since they share common descent patterns with fewer other species.
[10] Defined as "a large unit of land or water containing a geographically distinct assemblage of species, natural communities, and environmental conditions."

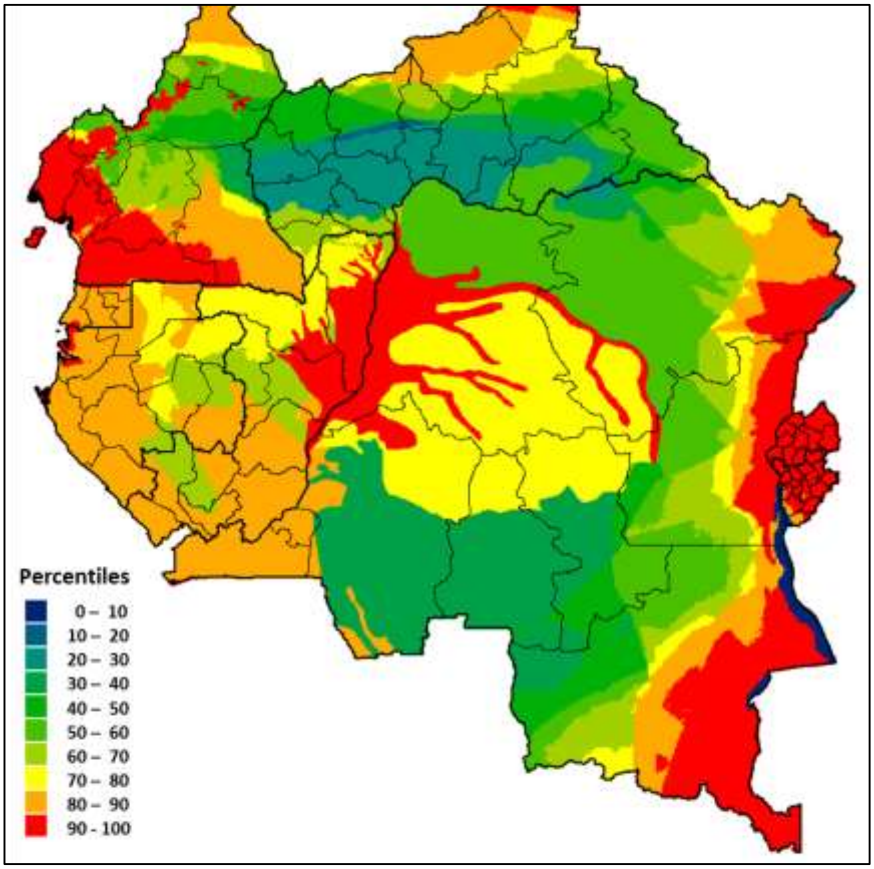
index is derived which measures the amount of an eco-region in a given area. The WWF ecoregions serve as a general proxy for distinctive plant, insect, and animal species that are not represented in the range maps provided by IUCN and BirdLife International.[11]

Each index generates a different set of priorities. A cautious approach is used whereby the indicator that generates the highest threat level is used. This is done by normalizing the indices for comparability using ranks measured as percentiles in each index and selecting the maximum index (risk) value as the eco-gradient measure for the cell. This approach gives parity to alternative vulnerability indicators and always picks the indicator that generates the highest threat level.

Figure 5 combines both sets of information, displaying the distribution of species' ecoregion index in the Congo Basin countries (because species do not reside within national boundaries, the entire region is displayed to show larger patterns). One striking feature is the blue/green (0-50) band that arcs from northern Cameroon to eastern DRC and back to southern DRC. Another is the prominent clustering of very high values in western Cameroon, along the border between Congo and the DRC, and along the eastern margin of the Basin. And finally there are the highly vulnerable "red strips" that identify the habitat of critically endangered species.

[11] The method for incorporating WWF ecoregions resembles this study's treatment of species endemicity. For the group of selected countries, the percent of total area accounted for by each ecoregion is computed. Its vulnerability index is then computed as the inverse of its area share and the appropriate index value is assigned to each pixel in the Congo Basin countries. This accounting assigns high values to pixels in smaller ecoregions, where clearing single pixels may pose more significant threats to biome integrity.

Figure 5. Composite species-ecoregion index, Congo Basin countries



For the purposes of this chapter, the most important message in the results is the striking non-uniformity of ecological vulnerability across forested areas. By implication, a full assessment of the benefits and costs of road upgrading should go beyond simple measurement of forest loss to an assessment of the potential impact of that loss on biological diversity.

The Stakes for Vulnerable Areas

This section joins the strands by combining predicted deforestation from road upgrading with the indices of ecological vulnerability (Figure 5). The multiple determinants of forest clearing can produce highly varied patterns of road corridor deforestation within the same region. Even more variety emerges when the vulnerability index is brought in, since the correlation between the measures of clearing and ecological vulnerability is close to zero ($\rho = -0.0356$).

The remaining expositional task of this sub-section is simplification, since combining the two indicators produces results for thousands of road segments. Instead the focus is on communicating the general tenor of results by focusing on the four-province area of DRC that were featured in Figures 2.

Figure 6 provides an illustration by overlaying the road network on a composite vulnerability map for four provinces in DRC (Kivu, Orientale, Equateur, Kasai Oriental). It provides a high resolution map that could be used as a preliminary tool to identify emerging hotspots of concern including where REDD opportunities may be high, as well as areas where infrastructure effects would be minimal. This map provides an immediate sense of potential opportunity and vulnerability at different points in a network. Figure 6 identifies ecological vulnerability in the provinces of concern. The red "bars" identify critical habitats for some DRC's endangered primates.

Figure 6: Eastern DRC - Ecological vulnerability map (spatially aggregated)

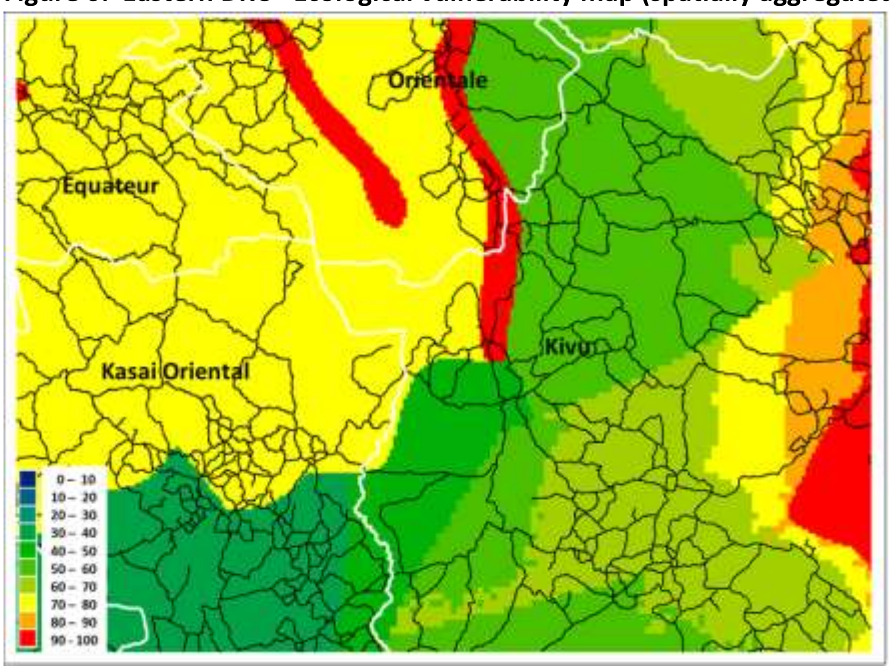
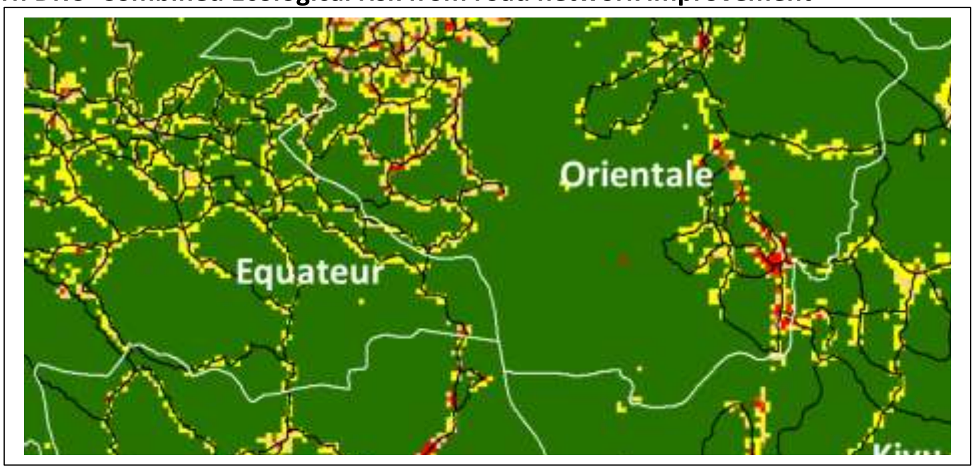


Figure 7 displays the combined impact indicator, which is the product of predicted percent deforestation from upgrading (Figure 4) and the vulnerability index (Figure 6). The indicator is standardized so that its range is 0 - 100. To discern the effect of combining the two indicators, compare Figures 4 and 7 for the dense road cluster south of the Kasai Oriental label. In Figure 7, the southern and western parts of the cluster are dominated by indicator scores in the range 0-10 (yellow), while the central and eastern parts have clusters in the range 30-100 (red). In part this reflects variation in biodiversity vulnerability, which is relatively low (green) in the southern part of the cluster and significantly higher (yellow) in the northern part. In conclusion, the figure below provides a visual and easy to comprehend assessment of vulnerability and risk that can be used for preemptive planning and policy making. An illustration is provided in the following chapter.

Figure 7: Eastern DRC -Combined Ecological risk from road network improvement



Concluding Remarks and Extensions

This chapter has illustrated a method and generated risk and vulnerability maps that are arguably of vital importance for informing DRCs planning process. Overall, the results suggests that the siting of infrastructure needs to be considered at the very outset of the planning process. Sequential decision making whereby location decisions occur first, followed by an Environmental Impact Assessment can lead to economically less favorable outcomes that can be avoided through careful upstream planning. There are now both new data and new techniques available that can be used to identify areas of opportunity, risk, and potential for REDD+ financing.

Using the best available data and robust econometric techniques this chapter finds large and highly-significant effects of road upgrading on the intensity and extent of forest clearing in road corridors. Predicted effects in road corridors vary widely with prior road conditions and locational economics, but increases in deforestation of 10-20% are typical. In addition, many corridors have significant extensions in the outer margin of forest clearing.

A high-resolution map of ecological vulnerability is developed. Overlaying the Basin-wide road network on this map provides first-order guide for risk assessment. Predicted deforestation is uncorrelated with the vulnerability indicator, so the variation in the two indicators separately is compounded in the combined measure. The implications for "smart" infrastructure location are suggested by the maps.

Overall, the results cast doubt on the utility of broad generalizations about the impact of road upgrading on deforestation, biomes, and vulnerable indigenous communities. The high-resolution spatial assessment finds impacts as varied as the economic and ecological conditions that prevail in different road corridors. By implication, road improvement planning in tropical forest regions is unlikely to maximize welfare unless it anticipates and incorporates such impacts.

The next chapter combines economic potential with the ecological impacts.

Annex 1 Econometric Results

Appendix Table: Regression results for DRC (all non-dummy variables in log form)

	(1) OLS	(2) OLS	(3) 2SLS	(4) GLS (IV)	(5) Robust (IV)
Distance from Road	-0.298 (29.97)**	-0.309 (30.43)**	-0.309 (30.43)**	-0.309 (8.80)**	-0.296 (32.77)**
Protected area x Distance from road	-0.165 (18.56)**	-0.204 (22.79)**	-0.204 (22.79)**	-0.204 (2.91)**	-0.152 (19.18)**
Road condition	0.544 (17.56)**	0.455 (13.76)**	0.455 (13.76)**	0.455 (1.57)	0.513 (17.49)**
Transport cost to nearest urban center	-0.481 (34.15)**		-0.952 (23.54)**	-0.952 (3.28)**	-0.876 (24.39)**
Euclidian distance to nearest urban center		-0.279 (23.54)**			
Land opportunity value	-0.091 (10.32)**	-0.023 (2.63)**	-0.023 (2.63)**	-0.023 (0.37)	0.004 (0.46)
Elevation	-0.066 (2.06)*	-0.130 (3.97)**	-0.130 (3.97)**	-0.130 (0.59)	-0.238 (8.18)**
Conflict intensity (1997 - 2007)	0.016 (5.52)**	0.029 (9.96)**	0.029 (9.96)**	0.029 (1.23)	-0.000 (0.10)
D2002	0.935 (21.93)**	0.934 (21.46)**	0.934 (21.46)**	0.934 (19.61)**	0.925 (23.92)**
D2003	1.269 (29.78)**	1.269 (29.15)**	1.269 (29.15)**	1.269 (22.76)**	1.246 (32.24)**
D2004	1.559 (36.58)**	1.558 (35.81)**	1.558 (35.81)**	1.558 (27.75)**	1.542 (39.91)**
D2005	1.827 (42.87)**	1.826 (41.97)**	1.826 (41.97)**	1.826 (32.71)**	1.810 (46.86)**
D2006	1.983 (46.56)**	1.982 (45.58)**	1.982 (45.58)**	1.982 (36.81)**	1.972 (51.07)**
D2007	2.155 (50.59)**	2.154 (49.52)**	2.154 (49.52)**	2.154 (38.55)**	2.145 (55.55)**
D2008	2.278 (53.50)**	2.278 (52.37)**	2.278 (52.37)**	2.278 (40.65)**	2.271 (58.81)**
D2009	2.462 (57.81)**	2.462 (56.60)**	2.462 (56.60)**	2.462 (44.19)**	2.456 (63.62)**
D2010	2.651 (62.25)**	2.650 (60.94)**	2.650 (60.94)**	2.650 (48.34)**	2.647 (68.56)**
D2011	2.747 (64.50)**	2.746 (63.14)**	2.746 (63.14)**	2.746 (48.95)**	2.738 (70.92)**
D2012	2.832 (66.48)**	2.831 (65.09)**	2.831 (65.09)**	2.831 (49.73)**	2.821 (73.06)**
Constant	4.810 (23.39)**	4.806 (22.07)**	6.747 (25.94)**	6.747 (4.07)**	7.255 (31.42)**
Observations	13758	13758	13758	13758	13758
R-squared	0.49	0.47	0.47	0.47	0.51

Absolute value of t statistics in parentheses
* significant at 5%; ** significant at 1%

Annex 2 Modeling the Economics of Road Improvement and Deforestation

As was noted in the introduction, this research aims to develop an analysis of road upgrading and forest clearing that incorporates both economic and conservation concerns. The objective is a methodology for prospective assessment that can inform infrastructure planning at the outset. To motivate the exercise, we consider the potentially-adverse impact of traditional road improvement planning, in which decision-making is sequential: Decisions on road improvement projects in an area are made first, followed by an EIA (Environmental Impact Assessment) that seeks to mitigate forest clearing by strengthening environmental management rather than affecting the selection of projects. The modeling exercise shows why coordinated infrastructure planning in such a sequential decision regime, while otherwise desirable for its direct economic contribution, may actually reduce welfare because it increases deforestation and the associated ecological impacts.

Consider two regions, labeled *i* and *j,* which sell their produce at a market at given distances d_i and d_j respectively. Each region is endowed with a given amount of land that can either be left forested, or converted to some alternative use such as agriculture whose outputs are transported to the market and sold at a given price. Let $L_i = L_i^F + L_i^A$ be the total endowment of land in region *i*, where L_i^F is forested land and L_i^A is agricultural land. The payoffs in region *i* to each activity are given by:

1. $\Pi_i = \big(P_i - d_i(1-q_i)\big)L_i^A - c_i {L_i^A}^2 + v(L_i - L_i^A)$

where P_i is the exogenous market price and $0 \leq q_i < 1$ is an index of road quality, with q = 0 representing an unimproved forest track. Improvements in road quality (*q*) lower transport costs and increase the profitability of agricultural production. With convex costs there are assumed to be diminishing returns to forest conversion ($c_i {L_i^A}^2$). Finally, forests left in their natural state generate a return of *v*, which could include livelihood and other unmarketed benefits obtained from the forest.

Maximizing (1), taking road quality as given, yields the optimal level of clearing (output) in region *i*:

2. $L_i^A = \frac{p_i - d_i(1-q_i)}{2c_i}$,

where $p_i = P_i + v$. The corresponding indirect profit function from the land use decision is:

3. $\Pi_i = \frac{(p_i - d_i(1-q_i))^2}{4c_i} + vL_i$

Region *j* is symmetric and its specification is suppressed for brevity. It is clear from equation (3) that higher market prices or improvements in road quality lead to greater land conversion (i.e. $\frac{\partial L_i^A}{\partial dq_i} = \frac{d_i}{2c_i} > 0$ and $\frac{\partial L_i^A}{\partial dp_i} = \frac{1}{2c_i} > 0$). This straightforward result reflects the fact that higher profitability of agriculture or increased market access renders deforestation and land conversion more profitable. The less well known question is how these incentives might vary under different decision making regimes. In what follows, we compare deforestation levels in each region under two contrasting forms of management. In the first, the decision on road quality improvements is made autonomously in each jurisdiction. In the alternative the budget allocation is coordinated to maximize the joint welfare of the two regions. In what follows we assume that environmental impacts are not considered in the decision making process.[12]

Consider first the case of autonomous decision making. For simplicity assume that there is a fixed budget B_i available for road quality improvements in region *i.* The cost of improving road quality is given by: $B_i = rd_iq_i$. If the budget constraint binds then road quality is given by:

4. $q_i^I = \frac{B_i}{rd_i}$

Thus road quality declines with distance (d_i) and the costs of road construction (*r*). Substituting in (2) the amount of land conversion is:

5. $L_i^A = \frac{p_i - d_i(1 - \frac{B_i}{rd_i})}{2c_i}$

In contrast. under coordinated management the budget is allocated to maximize the joint welfare of the two regions:

6. $Max\ W = \frac{(p_i - d_i(1-q_i))^2}{4c_i} + vL_i + \frac{\left(p_j - d_j(1-q_j)\right)^2}{4c_j} + vL_j$

$\quad$ *subject to* $B_i - rd_iq_i - rd_jq_j$

Which yields solutions for the optimal improvements in road quality:

[12] This describes a not uncommon situation where decision making is sequential, with decisions on road location made first, followed by an EIA process that typically seeks to mitigate impacts by strengthening environmental management rather than altering road routing.

7. $q_i^c = \frac{c_iB_i + r(c_i\theta_j - c_j\theta_i)}{rd_i(c_{i+}c_j)}$ and $q_j^c = \frac{c_jB_j + r(c_j\theta_i - c_i\theta_{j)}}{rd_j(c_{i+}c_j)}$

where $\theta_k = p_k - d_k$, for (*k = i,j*)

For later use it is instructive to observe that $\frac{\partial q_i}{\partial c_i} = \frac{(c_jB_i + rc_j(\theta_i + \theta_j))}{rd_i[rc_{i+}c_j]^2} > 0$.

As land conversion costs rise in a region, road quality is improved. Intuitively, road investments are made to equate the marginal payoffs from agricultural sales from each region. With diminishing returns to land conversion, it eventually pays to invest in the higher cost region. The following Lemmas compare road investments and deforestation rates under the different regimes:

Lemma 1 If the cost of land conversion between regions differs sufficiently, then road improvements in the high cost region will be greater under coordinated management than under autonomous management (i.e. $q_i^I < q_i^c$ *if* $\frac{c_i}{c_j} > \frac{(B_i + 2r\ \theta_{i)}}{(B_i + 2r\ \theta_{j)}}$).

Intuitively, under autonomous management, budgets available to each region are fixed, whereas under coordinated management the region with the higher costs of land conversion could receive a higher allocation to equalize marginal payoffs. An implication of this result is that total deforestation rates may differ across management regimes. This result is summarized in Lemma 2 and illustrated in Figure 1 below.

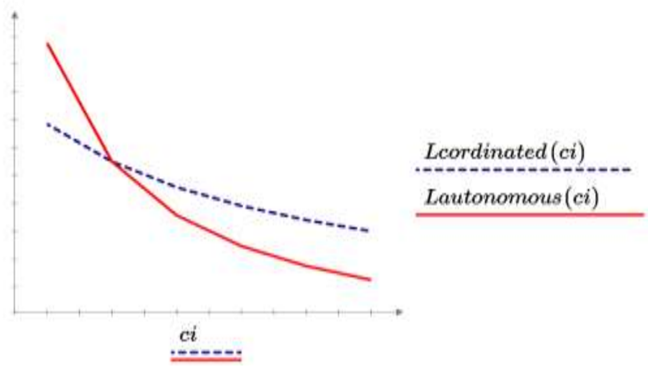
Lemma 2 Total deforestation rates will differ under the management regimes and will be higher under coordinated management if the cost of land conversion is sufficiently large in one of the regions (*i.e.* $q_i^I + q_j^I < q_i^c + q_j^c$ *if* $c_i > \frac{c_j(B + 2r\theta_i)}{(B + 2r\theta_j)}$).

When differences between regions are large, under coordinated management total payoffs are maximized by ensuring that the region with the comparative advantage in land clearing receives greater support on the margin, thus expanding the total volume of land cleared. This result follows from the convex cost of land conversion, which implies that the incremental returns to further deforestation will be lower in the region with a sufficiently high level of land conversion. Figure 1 illustrates this relationship – as costs in region *i* rise, it receives improved road quality and as a result incurs higher rates of deforestation and ecological losses. By implication, coordinated regional infrastructure planning, while promoted for its economic benefits, may actually increase deforestation in a sequential decision regime that selects road projects first and introduces environmental impact analysis ex-post.

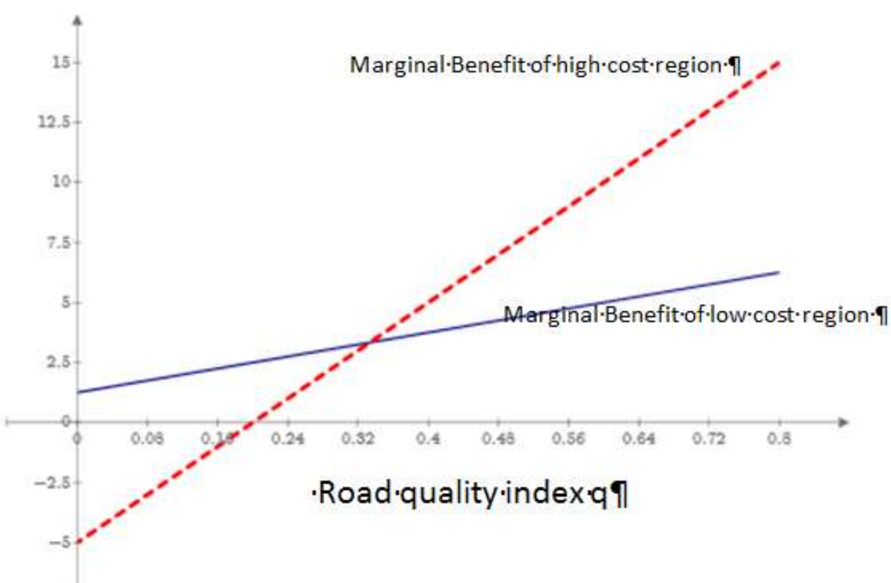
As an alternative, the approach developed in this paper seeks to improve the decision process by enabling simultaneous consideration of potential road projects and deforestation impacts.

Figure 1: Road planning regimes, road quality and deforestation

Planning regimes and deforestation rates



Marginal net benefits and road quality



Chapter 4: Economic and Ecological Impact of Prospective Road Investments

In the prior two chapters, methodologies were demonstrated which estimate the effects of reducing transport costs by building or improving the road network. Chapter 2 estimated the elasticity of local GDP to a drop in transport costs, and Chapter 3 estimated the effects of forest clearing, using Hansen forest data, to a decline in transport costs. In this chapter, these estimated elasticities are used in simulations to estimate the potential welfare benefits, as well as deforestation that would result from the two proposed road investments in DRC.

While this methodology must be used with due awareness of its shortcomings (described below), it does provide decision makers with the capability to quantifying potential induced local benefits (increased economic activity) and costs (increased deforestation) of numerous options, and prioritize those that should be evaluated in more depth. This methodology is performed in such a way that it could be applied to study any road improvement or new road construction project within DRC and to prioritize investments.

Two simulations are demonstrated below. The first estimates the benefits, in terms of increased GDP, and the costs, in terms of deforestation and potential biodiversity loss, from the major urban center road network improvement plan, introduced in Chapter 2. The second simulation estimates the same costs and benefits for a smaller project in the environmentally fragile northeastern part of the country, near Virunga National Park. This theoretical road improvement project improves a road that connects the city of Goma in the province of North Kivu to Bunia, in Orientale province.

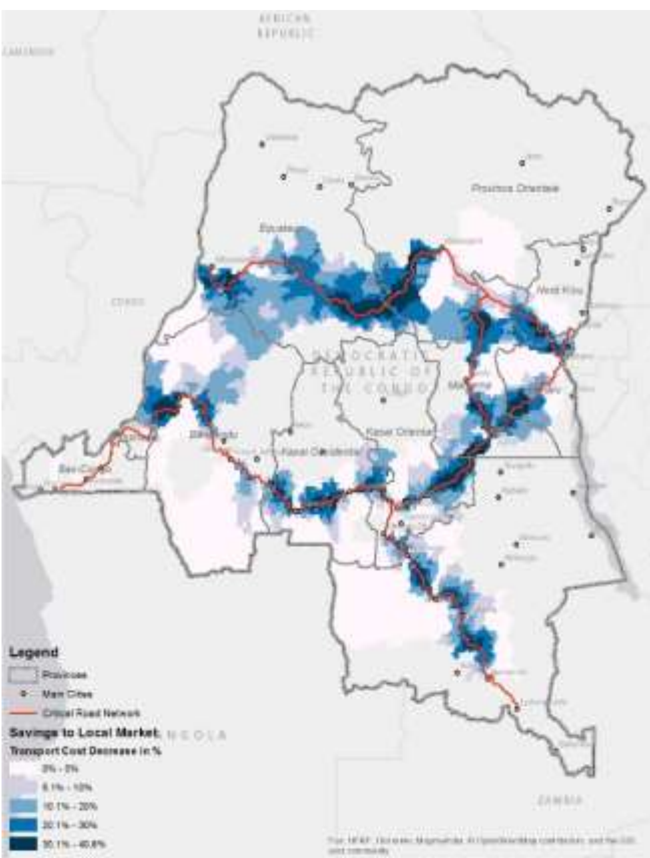
Major Urban Center Road Network Improvement Project

To estimate the impact of improving the quality of a road segment, the primary road network which connects 11 major urban centers with Kinshasa is considered as a prospective project. As shown in Chapter 2, Figure 4, the 6,500km of roads traverse much of the country, and connect many areas which are currently only connected by river or air travel. It is assumed that this network would be improved from its current quality, to good condition status, with several impassable missing links filled in. The baseline scenario (current quality) has only 20% of the network that is currently paved, and about 75% of the roads are in poor condition.

To calculate the change in transportation cost due to the improvement, the same procedure that was used to estimate the travel cost to the cheapest market, is again followed. That is, using the newly upgraded network, the optimal route to the cheapest market is re-estimated following the same procedure, thereby obtaining the cheapest travel cost for every cell, under the scenario that each of these roads is entirely in good, high quality condition. Then the results are compared to the baseline scenario to obtain the change in transport costs due to the project, for each grid cell. It is worth noting that the spatial model uses tertiary, secondary, and primary roads. Thus, the analysis is capturing rural connectivity plus market issues at the same time.

The percentage change in transportation costs for each cell, if the entire project were completed, is shown in Figure 1. Note that the reduction in transport cost to the local market is mostly localized to areas around the improved roads. This is unsurprising because areas that are far from these roads are likely served by markets (if any) that are also far from these roads, and are therefore not affected by the road improvements under consideration.

Figure 1: Change in transportation costs due to the major urban center road network improvement project



Source: Authors' calculations
The map shows the reduction in transport costs to the local market, due to the major urban center road network project. Note that in both the baseline case and the with-project case, a unimodal network is assumed where only roads (and thus no rivers) are used for transport.

Estimated Benefits: Increases in Local GDP

In the first simulation, the increase in local GDP due to the major urban center road network improvement project is estimated. In order to do this, three pieces of data are needed: baseline local GDP data, the change in transport costs (to the local market) due to the project, and the elasticity of local GDP to a reduction in local market transport costs. (Chapter 2 provides an explanation of these elasticities, and Box 3 provides details on how economic benefits are calculated.)

Box 3: Local GDP simulation

Once the elasticity of local GDP to changes in transport costs is estimated (see Chapter 2), simulating the benefits to a reduction in transport costs is straightforward. An elasticity is a measure of one variable's sensitivity to a change in another variables. So the elasticity of local GDP to transport cost to the local market, -0.0409, implies that a 10% decline in transport cost to the local market would increase local GDP by 0.409%. We can therefore use this elasticity to calculate the total increase in local GDP from the major urban center road network improvement project using the following formula:

$$\Delta GDP_i = \eta_M * \tau_{iM} * y_i;$$

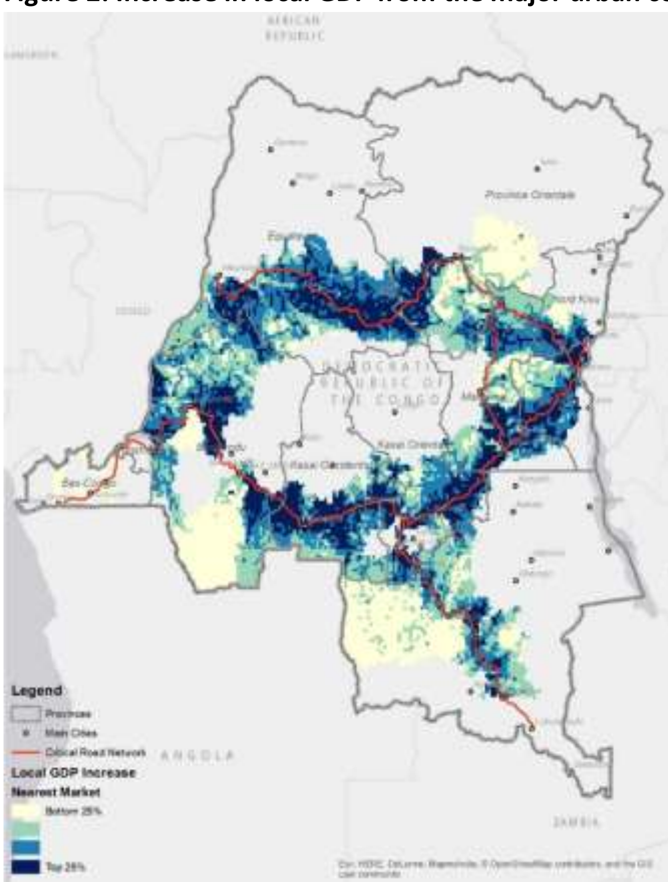
where ΔGDP_i is the total increase to local GDP in grid cell *i*, η_M is the local GDP elasticity of transportation costs to the local market, τ_{iM} is the percentage change in transportation costs to the local market in cell *i*, and y_i is baseline local GDP in cell *i*. The total increase in local GDP is then obtained by summing the increase in each grid cell.

The increase in local GDP is estimated in each grid cell separately, and then aggregated to arrive at the total benefit. Figure 2 shows the spatial distribution of the increase in local GDP.[13] The project is estimated to benefit a large land area around the entire network, with the largest benefits near Bandundu, Goma, and the long stretch of road between Mbandaka and Kisangani. By totaling up the benefits in all grid cells, a total annual benefit of US$18.1 million is arrived at.

[13] This image looks remarkably similar to Figure 1, which is to be expected; the difference between them is that the data used to create Figure 2 is multiplied by local GDP and the local GDP elasticity to transport costs.

This figure US$18.1 million/year needs to be contextualized. Firstly, this simulation represents a partial equilibrium estimate of the benefits of the road improvement project. If the project leads to significant structural change in the economy, then this methodology would not be a sufficient way to characterize and estimate those changes. Secondly, it is unlikely that benefits will appear all at once. Rather, benefits will take time to appear, and will likely be layered in over several years. Finally, these benefits are only a subset of the total benefits to reducing transportation costs. This model does not include benefits to decreasing transport costs between cities, to multiple cities, or between ports. Given that trade in DRC between cities (other than Kinshasa) is currently relatively low, those benefits are also probably low. Another important caveat to these estimates is that it is not possible to disaggregate the benefits to different sector of the economy.

Figure 2: Increase in local GDP from the major urban center road network improvement project



Source: Authors' calculations

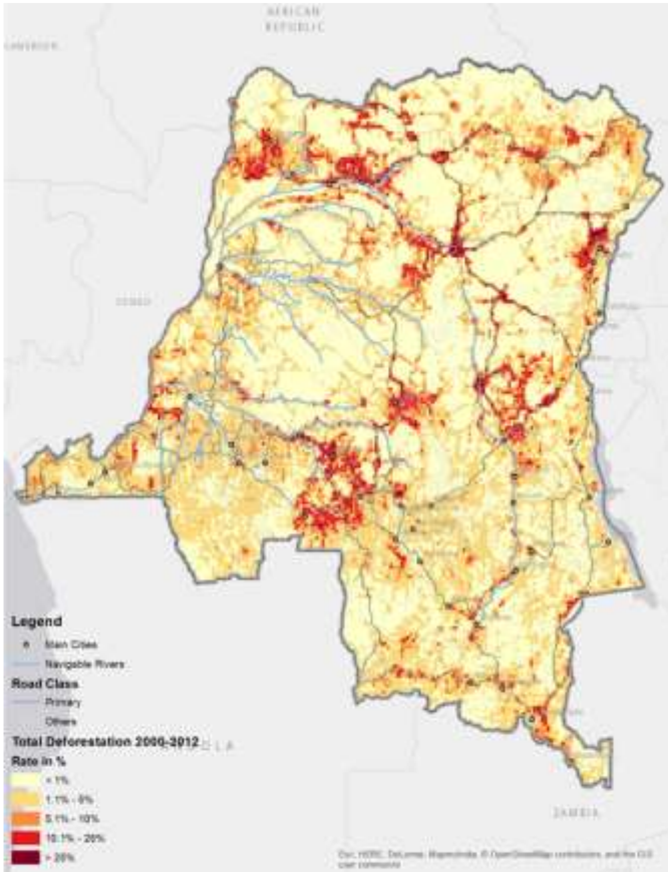
Estimated Deforestation: Forest Cover Loss

In this section, the estimated additional deforestation that may occur as a result of the major urban center road network improvement project is calculated. The process is similar to the procedure done above for local GDP. The only distinction is that for simulating the economic benefits of the road, only the reduction in transport costs to the local markets was considered. For simulating deforestation, the initial condition of the nearby road (e.g. poor, fair, or good condition) is also used as a factor for simulating deforestation. Road condition has been shown to be a significant determinant of deforestation in the analysis of the previous chapter, in addition to transportation costs.

Figure 3 shows a map of current deforestation in DRC, for the period 2000-2012, from Hansen et al.[14] Deforestation in DRC occurs for 3 main reasons: timber production (both formal and informal), wood fuel consumption, and land use change (mostly the conversion of forested areas in farmland). While there is insufficient data on how much deforestation is due to land conversion, it is clear that logging for wood fuel use outpaces timber production, with an estimated 72 million m^3 of fuel wood consumed each year, relative to only 300,000 m^3 of wood harvested in the formal timber sector, and an estimated 1.5-2.4 million m^3 of wood harvested in the informal timber sector, annually (Debroux et al., 2007).

Figure 3. Total Deforestation, 2000-2012

[14] Trees are defined as vegetation taller than 5m in height and are expressed as a percentage per output grid cell as '2000 Percent Tree Cover'. 'Forest Cover Loss' is defined as a stand-replacement disturbance, or a change from a forest to non-forest state, during the period

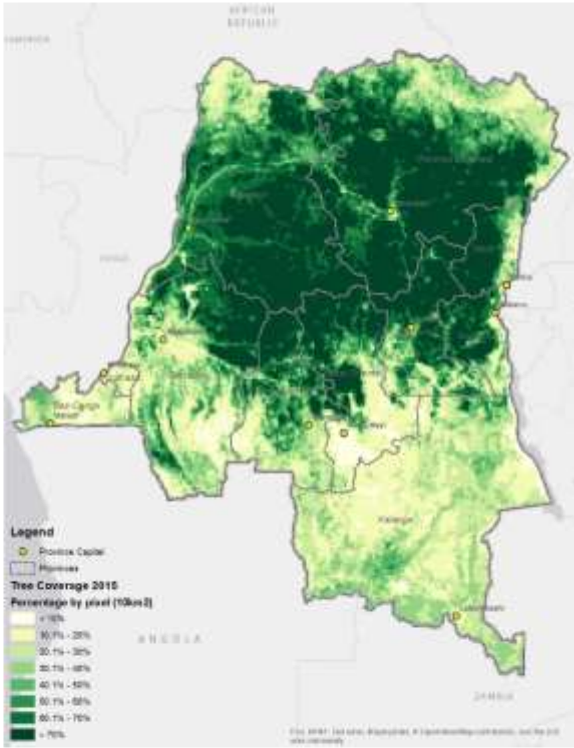


Source: Hansen et al. (2013)

The latest baseline forest cover provided by Landsat/TreeCover is available for the year 2005. Using Hansen deforestation data, this image is then updated to reflect estimated tree cover for 2015, as shown in Figure 4.[15]

Figure 4: Baseline Forest Cover, 2015

[15] Hansen deforestation data is available from 2000-2012. It is assumed that the average deforestation rate in each 10km x 10km cell continues for the years 2013-2014 to arrive at the 2015 Tree cover map.



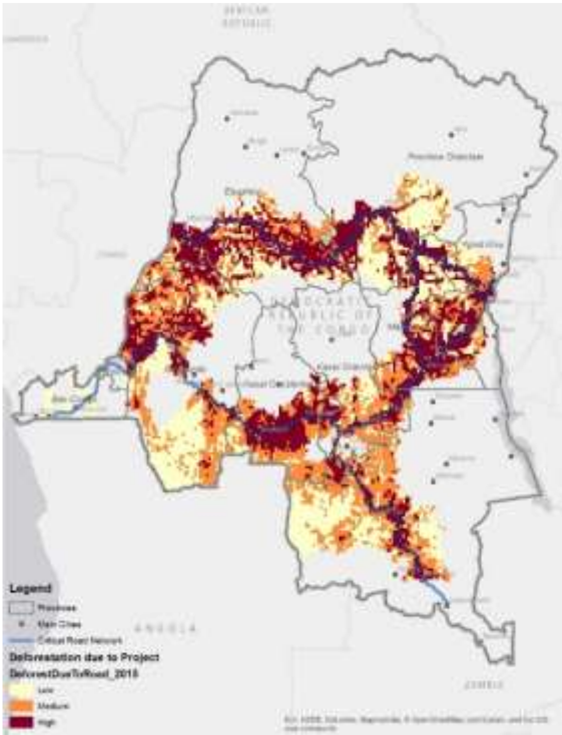
Source: Hansen, et al. (2013) and authors' calculations

Given the baseline 2015 Tree cover data, and the elasticity of deforestation with respect to both transport cost reductions and road quality improvements, estimated additional deforestation due to the major urban center road network project can now be estimated.

The estimated additional deforestation due to the major urban center road network improvement project is shown in Figure 5.[16] As the figure shows, much of the additional deforestation will occur near the major cities of Kananga, Kisangani, Maniema, as well as much of South Kivu and Maniema provinces.

Figure 5: Estimated additional deforestation from the major urban center road network improvement project

[16] In order to calculate this, the annual average number of pixel lost to deforestation in the recent past (2000-2012), the change in transport costs (to the local market) due to the project, and the elasticities of number of pixel cleared to changes in transport costs (see Chapter 4 for an explanation of this elasticity), are used.



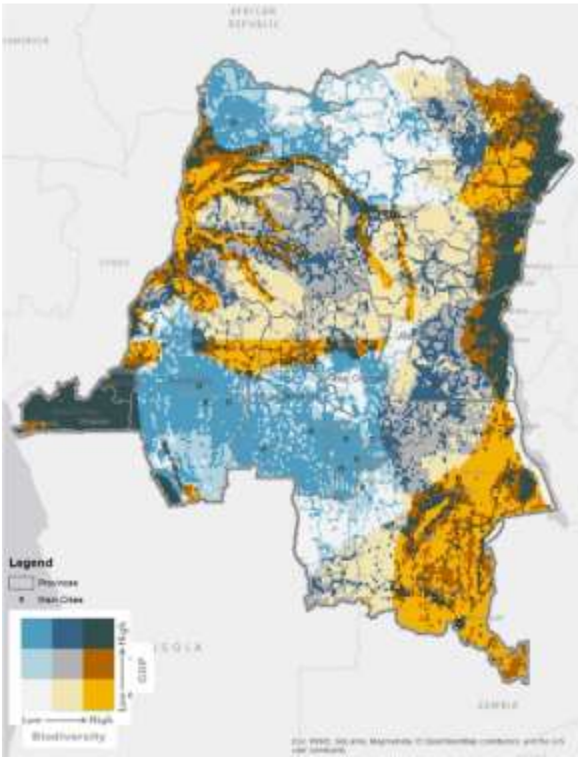
Source: Hansen et al (2013) and authors' calculations

Visualizing Opportunities and Safeguarding Against Risks

In this final section, the results from earlier in this chapter are combined to examine the areas most effected, in both positive (higher local GDP) and negative (increased deforestation and biodiversity loss) ways. However, before doing this, it is constructive to visualize the spatial distribution of the economy and ecology of the DRC. To do this, the intersection of local GDP (first presented in Chapter 1, Figure 1), and the composite species-ecoregion index presented in Chapter 3 (Figure 5), are shown in a combined map in Figure 6.

This map shows that, quite often, the regions of DRC that are most important economically also tend to contain the highest levels of sensitive biodiversity. The most important ecological areas, according to the composite species-ecoregion index, are along DRC's eastern and southeastern border, the Congo River and its tributaries, and much of the provinces of Bas Congo and Kinshasa. These also tend to be areas of higher population density and economic activity, with the notable exception of much of the eastern portion of Katanga province. Given that increased economic activity is typically followed by increased pressure on forests and biodiversity, significant risks to any development plan must be acknowledged so that effective policies and safeguards can be put in place.

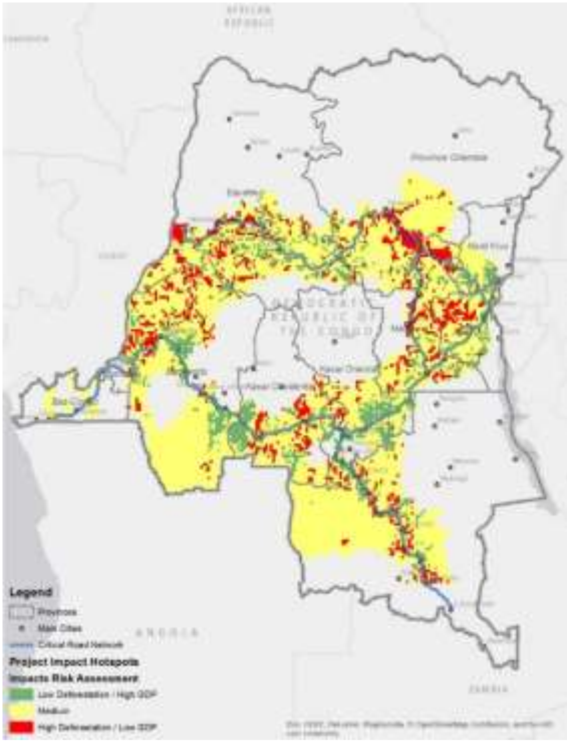
Figure 6. The Economy and Ecology of DRC



Source: Ghosh (2010) and authors' calculations

In order to get a clearer picture of the economic and ecological impact of the major urban center road network improvement project, as a first step, Figure 7 shows changes in local GDP and deforestation overlaid, to identify areas which would see the most benefits, of face the highest risks of loss. Areas in green are 'pure benefit' regions, where local GDP gains are very significant, and deforestation increases are very low. Red areas are the riskiest regions, which are estimated to have very low local GDP gains, but significant deforestation as a result of the project. These are the regions which would be most beneficial to protect, given that there would be little lost in terms of economic activity, and there is a significant risk to deforestation. The intermediate zone is in yellow

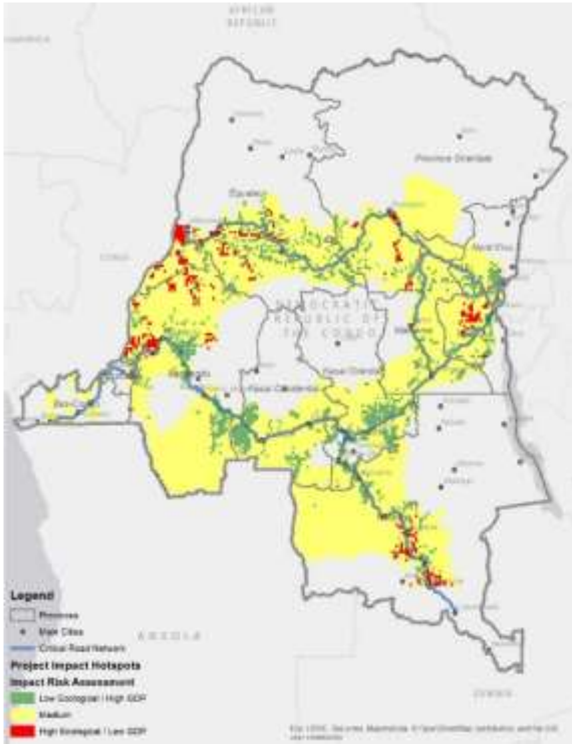
Figure 7. Major Urban Center Road Network Deforestation Risk Assessment



Source: Ghost et al (2010), Hansen (2013), and authors' calculations

As was shown by the composite species-ecoregion index, not all forested areas are equally important. In order to further prioritize the areas that would be in most need of protection, the regions at risk of high deforestation are further dissected to reveal those that have the most ecological importance. This is accomplished by intersecting the composite species-ecoregion index with the simulated deforestation due to the road improvement project. This is shown in Figure 8. Note that the red, high risk areas in Figure 8 area a subset of those in Figure 7. Given limited resources, these red areas represent the regions that are most important to protect, while also having a low potential economic impact from the project. A benefit of this exercise is that it shows that the truly high risk areas appear to be small when threats from the road are considered. It also suggests where conservation efforts ought to be directed.

Figure 8. Major Urban Center Road Network, High Ecological Risk Areas



Source: Ghost et al (2010), Hansen (2013), and authors' calculations

Virunga National Park Road Improvement Project

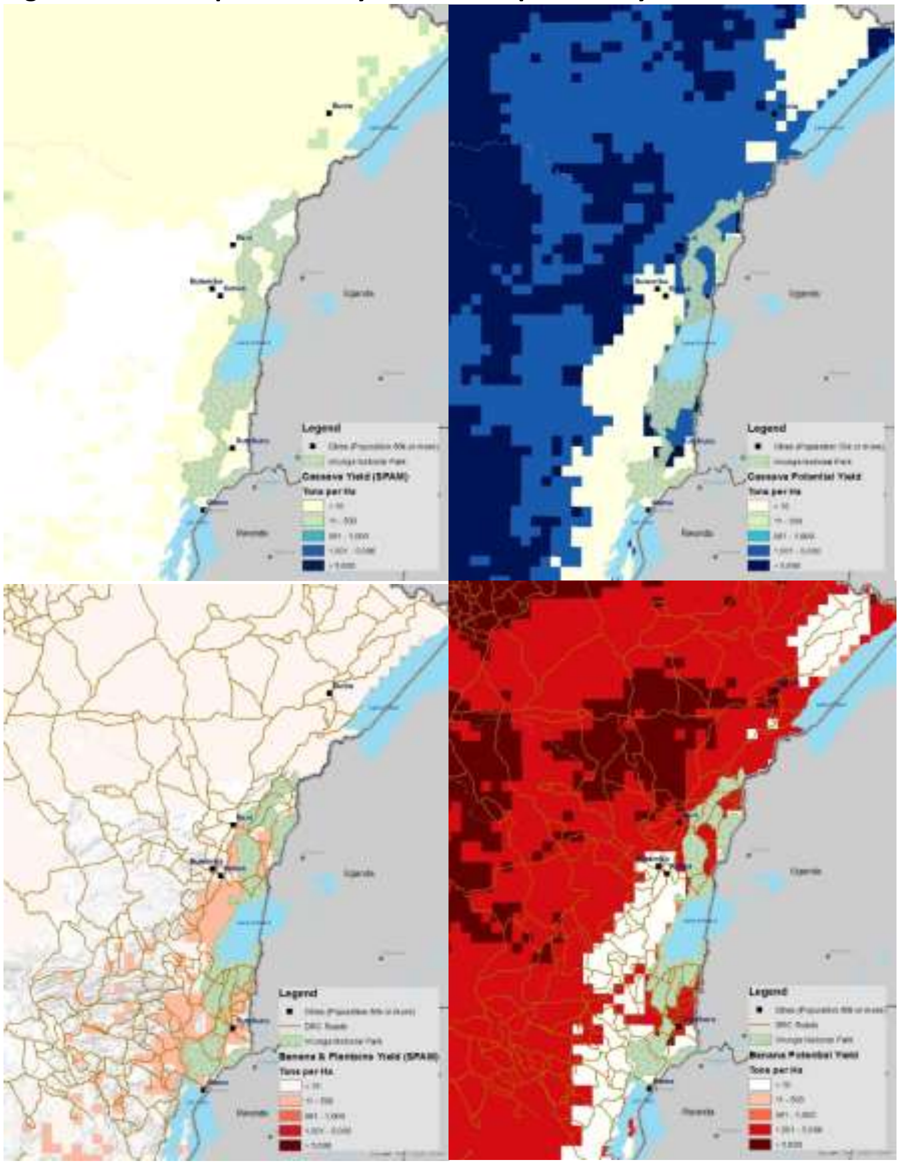
Next, we use the same techniques as above to examine the costs and benefits of a much smaller road improvement project, situated around Virunga National Park. This project would improve a 525 km road which connects the city of Goma, situated just south of Virunga National Park—between the park and Lake Kivu—to Bunia, approximately 100 km north of the park, near Lake Albert. The pathway of the road is shown in Figure 9. Despite being a very populated area (approximately 4.5 million Congolese live within a small area around the road), the current condition of the road is quite poor, and in many areas, impassable. The 140 km portion of the road that is paved is entirely in poor condition. The remaining 385 kms are unpaved, with 200 kms being in fair or good condition, and 185 kms in poor condition.

Figure 9: Virunga National Park road improvement map

Source: African Infrastructure Country Diagnostics and authors' calculations

A priori, improving this road may appear to be a significant opportunity to spur economic growth in the region. The surrounding area has significant deposits of mineral wealth including gold and the rare-earth mineral coltan. The land also contains very fertile soils which have very high agricultural potential. Figure 10 shows actual production yields versus potential yields for two important regional crops, cassava and bananas. The potential yields shown here are the 'ideal agronomical potential', i.e. the yields that could be obtained given a very high level of inputs and laboratory-like conditions. While these condition could of course never be achieved, it is clear from these images that there is significant room for yield improvement, and improving market access for farmers in the region may provide both the means and the incentives to adopt more input-intensive farming techniques which improve yields. Without taking into consideration any externalities, this road appears to be a major candidate for significant investments to spur economic activity.

Figure 10: Actual production yields versus potential yields for cassava and banana



Top left: Actual cassava yields (tons/ha) per 10km x 10km gridcell
Top Right: Potential cassava yields (tons/ha) per 10km x km gridcell according to soil and average climate conditions
Bottom left: Actual banana yields (tons/ha) per 10km x 10km gridcell
Top Right: Potential banana yields (tons/ha) per 10km x km gridcell according to soil and average climate conditions
Sources: Actual production yields are from the Spatial Production Allocation Model (SPAM) form Harvestchoice (2012) and are for the year 2000. Potential yields are from FAO and IIASA (2000)

Nevertheless, road infrastructure development in this region may come with deep trade-offs. The land around the potential road project is heavily forested, and includes one of the world's most important national parks. Virunga National Park was established in 1924 and was the first designated national park in Africa. While it was originally established to protect one of only two populations in the world of the now critically endangered mountain gorilla, the park contains other exceptional biodiversity, including both the forest and savannah elephant, Okapi, giraffes, and chimpanzees. As demonstrated in chapter 3, improving the road around Virunga has the potential to disrupt this biome. Environmental factors aside, Virunga National Park has the potential to become one of the greatest tourist attractions on the continent if the conflict and security issues in eastern DRC could be resolved. Destroying this natural capital would therefore not only be an environmental tragedy, but would also eliminate a potentially significant source of future income for the country's impoverished inhabitants.

Given these immense tradeoffs that come with this project, this is an ample example of a project that would benefit from the analysis developed in this report. The next two sub-sections show the calculations needed to quantitatively evaluate the costs and benefits to this project.

Estimated Benefits: Increase in Local GDP

As with the major urban center road network simulation, this simulation begins with an estimate of local transportation costs to the local market. First, the optimal route, and the transport cost associated with that route, is calculated, given the current status of the road. Then, the geospatial model is updated to reflect the entirety of this road becoming good condition. Figure 11 shows the original transport costs pre-improvement, and the estimated reduction in transport costs due to the intervention. Notice, as would be expected, that transport costs are lowest nearest to the road and the major cities (which are also markets according to the definition in the geospatial model), and increase with a fairly even gradient as one moves away from the main population center around the border with Rwanda and Uganda. Similarly, the bulk of the transport costs reduction occurs for those living in close proximity to the road. This is because it is measured as a percentage of the original transport cost. As one moves farther away from the road being improved, they will spend relatively less time of their commute driving on the improved road, and thus will have their overall transport costs reduced by a lower percentage, even if the overall level of transport costs declines more.

Figure 11: Virunga National Park regional transport cost pre-intervention versus change due to intervention

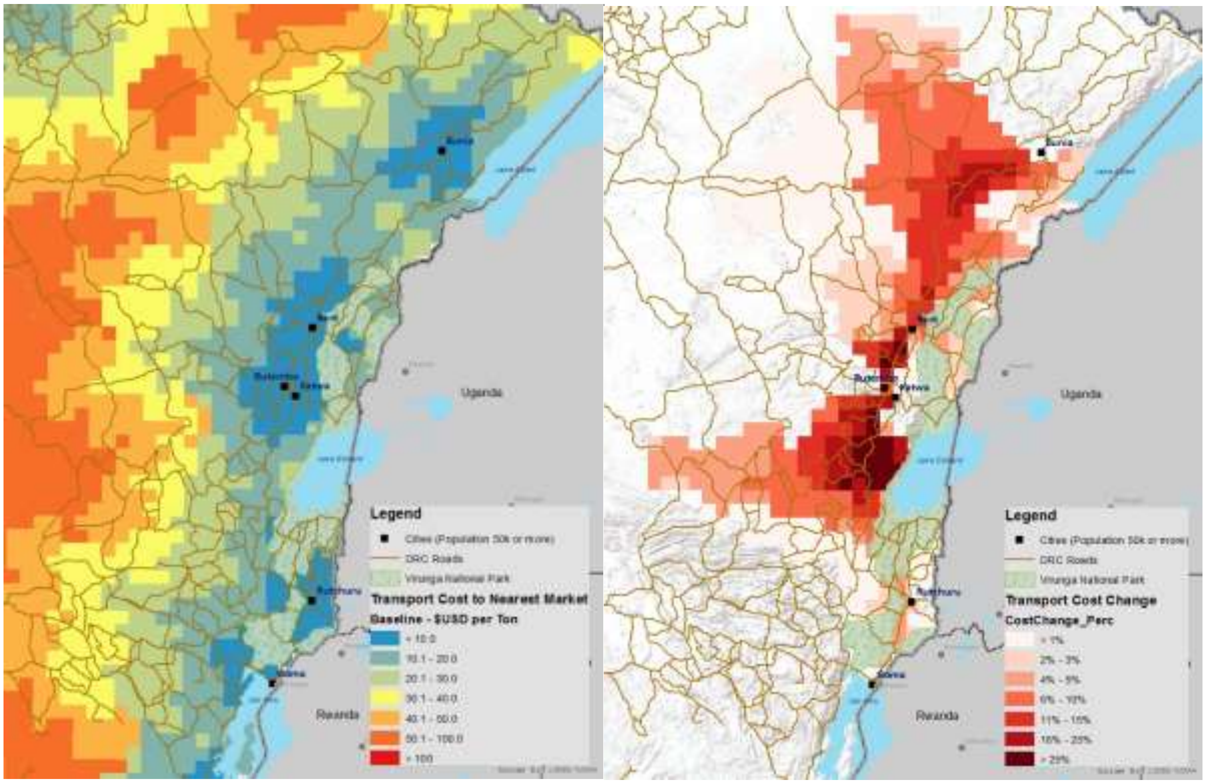
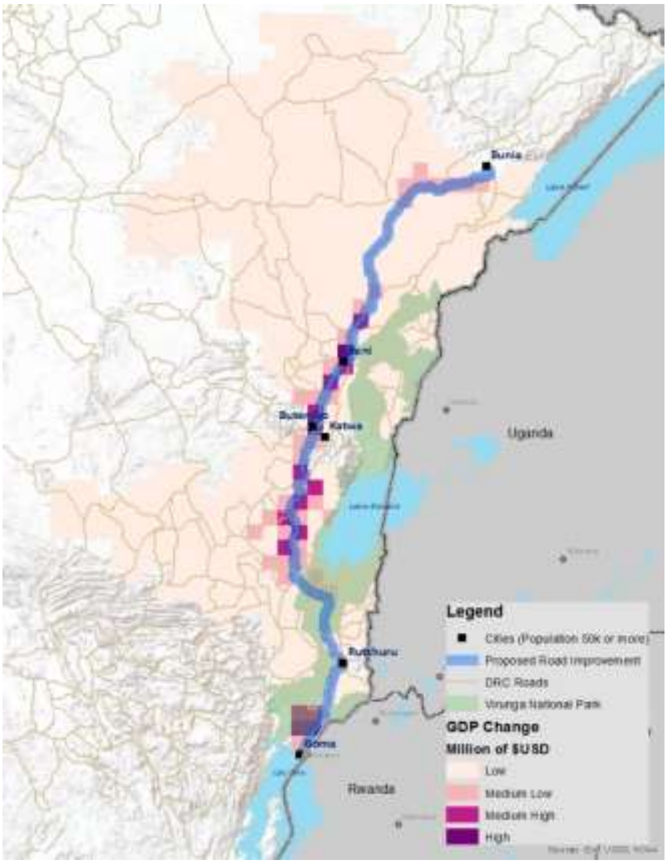


Image on right: Transport costs to the cheapest market given current road conditions
Image on left: Transport cost reduction as a percentage of original transport costs, due to the Virunga National Park Improvement Project
Source: Authors' calculations

Next, local elasticities are generated using the same methodology described in Chapter 2. Benefits, in terms of the increase in local GDP, are then calculated at the pixel level, and aggregated to arrive at a final range of $7.29 million- $31.9 million per year above the baseline, depending on whether one uses a local elasticity, or the national elasticity calculated in Box 2 of Chapter 2. Figure 12 shows a distribution of these benefits. Note that they are even more clustered around the road than even the change in transport costs, shown in Figure 11. This is because the local GDP increase is the intersection of the baseline local GDP and the percentage change in transport costs, both of which are highly clustered around the road themselves. Multiplying these two together magnifies this clustering even further. Again, several caveats must be noted. First, it is unlikely that these benefits would occur all at once. Rather, the benefits would likely layer in over several years, as individuals in this region started adapting to the new infrastructure, making new investments in their farms or business, and setting up new networks in the cities in the region. Second, this methodology only estimates the benefits to an increase in *local* transportation to the cheapest market. Having cheaper access to multiple markets may bring additional benefits, as well as connecting multiple cities together (such as Goma, Butmebo, and Bunia). Finally, these are only gross benefits, and do not factor in the cost of the road upgrade, nor the on-going maintenance costs required to maintain the roads.

Figure 12: Local GDP change due to the Virunga National Park road improvement project



Note: GDP increase is shown in qualitative terms because the actual values are dependent on the elasticity chosen for the simulation. Because all cells are multiplied by the same elasticity, choosing the locally estimated elasticity versus the national elasticity will result in the same percentage change in local GDP for every cell, and therefore the relative difference in local GDP will remain the same, as shown in the map.
Source: Baseline local GDP is from Ghosh et al (2010)

Box 4: Estimating agricultural benefits

This report has focused on estimating aggregate, multi-sector economic benefits from road construction. However, using a similar methodology, it is also possible to estimate benefits for a particular sector. The only requirements are spatially disaggregated output data, and a production function which holds under the assumptions of linear econometric estimation strategies. Estimating an agricultural production function is quite common in the economics literature, and in the context of the DRC, requires very little additional data. Because most agricultural production is at the subsistence level, it is safe to assume that the only major inputs are land (e.g. soil quality and climate), and labor (which can be proxied by population in the surrounding area). In addition, a novel dataset known as the Spatial Production Allocation Model (SPAM) from HarvestChoice (2012) provides baseline agricultural production data, by crop, in a gridded fashion similar to that used by the local GDP data used in this study.

Using the SPAM data, an agricultural production function can be estimated which generates elasticities which describe how production of a given crop changes, for a percentage change in market transport costs. This agricultural production function is given in the following equation:

$$\ln(P_i^k) = \beta_0 + \beta_1 \ln(TM_i) + X_i'\gamma + \varepsilon_i \qquad (2)$$

where P_i^k denotes the total production of crop k in grid cell i, TM_i is the transport cost to the local market, and X_i is a vector of regional controls. Those controls include ln(population), ln(population)^2, ln(crop k potential yield), ln(crop k potential yield)^2, ln(distance to nearest mine), and a measure of conflict near the gridcell and the local market. As with the local GDP regressions, to account for the endogeneity of both market cost and the conflict variables an instrumental variable approach is taken following Ali (2015) (see Ali (2015) for details on the instrumental variables used and a discussion of the conflict measures).

With each crop estimated separately, national crop-specific elasticities are calculated. Those elasticities are shown in Table 2 below. Note that the elasticities are modified so that they show the percentage change in crop production for a corresponding 10% reduction in market transport costs.

Table 2: Impact of transport costs reductions on crop production

Crop	**Elasticity (change in crop production for each 10% reduction in market transport costs)**
Cassava	2.6%***
Bananas/Plantains	12.4%***
Maize	0.11%
Ground nuts	6.6%***
Rice	4.6%***
Beans	12.3%***

***Significant at the 1% level, ** Significant at the 5% level, * Significant at the 10% level

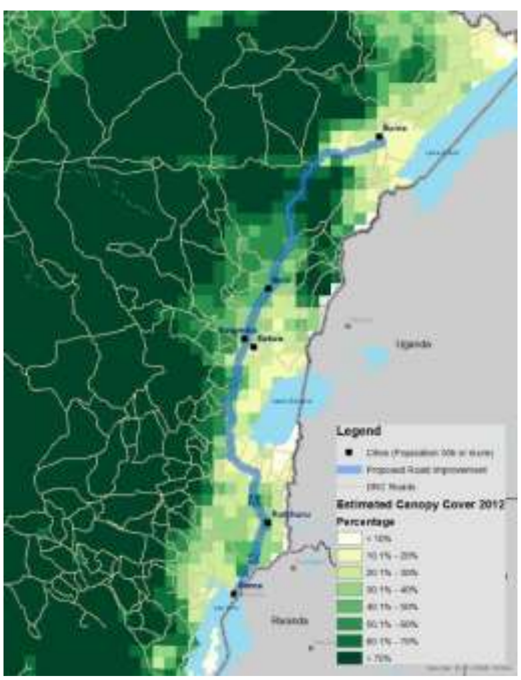
Interestingly, the results show the bananas and plantains have the highest transport cost elasticities. This is not surprising given that they are highly perishable, and therefore need to be sold quickly after harvesting. On the other hand, cassava and rice, which are highly non-perishable, have relatively low transport cost elasticity, reflecting the fact that market access may not be such an important factor when it comes to production decisions.

Using these elasticities, it would be straightforward to perform simulations on agricultural output, in a similar manner that simulations on local GDP are performed in this report. Note that because the data is at the spatially gridded level, and not the farmer or plot level, the simulation results would be agnostic with respect to whether the production change is due to intensification or extensification. However, a more complex model which also takes into account total harvested area could be adopted to distinguish between these two mechanisms.

Estimated Deforestation: Forest Cover Loss

Using the methodology established in Chapter 3, the predicted additional deforestation due to the Virunga National Park road improvement project is now estimated, to see which regions are most at risk. Baseline forest cover in the year 2012 is shown in Figure 13. As is evident from the map, considerable deforestation has already occurred around the region of the road

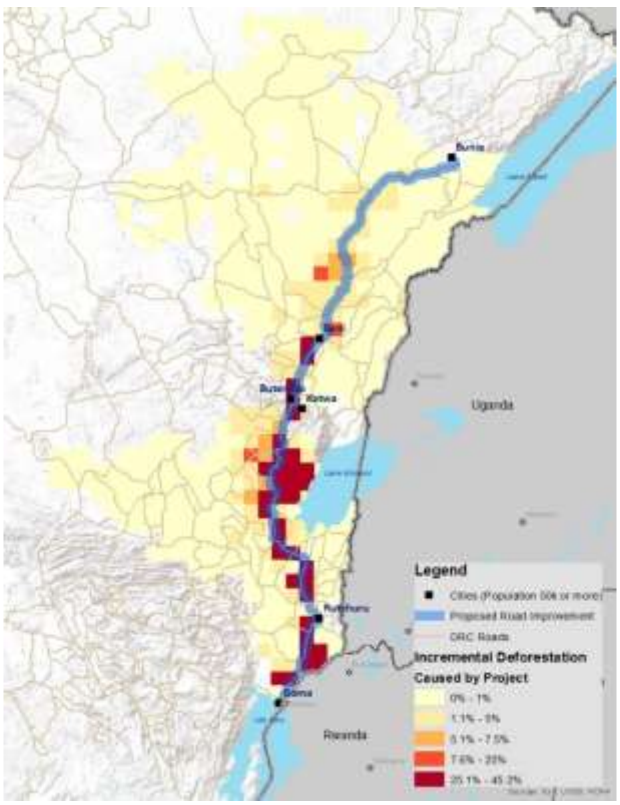
Figure 13: Baseline forest cover, 2012, Virunga National Park



Source: Hansen, et al. (2013) and authors' calculations

Figure 14 now shows the estimated annual new deforestation that would occur due to the road improvement project. The biggest risk to deforestation are those regions which have already shown a propensity to be deforested, and which are nearest to the population centers and the improved road. This simulation shows that the areas that would be most stressed are near those near Lake Edward, the corridor between Goma and Rutshuru, and the corridor from Katwa, to Butembo, to Beni. To a much lesser extent, additional deforestation may also occur to the west and northwest of Bunia, and to the northwest of Goma.

Figure 14: Additional annual deforestation due to the Virunga National Park road improvement project

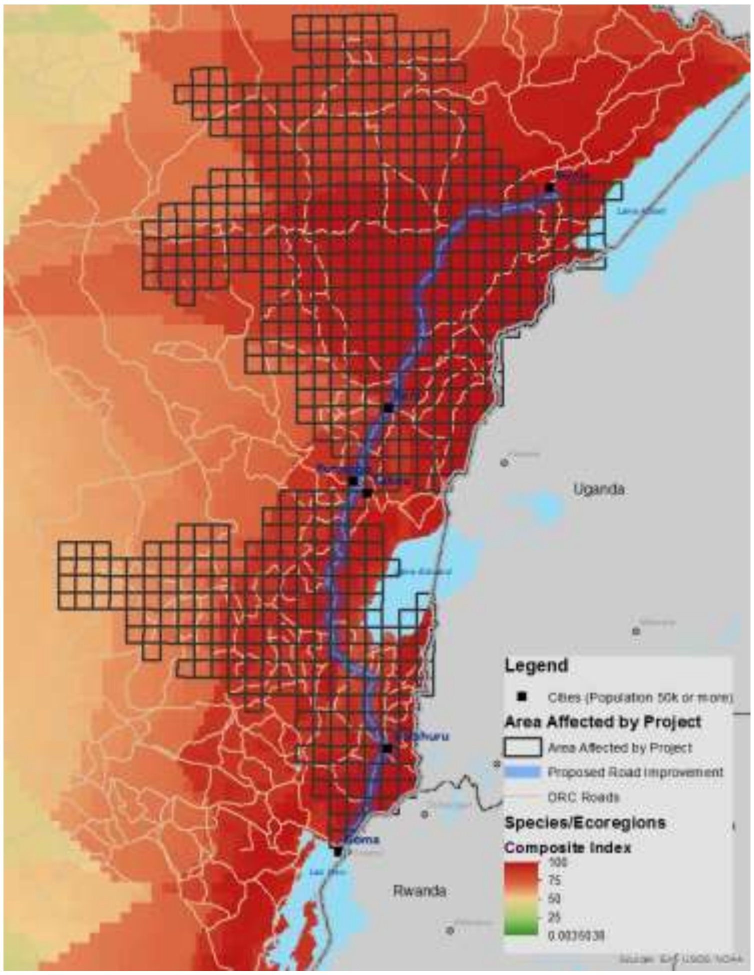


Source: Hansen, et al. (2013) and authors' calculations

As a final point of analysis, the estimated additional deforestation due to the project is layered on top of the current biodiversity index to see which threatened areas have the most biodiversity, and are therefore worth the most to protect. This composite map is shown in Figure 15. The grid cells outlined in black are those in which deforestation is predicted to increase because of the project. Although this does not distinguish by the intensity of deforestation, it allows one to compare the gradient of biodiversity within the areas affected, to see which areas are ecologically most important.

Comparing Figure 14 with Figure 15, it is clear that some of the regions with the highest ecological value also coincide with the regions predicted to experience the highest rate of deforestation from the project.

Figure 15: Biodiversity composite index compared to estimated additional deforestation due to the project



Source: Authors' calculations

The important conclusion from this is that the Virunga National Park road project poses a very significant risk to the forests and to high value biodiversity in the region. Before undertaking such a project, stakeholders should carefully compare the estimated benefits with these costs, to ensure the tradeoffs are worthwhile. This analysis also identifies the regions most at risk, so that if the project is deemed to be economically viable, safeguards can be put in place to protect the most fragile and vulnerable areas.

Chapter 5: Summary and Conclusions

The Democratic Republic of Congo's transport infrastructure is amongst the sparsest and most dilapidated in the world. While improving the transport network by itself will not be sufficient to cause growth and raise the millions of Congolese out of extreme poverty, any successful development plan must include infrastructure investments as a core component. The purpose of this study is therefore to demonstrate several techniques which can be used to evaluate pathways to sustainable growth in the DRC via transportation infrastructure improvement. This report attempted to take this holistic approach to evaluating the impact of road network improvement. Chapter 2 gave an overview of the current state of DRC's transport system, prescribed two potential transport investment opportunities, and presented an econometric model to estimate the economic benefits from reducing local transportation costs. Chapter 3 examined the potential for deforestation that could occur from infrastructure investments, specifically estimating total losses as well as possible biodiversity impacts that this may have on the local biome. Finally, Chapter 4 combined the knowledge from the previous chapters to simulate the effects of two separate road investment projects: improving a national roads network which connects major urban centers with Kinshasa, and improving a much smaller road corridor near Virunga National Park. Both economic benefits due to local transport cost reductions, as well as costs in the form of additional forest depletion were estimated.

Modeling Transport Cost in DRC and its effects in the Economy

A geospatial model was developed which seeks to simulate how individuals and traded goods are moved around the DRC. This model takes the road and river network (including both location and quality information), land topography, and population data as inputs, and makes several simplifying, yet plausible assumptions about how local farmers, traders, and other economic agents will move around the country, given these inputs. The culmination is a model which allows one to estimate transport costs to and from any location within the DRC, and transport routes that a cost minimizer would take to ship products to market.

From the analysis it is clear that, aside from some isolated areas in the northwest part of the country, rivers are used relatively infrequently for local transport. Specifically, only 14% of DRC individuals and 7% of the country's GDP, are in areas where it would be cost effective to use river transport for any portion of their trip to the local market, implying that investments in river transport will not have a significant impact on local market transport, given the current economic geography of the country. It is therefore evident that the road network is likely much more important for local transport than river transport. However, access to river transport becomes more important for longer distance travel and for goods with a relatively low value to bulk ratio, or which are highly perishable. When minimizing travel costs to Kinshasa, the geospatial model indicates that approximately 80% of DRC's population, and nearly 60% of GDP, are in areas where the more efficient travel path utilizes river travel, at least in part, in order to transport goods to Kinshasa. While cost savings to local transport are quite low and isolated only to areas right along the river, cost savings to Kinshasa transport are much greater and are achieved through nearly the entire country, save the southern part of the country which is mostly outside of the Congo River basin.

Finally, an econometric model is estimated which shows how reducing transport costs to the local market can have an impact on GDP. When controlling for various important factors, including local population, agricultural land quality, proximity to mining sites, and the presence of conflict, it is found that reducing transport costs by 10% can, on average, increase local GDP by 0.46%. While it may be intuitive that reducing transport costs can have a positive impact on the economy, quantifying these benefits are useful for conducting impact analyses, as is demonstrated in Chapter 4.

Estimating deforestation and biodiversity impacts of improving roads

Using the best available data and robust econometric techniques the report also finds large and highly-significant effects of road upgrading on the intensity and extent of forest clearing in road corridors. Predicted effects of deforestation around improved road corridors vary widely with prior road conditions and locational economics, but increases in deforestation of 10-20% are typical. More specifically, the deforestation assessment found remarkably robust and stable econometric estimates across different statistical specifications in the regressions suggesting that forest clearing intensity declines on average with: (i) distance from roads, (ii) closeness to protected areas and (iii) less accessible terrain (e.g. higher elevation). It increases on average with (iv) improvements in road conditions, (v) the agricultural value of land (opportunity cost), (vi) closeness to population agglomerations (i.e., urban centers) and (vi) conflict intensity. Two patterns are noteworthy. First, upgrading roads from very poor to good condition produces near-complete deforestation within a narrow corridor (of about 1-1.5 km radius) straddling the road. Second, the impact is non-linear and deforestation intensity falls very rapidly as distance from the road increases. Most of the deforestation occurs within about a 2km radius of the road.

Since not all forest land is of uniform ecological value, nor is it of uniform economic value, this report also develops a metric to identify areas that are of high ecological value and at higher risk of degradation. A high-resolution map of ecological vulnerability is developed that combines information on species as well as ecosystems including measures of geographic vulnerability, extinction risk, and other aspects of the ecosystem captured through a measure of biomes developed by WWF.

Overall the results suggests that the siting of infrastructure needs to consider effects on deforestation and biodiversity loss at the very outset of the planning process. Sequential decision making whereby location decisions occur first, followed by an environmental impact assessment can lead to economically less favorable outcomes that can be avoided through careful upstream planning.

Scenario Analysis

In the final chapter, the econometric results from Chapters 2 and 3 were used in two simulations to estimate the potential welfare benefits, as well as deforestation, which would result from the completion of 1) a specific proposed road investment project which connects major urban centers to Kinshasa with high quality roads in good condition, and 2) a road connecting two major cities in the eastern DRC near Virunga National Park. Keeping in mind that the benefits are estimated using a partial equilibrium framework, and that the benefits are only a subset of the total benefits to reducing transportation costs (other benefits include those stemming from improved transport between cities, increased access to multiple cities rather than solely the cheapest one, and better access to ports), these estimates are likely a very conservative, minimum benefit.

In a similar manner, simulations were done which estimate the total deforestation due to these two projects. The methodology identifies areas which are most at risk for new deforestation due to the project. It also allows for forest prioritization, by overlaying a composite biodiversity index which accounts for the fact that not all forests are identical, and the ecological value of different regions can vary significantly.

Finally, the results from the major urban center road network project are combined to create a map which gives an indication of which areas of the country would benefit most from the proposed project, and which areas pose the greatest risks in terms of deforestation. Maps similar to these can be used to help plan the location of future transportation investment projects and help ensure these projects have the largest expected economic benefits, while also minimizing environmental impacts.

It is important to conclude by highlighting the caveats to this analysis. First the assessment has been conducted in an environment where data is limited, so there would be merit in replicating the analysis with better data. Second, no attempt has been made to conduct a full benefit and cost analysis. This partly reflects that difficulties in defining environmental costs and benefits, especially those related to biodiversity. Third, the simulations are based on the assumption that all benefits are immediate, whereas in reality benefits would evolve as the economy moves to a new equilibrium. Fourth, since we deal with aggregate benefits we are unable to identify which sectors of the economy are most responsive to transport cost improvements, or are most damaging to the environment. Once more, this reflects the lack of data at the desired spatial scale. Finally the focus here is on benefits that derive from reductions in transport costs to local markets. It would be straightforward to extend the analysis to other markets or complement the estimates with those derived from gravity models of inter-regional trade.

References

Ali, R., A.F. Barra, C.N. Berg, R. Damania, J. Nash, and J. Russ (forthcoming) "Agricultural Technology Choice and Transport," American Journal of Agricultural Economics.

Ali, R., A.F. Barra, C.N. Berg, R. Damania, J. Nash, and J. Russ (2015). Infrastructure in conflict-prone and fragile environments: evidence from the Democratic Republic of Congo (No. 7273). The World Bank.

Angelsen, A. et al. Environmental Income and Rural Livelihoods: A Global-Comparative Analysis, World Development (2014), http://dx.doi.org/10.1016/j.worlddev.2014.03.006

Bahwere, Paluku, and Philippe Donnen. "Nutritional status of the populations of the Congo Basin: Today and tomorrow." Population X1000 (2008).

Block, Steven. The decline and rise of agricultural productivity in sub-Saharan Africa since 1961. No. w16481. National Bureau of Economic Research, 2010.

Chomitz, Kenneth M., and David A. Gray. "Roads, land use, and deforestation: a spatial model applied to Belize." The World Bank Economic Review 10.3 (1996): 487-512.

Cropper, Maureen, Jyotsna Puri, and Charles Griffiths. "Predicting the location of deforestation: The role of roads and protected areas in North Thailand." Land Economics 77.2 (2001): 172-186.

Debroux, Laurent, et al. "Forests in post-conflict Democratic Republic of Congo: Analysis of a priority agenda." Selected Books 1 (2007).

Deininger, Klaus W., and Derek Byerlee. Rising global interest in farmland: can it yield sustainable and equitable benefits?. World Bank Publications, 2011.

Dorosh, Paul, et al. "Crop production and road connectivity in Sub-Saharan Africa: a spatial analysis." *World Bank Policy Research Working Paper Series, Vol* (2010).

FAO and IIASA (Food and Agriculture Organization of the United Nations and the International Institute for Applied Systems Analysis). 2000. “Global Agro-Ecological Zones (GAEZ).” FAO, Rome; and IIASA, Laxenberg, Austria.

Gaveau, David LA, et al. "The future of forests and orangutans (Pongo abelii) in Sumatra: predicting impacts of oil palm plantations, road construction, and mechanisms for reducing carbon emissions from deforestation." Environmental Research Letters 4.3 (2009): 034013.

Growth, Reconciling Economic, and Forest Protection. "Deforestation Trends in the Congo Basin." (2013).

HarvestChoice. 2012. "Spatial Allocation of Agricultural Production." International Food Policy Research Institute, Washington, DC, and University of Minnesota, St. Paul, MN. http://harvestchoice.org/node/2248.

Ulimwengu, John, et al. "Paving the way for development." The impact of transport infraestructure on agricultural production and poverty reduction in the Democratic Republic of Congo. International Food Policy Research Institute Discussion Paper 840 (2009).

World Bank. Democratic Republic of the Congo River and Urban Transport Review. Report. no. ACS9800. Washington, DC: 2014.