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The Environmental Impacts of Soybean Expansion And Infrastructure Development in Brazil's Amazon Basin

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Abstract

For decades, the development of transportation infrastructure in the Brazilian Amazon has been the government's main social and economic development policy in the region. Reductions in transportation costs have not only opened the agricultural frontier to cattle ranching and logging but have also caused more than two-thirds of Amazonian deforestation. Currently, soybean cultivation is a new economic force demanding improvements to roads in the region. Profitable soybean crops have spread over the Mato Grosso's *cerrados* and now head toward the core of the Amazon rain forest. One of the main constraints for soy expansion into the Amazon has been the poor condition of roads. In this study, we analyze the effect Amazon transportation infrastructure programs have on soybean expansion by lowering transport costs. The analysis is based on spatial estimates of transportation costs for the soybean sector, first using current road networks and then projecting changes based on the paving of the Cuiabá-Santarém road. Our results indicate that paving the Cuiabá-Santarém road would reduce transportation costs by an average of $10 per ton for farmers located in the northern part of Mato Grosso, by allowing producers to reroute soybean shipments to the Santarém port. Paving the road also would expand the area where growing soybeans is economically feasible by about 70 percent, from 120,000 to 205,000 km^2. Most of this new area would be located in the state of Pará and is covered largely by forests. A Cost-Benefit analysis of the road project indicates that the investments in infrastructure would generate more than $180 million for soybean farmers over a period of twenty years. These benefits, however, ignore the project's environmental impacts. If the destruction of ecological services and products provided by the existing forests is accounted for, then the Cuiabá-Santarém investment would generate a net loss of between $762 million and $1.9 billion. This result shows the importance of including the value of the natural capital in feasibility studies of infrastructure projects to reflect their real benefits to society as a whole.

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1. Introduction

Historically, transportation networks have played a fundamental role in the worldwide expansion of grain production. Principal producing nations, such as the Unites States, have an extensive transportation system that lowers their transportation costs. The economic benefits of these investments have not been lost on developing nations, which seek to increase their share in the world commodity markets.

Investments directed by the Brazilian Government's last three Pluriannual Plans have improved transportation networks and built infrastructure projects (ports, waterways, and hydroelectric power plants) in the Amazon region. These federal programs aim to integrate isolated urban centers into the market economy, improve the quality of life for Amazonian inhabitants, and promote the expansion of the agricultural frontier (Brazil, 1999a, 1999b; Nepstad et al., 2001; Carvalho et al., 2002). The ultimate goal of these plans is to encourage the social and economic development of the Amazon.

The most recent Pluriannual Plan (PPA) for the period 2004-2007 includes roughly $1 billion to pave and/or open 5,304 km of roads in the Legal Amazon[i] (Brazil, 2004). These expenditures continue a pattern started three decades ago, which was designed to expand cattle ranching and logging activities in the Amazon by reducing transportation costs. The success of these efforts is measured by significant changes in land use. Between 1978 and 1994, approximately 318,000 km^2 of forest were eliminated within 50 km of major paved highways, accounting for more than two-thirds of the total Amazon deforestation (Nepstad et al., 2001; Alves, 2002).

Currently, the incentives for additional investments in transportation infrastructure come from the boom in soybean production. Between 2000 and 2005, soybean acreage in the Amazon basin increased from 31,000 to 70,000 km^2, and annual production increased from 9 to 20 million tons. Most of this increase occurred in the state of Mato Grosso - Brazil's largest soybean producer - which supplies about 35 percent (18 million tons) of the Brazilian total (IBGE, 2007). The increases in production and harvested area are associated with infrastructure projects such as the port of Santarém, located at the junction of the Tapajós and Amazon Rivers, and the paving of primary and secondary roads by private and governmental initiatives.

Investments in transportation networks boost soybean production by reducing the local price of purchased inputs such as pesticides and increasing the price of soybeans received by farmers, net of the transportation costs. The resultant increases in rent also provide economic incentives for additional investments to pave roads and build new export ports. Of these two causal relationships, most empirical analyses indicate that economic activity and population growth encourage road improvement, rather than the commonly held theory that roads encourage economic activity (Andersen et al., 2002).

Roughly 30 percent of the cost of producing soybeans is associated with transportation; therefore, high transportation costs are assumed to be the main constraint on the expansion of industrial agriculture in the Amazon (Vera-Diaz, 2004). To evaluate the effect of future investments, we quantify soybean transportation costs and assess changes associated with paving the road between Cuiabá and Santarém. A least-accumulative-cost approach is used to estimate the cost of shipping soybeans ($/ton) from each location in the Brazilian Amazon Basin to soybean export ports. Transportation costs maps for the entire Amazon are generated under the current road network conditions, simulating the pavement of the Cuiabá-Santarém road (BR-163). Costs and benefits that are associated with paving BR-163 are generated by considering capital and maintenance costs of the investment and benefits earned by soy farmers due to reductions in transportation cost.

This paper is organized into five sections. The next section focuses on paving the Cuiabá-Santarém highway, the most important infrastructure project promoting soybean expansion in the Amazon. Section 3 describes the methodology used to estimate soybean transport cost surfaces. Data sources and data manipulation are illustrated in Section 4. The results are explained and discussed in Section 5. Conclusions and remarks are provided in Section 6.

2. Infrastructure Projects Promoting Soybean Spread

Of the investments in the Brazilian Pluriannual Plan 2004-2007, soybean production would be most affected by paving the Cuiabá-Santarém road (BR-163). Opened in the 1970's, the BR-163 road runs 1,756 km, connecting the city of Santarém, which is located in the Amazon rainforest, to Cuiabá, which is the capital of Mato Grosso. Currently, only 44 percent of this road is paved--the remaining 990 km are unpaved and traverse an inaccessible, sparsely populated forest. The lack of pavement impedes the flow of traffic most of the year.

The Brazilian government considers paving the Cuiabá-Santarém road to be a priority for regional and national integration and its completion, which is planned for 2008, would reduce the cost of exporting soybeans. Currently, soybeans harvested in Mato Grosso's north are trucked approximately 2,000 km to reach Paranaguá and Santos ports in the Brazilian southeast. Paving BR-163 road will reroute soybeans north to the export port in Santarém, which is 800 km closer. The resulting trip to Europe will be about seven days shorter. Roughly 7,991 km separate the ports at Santarém and Rotterdam, the principal destination for soybean exports to Europe, as opposed to the 10,000 km that separate Rotterdam from the current ports of Santos and Paranaguá. The difference represents about $2 per ton in navigation costs. According to GEIPOT (2000), paving the Cuiabá Santarém road would save more than $11 per ton of soybean for farmers located along this corridor in the northern region of Mato Grosso.

Paving the BR-163 would also benefit Manaus' industrial center. Its industrial production, which includes electronics, automobiles, chemicals, and others, is currently transported from Manaus by the Amazon River to Belém. From there it is transferred to trucks that travel via the Belém-Brasília highway and BR-153 to markets located in the south and southeast regions of Brazil. Paving BR-163 would provide a new transportation route via Amazon River from Manaus to Santarém and via BR-163 from Santarém to the south's markets. This new route would cut four days off the trip between Manaus and São Paulo – the most important Brazilian consumer center – and reduce transportation costs by 20 percent (Grupo GPT- Tecnocargo, 2003).

3. Methodology

For this study, we calculated transportation cost surfaces for the soybean sector using cost-distance and cost-allocation functions available with the ArcGIS software. The objective of the cost functions is to determine the least-cost path to reach a source for each pixel in the study area. The Cost-Distance function calculates the least accumulative cost distance for each pixel to the nearest source over a cost surface. The Cost-Allocation function calculates for each pixel its nearest source based on the least accumulative cost over a cost surface (ESRI, 2008).

All cost functions require an input source location dataset and a cost raster dataset[ii]. The input source location is a raster dataset that identifies the locations for which the least accumulated cost distance is calculated for every pixel. These locations are represented by the main markets for commodities.

The cost raster defines the impedance or cost to move planimetrically through each pixel. The value at each pixel in this raster represents the cost per unit distance for moving through the pixel. Each pixel value is multiplied by the pixel resolution, while compensating for diagonal movement, to obtain the total cost of passing through the pixel. For instance, if the pixel size is expressed in meters, the cost assigned to the pixel is the cost to travel one meter within the pixel. The units assigned to the cost raster can be any type of cost desired: dollar cost, time, energy expended, etc.

The source location raster and the cost raster are used to calculate the cost distance raster and the cost allocation raster. This procedure is carried out by using map algebra commands available in ArcGIS to run the functions cost-distance and cost-allocation. The cost-distance raster identifies, for each pixel, the least accumulative cost distance over a cost surface to the identified source locations (market destination). We call the cost-distance raster a transportation cost surface.

The cost-allocation raster identifies the zone of each source location that could be reached with the least accumulative cost. We call the cost allocation raster as catchment area.

The methodology described above is used to calculate the least-accumulative-cost from each pixel in the Brazilian Amazon Basin to the nearest soybean export port. The output of this operation is called “transportation cost surface.” For this analysis, transportation costs are defined as the price paid by farmers to ship their soybeans to the main export ports.

In this study, the source location raster is depicted by the export port raster and the cost raster is represented by the land-use cost raster. These rasters are built using the Lambert Azimuthal projection and have one km^2 resolution.

The export port raster includes the ports of Santos, Paranaguá, Santarém, Itacoatiara, and Itaquí, which are the main soybean export ports in Brazil. Roughly 70 percent of Brazilian soybean production is traded in the international market (CONAB, 2005), therefore we assume that these ports represent the areas where soybeans are shipped.

The land-use cost raster is the composite of two rasters: the land cover raster and the road network raster. The land cover raster consists of five categories; (1) forest, (2) flooded forest, (3) agriculture, (4) grassland and savannas, and (5) water bodies. The road network raster classifies roads as either (6) paved or (7) unpaved. The first step is to assign cost values or friction coefficients to the categories defined in the land cover and road rasters. These cost values are explained below. Second, the land cover and road rasters are overlaid and the smaller of two friction or cost coefficients are used to generate a cost surface (land-use cost raster).

The land-use cost raster represents the cost to move planimetrically from production pixels to ports. The value of each pixel represents the cost per distance ($/ton/km) to move soybeans through the pixel. These costs are based on the notion of friction--some pixels are more difficult and costly to traverse than others. For instance, paved roads are relatively easy to travel and have a low coefficient of friction as compared to unpaved roads (Stone, 1998).

For this study, the cost (friction) coefficients are based on previous estimates for the cost of transporting products over various land use surfaces such as paved roads, unpaved roads, grasslands, savannas, and forests (Veríssimo et al., 1992; Barros and Uhl, 1995; Veríssimo et al., 1995; Barros and Veríssimo, 1996; Guimarães and Uhl, 1998; Stone, 1998; Nelson et al., 1999; Nepstad et al., 1999; Vera-Diaz et al., 2007). These estimates are derived largely from the logging industry. The cost of moving timber can serve as a proxy for the cost of moving soybean because both products are shipped in trucks of similar weight, volume, and length. Timber cost estimates are calibrated to reflect the soybean sector conditions based on information about the cost of shipping soybean by paved and unpaved roads provided by the Freight Information System

(SIFRECA, 2006). The cost coefficients used for each category of land use are shown in Table 1.

Table 1. Cost of traversing different land surfaces

Land Use Category	$/ton/km
Paved Road	0.05
Unpaved Road	0.15
Agriculture	0.20
Grasslands and Savannas	0.30
Forest	3.00
Flooded Forest	3.00
Water Bodies	3.00

Finally, the land-use cost raster is used in combination with the export port raster to calculate: 1) the cost-distance raster (transportation cost surface), that is, the lowest cost path from each pixel in the Amazon Basin to reach an export port, and 2) the cost-allocation raster, that is, the area of each port that could be reached with the least accumulative cost or, in other words, the catchment area of each port. The transportation cost and catchment area rasters are computed in ArcGIS using the cost-distance and cost-allocation functions, respectively.

To assess the effects of paving the BR-163 between Cuiabá and Santarém, this improvement in the road network raster is implemented by changing the relevant pixels from unpaved to paved and by changing the cost values. This new raster is used to generate a new minimum cumulative transportation cost surface using the techniques described above. The change in the catchment area due to paving the Cuiabá-Santarém road is estimated by calculating the percentage change in area.

4. Data Sources and Data Manipulation

Most of the data are obtained from a spatial dataset assembled by the Woods Hole Research Center (WHRC), the Amazon Environmental Research Institute (Instituto de Pesquisa Ambiental da Amazônia – IPAM), and the Socio-Environmental Institute (Instituto Socio-Ambiental – ISA). The dataset includes three layers of land use, road network, and ports, which are stored in Arc View and Arc Info file formats. These layers are re-projected from a geographic projection measured in degrees to a Lambert Azimuthal projection measured in meters. All coverages are converted to one kilometer of spatial resolution and raster format. Data on land use are derived from (Eva et al., 2002). These authors generate a land cover map of South America for 2000 using data from microwave and optical sensors on earth observing satellites. The original land use map has more than forty classes, which are reclassified into the five categories of forest, flooded forest, agriculture, grassland and savannas, and water bodies.

Data on the road network are obtained from WHRC et al. (2000). These data include paved and unpaved roads for all of Brazil. These data are assembled from several sources, including fieldwork carried out by these institutions in the Amazon region. The map of the ports complied by WHRC et al. (2000) includes the main Brazilian export ports. Most of the soybeans exported from Brazil are shipped from five ports: Itacoatiara port on the Amazon River, Santarém port on the junction of Tapajós and Amazon Rivers, Itaquí port on the Atlantic Coast in Brazil's northeast, and Paranaguá and Santos ports on the Atlantic Coast in Brazil's southeast. These ports handled about 67 percent of the soybeans exported from Brazil in 2004.

5. Results and Discussion

Soybean transportation costs vary greatly across Brazil. Regions in the northeast and southeast have the lowest transportation costs, ranging from 0 to 116 dollars per ton of soybean hauled[iii], with an average of $70 per ton (Figure 1). These relatively low costs are associated with the high quality of the road network, proximity to the Atlantic coast and to the principal consumer centers, and large extensions of agricultural and pasture lands where the friction or cost of the movement of freight is lower.

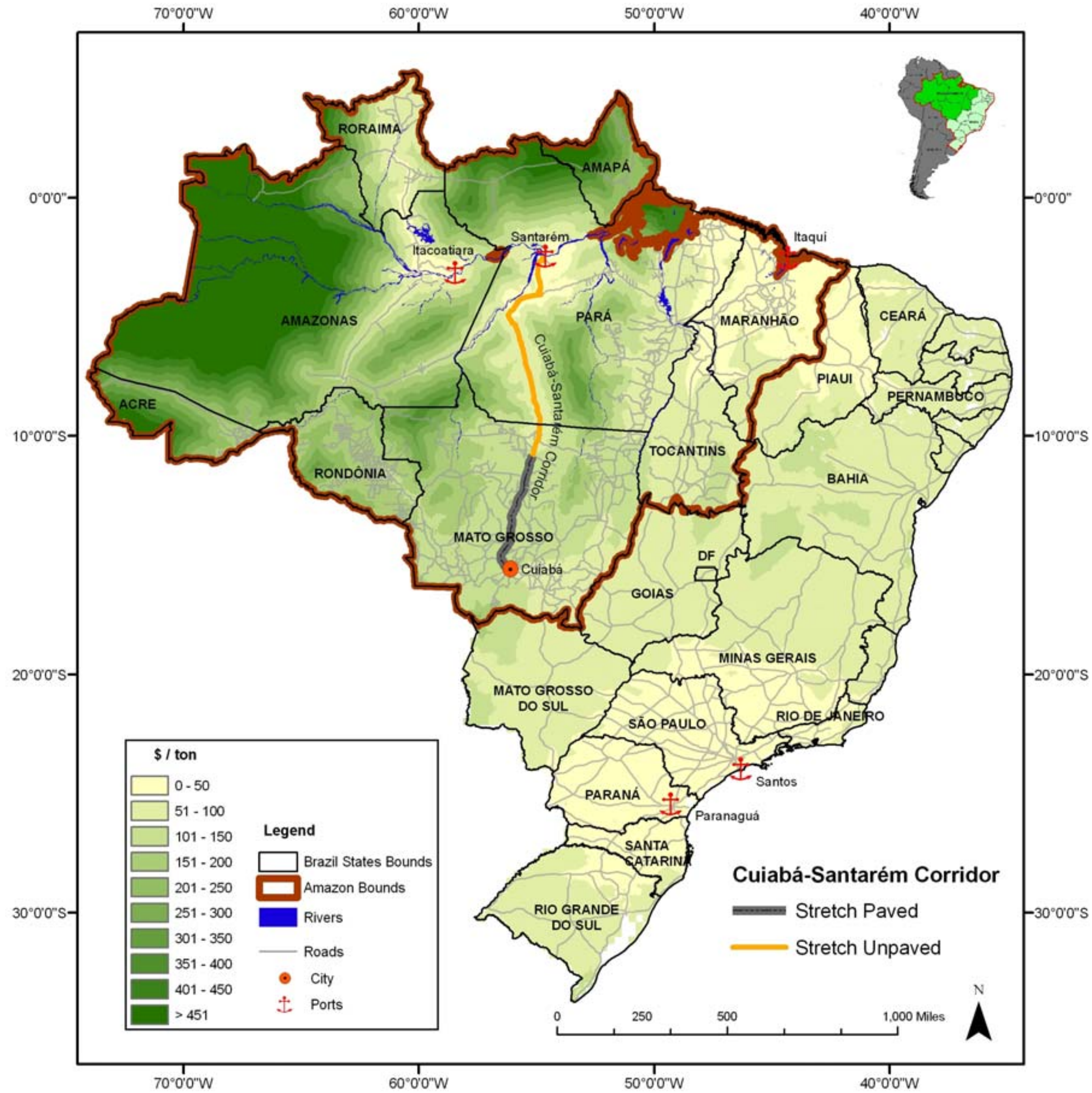
As expected, the Amazon Region has the greatest transportation costs, which range from 0 to 1,156 dollars per ton of soybean shipped with an average of $245 per ton (Figure 1). High costs are due to vast areas of rainforest and the poor quality of roads. Only about 9 percent of the total road network (240,898 kilometers) is paved (Table 2).

5.1 Transportation Cost Variability across Amazonian States

In general, government investments in road infrastructure lowered transport costs in the eastern Amazon relative to the western Amazon. About 90 percent of the roads in the Amazon basin are located in the eastern states of Maranhão, Tocantins, Mato Grosso, Rondônia, and Pará (Table 2). The relatively low transportation costs here generated an area known as the "Deforestation Arch."

Because of differences in the concentration of roads, there is substantial variation in transportation costs across Amazonian states. The states of Maranhão and Tocantins have the lowest average transportation costs of $38 and $79 per ton of soybean, respectively (Table 3). These states have densely clustered roads with 80,314 kilometers of length connected to both the port of Itaquí (Maranhão) and the domestic markets of southern Brazil. Moreover, access to these states also is facilitated by large areas of open pasture and/or agriculture. Low transportation costs probably contributed to the rapid expansion of soybean production in Maranhão (28 percent per year) and Tocantins (57 percent per year) between 2002 and 2004 (IBGE, 2007).

Figure 1. Brazil's soybean transportation costs



Amazonas is the largest Brazilian state with an area of about 1.5 million km^2 (IBGE, 2007), which includes vast areas of untouched rainforest and a sparse road network (6,500 kilometers). Of these roads, 73 percent are unpaved (GEIPOT, 2005). Consequently, the state of Amazonas has the highest average transportation cost of $438 per ton of soybean (Table 3). In some areas, costs are more than $1,000 per ton, which makes soybean production there economically unfeasible[iv]. Due to these high transportation costs, current local soybean production is economically insignificant. Some soybeans are produced on experimental plots developed by the AMaggi Group in the municipality of Humaita. The soil there presents drainage problems for planting soybeans but the location offers easy access to the international markets through Itacoatiara port (Fearnside, 2001). Currently, this port exports roughly one million tons of soybean coming from Rondônia and the northwest portion of Mato Grosso via the Madeira River.

Table 2. Amazonian road network, 2000

Amazonian States	Total	Paved		Unpaved	
		Km	%	Km	%
Acre	5,399	838	16	4,561	84
Amazonas	6,200	1,705	28	4,495	73
Amapá	2,138	223	10	1,915	90
Maranhão	53,247	5,407	10	47,840	90
Mato Grosso	84,555	4,509	5	80,046	95
Pará	34,575	3,840	11	30,735	89
Rondônia	22,433	1,417	6	21,016	94
Roraima	5,284	900	17	4,384	83
Tocantins	27,067	3,471	13	23,596	87
Total Legal Amazon	240,898	22,310	9	218,588	91
Brazil	1,724,929	164,988	10	1,559,941	90

Source: GEIPOT(2005)
This data includes just federal and state roads.

Table 3. Soybean transportation costs in Amazonian States

Amazonian States	Transportation Cost ($/ton)		
	Minimum	Maximum	Average
Acre	177	595	317
Amazonas	0	1,156	438
Amapá	57	636	315
Maranhão	0	96	38
Mato Grosso	73	418	154
Pará	0	604	173
Rondônia	135	318	190
Roraima	25	600	147
Tocantins	29	121	79

Similar to Amazonas, the states of Acre and Amapá exhibit high average transport costs of $317 and $315 per ton, respectively (Table 3). Again, these high costs are caused by the low capacity and poor condition of the roads. Acre has 5,399 kilometers of roads (16 percent paved) whereas Amapá has just 2,138 kilometers (10 percent paved), both states representing only three percent of Amazonian road network (Table 2).

Furthermore, these states are located in remote and unsettled areas which are covered largely by dense forest, which increases the friction or impedance to the movement of freight and passengers.

The costs of shipping soybeans in Roraima range from $25 to $600 per ton, with an average of $147 per ton (Table 3). As expected, the lowest transportation costs occur along the BR-174 road, which is the only stretch of paved road in Roraima. BR-174 connects the capital cities of Manaus (Amazonas) and Boa Vista (Roraima) and continues north toward the Venezuelan frontier. The paving BR-174 in 1988 and the existence of large areas of *cerrado*, which is ideal for growing soybeans, have stimulated significant migration of soybean farmers from southern Brazil to the state of Roraima. Demand from Venezuela and elsewhere in the Caribbean may provide a market for additional soybean production from Roraima. Currently, Roraima's farmers plant 130 km^2 of soybeans, which produce 36,000 tons/year (IBGE, 2007).

Rondônia's average transportation costs are $190 per ton of soybean (Table 3). Although Rondônia has 22,433 kilometers of roads, only 6 percent are paved (Table 2). Nonetheless, transportation costs could be much lower than estimated because the methodology used in this analysis does not examine the cost of moving soybeans by river barge, which could be much less expensive than road transport. Currently, most of soybeans harvested in Rondônia are transported by the Madera waterway in barges that travel 1,056 km from Porto Velho up to the ocean freighter port in Itacoatiara at the Amazon River. The inauguration in 1997 of the Madera waterway, the construction of grain storage facilities in the ports of Porto Velho and Itacoatiara, and the proximity of these ports to the international markets increased soybean rents in the municipalities of Vilhena and Cerejeiras in the southern part of Rondônia, which produced more than 140,000 tons of soybeans in 2005 (IBGE, 2007).

The costs of transporting soybeans in the state of Pará vary from $0 to $604 per ton, with an average of $173 per ton (Table 3). Only 11 percent of the 34,575 kilometers of road in Pará are paved (Table 2). Transportation costs are relatively low near the port at Santarém, which was opened by the transnational corporation Cargill in 2003. This new port encourages the migration of capitalized land buyers from the states of Mato Grosso, Paraná, and Rio Grande do Sul to the municipalities of Santarém and Belterra, which in turn leads to the expulsion of local communities and encourages the conversion of forests to soybean fields (Steward, 2004). Between 2003 and 2005, the soybean acreage in these municipalities increased from 60 to 355 km^2, with production currently estimated at 102,000 tons/year (IBGE, 2007). In 2004, the port of Santarém exported 456,000 tons of soybeans (2.4 percent of the Brazil's total). Most of these soybeans are grown in Rondônia and northwestern Mato Grosso and reach the port via the Madeira waterway. Should the Cuiabá-Santarém road be paved, an additional one million tons may reach the port via truck from northern Mato Grosso. The southeastern portion of Pará also has low transportation costs due to its proximity to the dense road network of Maranhão and Tocantins states. Indeed, pasturelands in the municipalities of Santana de Araguaia and Conceição do Araguaia are being converted to soybean production (Alencar et al., 2004).

Mato Grosso's transportation costs range from $73 to $418 per ton of soybean shipped, with an average of $154 per ton (Table 3). These relatively low costs are due to an extensive road network. Mato Grosso has the largest road network of all Amazonian states, 84,555 kilometers, but less than 5 percent is paved (Table 2.). The central and southeast parts of Mato Grosso have the lowest transportation costs, less than $100 per ton, due densely clustered roads and a landscape composed of pasturelands and savannas (*cerrado*). Transportation costs are higher in northern Mato Grosso due to the predominance of dirt roads and large areas of transition forest. These costs have not slowed soybean expansion in Mato Grosso, however. Plantings increased from 20,000 km^2 in 1994 to 61,000 km^2 in 2005 and annual production increased from 5 to 18 million tons (IBGE, 2007). This increase is motivated mainly by improvements in local transportation infrastructure, advances in soil management in the *cerrado*, and the development of soybean varieties that can generate large yields, up to 3,000 kg/ha, in hot and humid climates (EMBRAPA-SOJA, 2002).

Recently, soybeans have been planted in the border region at the northern part of Mato Grosso. Despite higher transportation costs, expanding production in this area is economically feasible due to new cultivars suited to hot, humid conditions, as well as the application of fertilizer and limestone to increase yields (EMBRAPA-SOJA, 2002). Large grain companies are attracted to these new production zones with the hope of reducing transport cost via economies of scale. These gains are enhanced by the construction of grain storage facilities and the availability of credit for farmers, which is issued mainly from Cargill, Bunge, ADM, and the AMaggi Group (Alencar et al., 2004; Vera-Diaz, 2004).

Soybean production has also increased in the Chapada dos Parecis region, in the northwest part of Mato Grosso, motivated by new transportation alternatives such as the Madera waterway[v]. An increasing share of the soybeans harvested in this region is trucked to Porto Velho (Rondônia) and from there transferred into barges that travel by the Madera River up to the Itacoatiara port. Nevertheless, most of Mato Grosso's soybean production is transported about 2,000 km to the ports of Santos and Paranaguá in the Brazilian southeast, which export more 10 million tons/year, about 56 percent of Brazilian soybean exports (CONAB, 2005). Available capacity limits the ability to reach these ports during the soybean harvest season. Currently, congestion can create lines of soybean trucks nearly 100 kilometers in length. Despite these costs, the Santarém port is not a viable alternative for soybeans produced in Mato Grosso because of the poor condition of the Cuiabá-Santarém road.

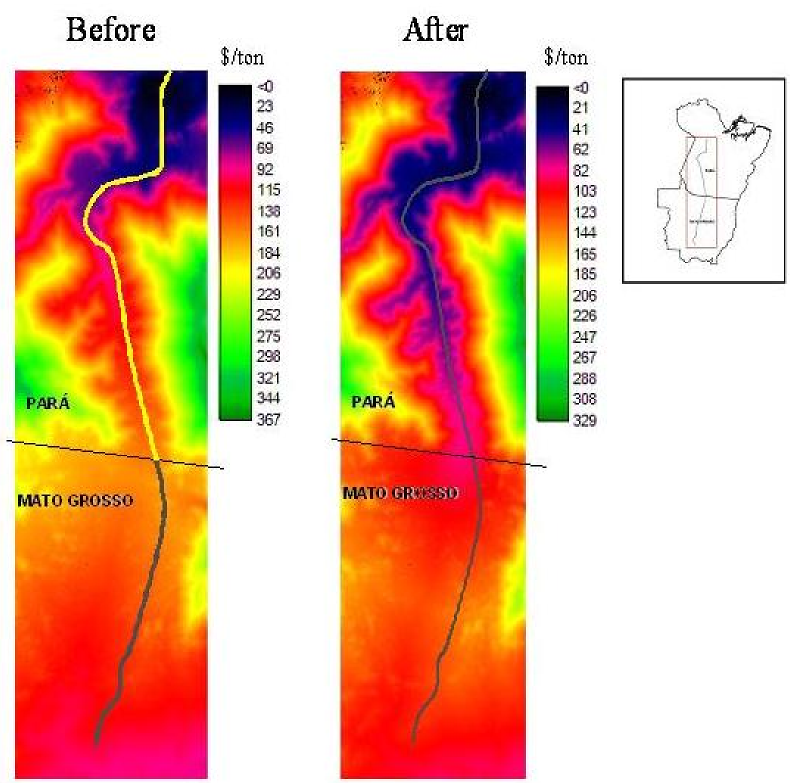
5.2 Cost Reductions from Paving the Cuiabá-Santarem Road

The limits on soybean production in Mato Grosso and elsewhere may change if the Cuiabá-Santarém road is paved. A comparison of transport costs before and after paving BR-163 indicates that this improvement would reduce transportation costs significantly (Figure 2). To quantify this effect, a rectangular area of 450 x 1,535 kilometers is selected. This area covers the entire length of Cuiabá-Santarém road (1,756 km), and 225 km of each side that it influences. Under current conditions, 17 percent of the area (120,000 km^2) has transport costs less than \$100 per ton; however, paving BR-163 would increase this area to 205,000 km^2 (Table 4). Lower transportation costs would be concentrated in the state of Pará and would encourage the conversion of vast areas of forest to agricultural uses.

The catchment area of each export port in the Amazon Region also is estimated in the two scenarios considered. As expected, paving BR-163 road increases the area covered by the Santarém port from 945,000 km^2 to 1,284,000 km^2. Much of this 239,000 km^2 increase is located in Mato Grosso's northern region, where soybeans currently are shipped to the ports of Santos and Paranaguá (Table 5).

On the other side, the analysis of private costs and benefits generated by paving BR-163 shows that this investment would increase rents for soybean farmers. According to a feasibility study elaborated by the Brazilian government, paving the Cuiabá-Santarém road would generate at least \$2 billion of net benefits in a time frame of 25 years. Soybeans exports represent approximately 86% of these estimated benefits (Brazil, 2005). The environmental losses of paving the Cuiabá-Santarém road are not reflected in the government study even though the impacts on the environment that would result from this investment are undeniable.

Figure 2. Transport cost change after paving Cuiabá-Santarém Road



Our own Cost-Benefit analysis is based on the net present value (NPV) of the costs and benefits of the investment, which are estimated over a span of 20 years starting on 2005. Private benefits are estimated for the soybean sector, which gains the most from paving BR-163. These benefits include reductions in the cost of shipping soybeans and fertilizers from production areas located along BR-163 in the northern part of Mato Grosso to the Santarém port. Private costs include the capital cost for paving BR-163 and maintenance costs on subsequent years.

Table 4. Simulating the paving of Cuiabá-Santarém Road (BR-163)

Transport Costs	Current Road Network		Paving BR-163 Road	
	Area (km^2)	% Total Area	Area (km^2)	% Total Area
< $50 / ton	31,430	5	57,709	8
< $100 / ton	120,521	17	205,121	30
< $130 / ton	284,007	41	452,945	65

* The total area is 691,967 km^2

Table 5. Area influenced by each port before and after paving the BR-163 Road

Export Ports	Current Road Network		Paving BR-163 Road	
	Area (km^2)	%	Area (km^2)	%
Santarém	938,177	19	1,277,321	25
Itaquí	1,178,972	23	1,119,404	22
Itacoatiara	1,947,667	39	1,906,653	38
Santos-Paranaguá	952,959	19	714,397	14
Total	5,017,775	100	5,017,775	100

Spatial estimations of transportation costs show that paving the remaining 990 km between Guarantã do Norte (Mato Grosso) and Santarém (Pará) would reduce transportation costs by $10 per ton on average for the main soy producing municipalities located in the northern part of Mato Grosso[vi]. This would generate a total benefit for soy farmers of $442 million in 20 years[vii], at a discount rate of 10 percent[viii].

The estimated costs for paving and maintaining BR-163 are $256 million using the same discount rate (10 percent). This includes a total capital cost of $206 million for paving BR-163[ix], which would be spent during the first four years of the project starting in 2005 and a total discounted stream of maintenance costs of $50 million[x] (at approximately $3.1 million a year). Maintenance costs are discounted over a span of 16 years, from 2009 through 2024.

The Cuiabá-Santarém investment would thus generate a net present value of $186 million (Table 6), an internal return rate of 8 percent, and a benefit-cost ratio of 1.7. The positive net benefits make the project justifiable from the private sector's perspective. Nevertheless, this investment also would cause significant environmental impacts, including deforestation, increased fire risk, and loss of biodiversity. These costs are difficult to value and so are not included in this calculation. Deforestation is linked to infrastructure development, particularly roads, in the Amazon Basin. Several studies show that more than two-thirds of Amazon deforestation takes place within 50 km of major paved roads, where agriculture, cattle ranching, and logging activities become economically feasible (Fearnside, 1986, 1987; Kaimowitz and Angelsen, 1998; Nepstad et al., 2001; Alves, 2002; Alencar et al., 2004).

Table 6. Net Present Value of Paving Cuiabá-Santarém Road

Present Values	**$ Million**	**$ Million**
Benefits		
Reduction on transportation costs for soy farmers		442
Costs		256
Capital costs for paving BR-163	206	
Maintenance costs	50	
Net Present Value (Benefits – Costs)		**186**

Nepstad et al. (2001) forecast that paving the Cuiabá-Santarém road would cause an additional 22,000 km^2 to 49,000 km^2 of deforestation along the BR-163. This change implies a loss of natural capital of $948 million to $2.1 billion at a 12 percent discount rate. This total is based on a simple estimate for the Total Economic Value (TEV) of standing forest of $431 hectare[xi] (Andersen et al., 2002). If these environmental losses are included in the Cost Benefit Analysis, then paving the BR-163 would generate a loss of between $762 million and $1.9 billion. Thus, the positive benefit estimated for soybean farmers would become negative for society at large.

Environmental groups and other members of civil society have been very proactive in raising the issue of the social and environmental impacts associated with this investment. A study performed by Alencar et al (2005) estimated the net present value of paving the Cuiabá-Santarém road at US$166 million over a 20-year time horizon (2005-2024) and environmental costs at US$1.941 billion in a business-as-usual scenario. These values are comparable to our results, confirming the importance of including environmental losses on feasibility studies of infrastructure projects.

5.3 Transportation Costs Affect Competitiveness of Brazilian Soybean Farmers

In spite of Brazil's large and clear advantage in soybean production, its transportation costs are much higher than those in the United States. The U.S. is the world's largest producer of soybean, supplying 35 percent of the world total (USDA-FAS, 2004). In the U.S., the cost of transporting a ton of soybean from farms to export port averages $15. Brazilian farmers, on the other hand, pay an average of $37 per ton (Castro, 2005).

The large differences in transportation costs stem from the cost and availability of competing modes of transportation. . For each one dollar spent in river transportation, transport by train cost $3 and transport by truck costs $5. In the US, 61 percent of soybeans travel by rivers, whereas 67 percent of Brazilian soybeans are shipped by roads. In Brazil, the cost increase due to truck travel is greater, since less than 10 percent of the 1.7 million kilometers of roads are paved (GEIPOT, 2005).

The Brazilian National Association of Grain Exporters (ANEC) estimates that the 19 million tons of soybeans (grain) trucked to the export ports in 2004 cost roughly $933 million of the $5 billion earned from soybean exports. These costs would drop to $288 million if the Brazilian transportation system could reduce costs to the level paid by US farmers (Castro, 2005).

Brazilian exports of agricultural products are impeded by reliance on an underdeveloped road network. This limit is exacerbated by recent opening of new agricultural frontiers in the distant Center-West and North of Brazil, which are farther from the coast and consumer centers. Despite these limits, Brazilian soybean growers are competitive in the global market because their low labor and land costs (Baumel et al., 2000).

6. Conclusions

The Amazon's large-scale agricultural expansion is an ongoing process driven by a multiplicity of economic, physical and political factors, each with different weights and roles. Nevertheless, most studies indicate that the construction and improvement of the road network would extend the agricultural frontier and promotes tropical deforestation. The recent boom in soybean cultivation in the Amazon is strongly encouraged by reductions in transportation costs, which are an important determinant of soybean yields and rents (Vera-Diaz et al., 2008).

Analyses show that the cost of shipping soybeans varies significantly across the Amazon Region. In general, lower costs are associated with a network of paved roads that cross large areas of pasture and savannas. Infrastructure development programs such as paving the Cuiabá-Santarém road reduce transport cost, thereby opening new areas in the core of the Amazon rainforest to soybean production and other economic activities such as logging, slash-and-burn agriculture, and cattle ranching. Results indicate that paving BR-163 would reduce the cost of shipping soybeans by $10 per ton on average for farmers located in the northern part of Mato Grosso by rerouting soybean exports to the Santarém port. The Cost-Benefit analysis of this investment suggests that it would increase rents by more than $180 million over a span of 20 years. However, these gains would be more than offset by negative environmental impacts. The loss of natural capital is not counted in the feasibility study of the Cuiabá-Santarém road carried out by the Brazilian Government, leading to an overestimation of the benefits of paving this corridor.

In this study, soybean transport costs are estimated assuming that they reflect distance in a reasonably consistent way. In reality, transport rates rarely are based strictly on distance. Freight rates are complex and are shaped by several other factors, such as tapering fares, grouping, and competition (Taaffe et al., 1996). Although these factors are not considered in this study, our estimates for transport costs are consistent with observed values. Nonetheless, the accuracy of these results is limited by the lack of a complete Brazilian road map that incorporates municipal roads. A finer road layer as well as the inclusion of other modes of transport, such as railroads and waterways, would improve the estimates for the cost of transporting soybeans.

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NOTES

[i] The Brazilian Amazon region, also knows as the North Region, includes seven states: Amazonas, Acre, Amapá, Pará, Rondônia, Roraima, and Tocantins. The Legal Amazon is a larger area including the states of Mato Grosso and Maranhão (the part west of meridian 44ºW), which was defined for regional planning purposes (Andersen *et al.*, 2002).

[ii] Raster is a GIS format represented by pixels.

[iii] Transport costs close to 0 could be feasible in soy-planted areas near the export ports.

[iv] According to the Brazilian National Association of Grain Exporters (ANEC), the cost of transporting a ton of soybeans in Brazil from farms to export port averages $37 (Castro, 2005). This value shows high variability across Brazilian territory, reaching in some cases up to $100 per ton. This study defines $100 per ton as the threshold for "economically feasible" transport costs, above which costs are considered prohibitive.

[v] Waterways are not included in the estimate of transportation cost surfaces because, for those areas served by the Cuiabá-Santarém road, there is no water alternative to be built in the medium term. Currently, there is a proposal being analyzed by the Brazilian government for the construction of the waterway Tapajós-Teles Pires. However, it has not been included as a priority in the government's Pluriannual Plans.

[vi] This analysis encompassed the municipalities of Lucas do Rio Verde, Nova Mutum, Nova Ubiratã, Santa Carmem, Sinop, Sorriso, Tapurah, and Vera. Currently, soy production from these municipalities is shipped to the port of Santos in the Brazil's southeast. This study assumes that after paving BR-613, 70 percent of soy production would be shipped to the port of Santarém.

[vii] These numbers are based on the quantity of soy exported from these municipalities in 2004 (3.3 million tons or about 70 percent of total soy production (IBGE, 2007) and the quantity of fertilizers imported, which is estimated in 0.5 ton per hectare of soy planted (GEIPOT, 2000; Alencar *et al*., 2005). Projections for soy production over the next 20 years were estimated considering annual growth rates of 6 percent between 2004 and 2012 and 2 percent after 2012 as forecasted by GEIPOT (2000).

[viii] This discount rate is commonly used for infrastructure projects in developing countries.

[ix] The paving costs of BR-163 were estimated based on a value of $262 thousand/km for a total of $260 million (2003 dollars), as indicated in the Environmental Impact Report of the investment (DNIT and ECOPLAN, 2003).

[x] Maintenance costs were estimated on $9.4 million a year (Alencar *et al.*, 2005), which consists of $8.6 thousand/km plus an additional of 25 percent for maintaining stretches of BR-163 already paved.

[xi] It includes losses of ecological services and products provided by standing forest such as sustainable timber supply ($233 ha), non-timber products ($4 ha), protection against fire ($67 ha), tourism ($7 ha), carbon storage ($100 ha), biodiversity protection ($5 ha), recreational value ($7), and existence value ($8 ha) for a total of $431 per ha (Andersen *et al.*, 2002).

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