Road Impacts in Brazilian Amazonia

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We examine the evidence on Amazonian road impacts with a strong emphasis on context. Impacts of a new road, on either deforestation or socioeconomic outcomes, depend upon the conditions into which roads are placed. Conditions that matter include the biophysical setting, such as slope, rainfall, and soil quality, plus externally determined socioeconomic factors like national policies, exchange rates, and the global prices of beef and soybeans. Influential conditions also include all prior infrastructural investments and clearing rates. Where development has already arrived, with significant economic activity and clearing, roads may decrease forest less and raise output more than where development is arriving, while in pristine areas, short-run clearing may be lower than immense long-run impacts. Such differences suggest careful consideration of where to invest further in transport.

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1. INTRODUCTION

The roads of Brazilian Amazonia are often portrayed in a melodramatic fashion. For decades, pictures have shown dirt paths, smoldering forest remains, poor people, and perhaps a message: these are unpaved roads; imagine what paving and capital investment could do! Such "visual cost-benefit analysis," not surprisingly, conveys some truths but not all. When deforestation occurs, it does indeed affect ecosystems. Roads increase access to forest and clearing follows, with ecological impacts: providing suitable habitat for some species but reducing and fragmenting other habitats, degrading streams and water quality, fostering the spread of exotic invasive species, causing wildlife mortality and species loss, and even bringing about local climate change [*Trombulak and Frissell*, 2000; *Forman et al.*, 2003; *Fearnside*, 2007]. All are important potential impacts of forest loss discussed expertly in other parts of this book.

This chapter is based on people-focused research from across Amazonia and over time. We present the view that roads differ in their forest impacts, and forest loss is not their only impact. While on average new road investments increase deforestation, it must be recognized that a road's forest impact depends on the context in which the investment in lowering transport cost occurs. Further, loss of forest is not the only consideration, as there are numerous impacts of roads on the Amazonian ecosystem and on human welfare.

We refer to work at different scales. This chapter's authors, and certainly the larger group whose research we cite, analyze scales from the household to the village, county, state, Brazilian Amazônia Legal, country of Brazil, and the

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multicountry Amazon basin. Although each scale may highlight different points, it is always important to consider the impact of roads within a wider context.

We start with the long view in time and space. Remote sensing can be used at the temporal scale of decades and the spatial scales of Brazil and the entire Amazon basin (Brazilian Amazonia is a large component of both of these) to study the change in broad forest coverage [see *Alves et al*., this volume]. On the people side, census data of good quality and reasonable spatial and temporal coverage and frequency exist at these large scales. At this level of aggregation, it is clear that transport costs influence land use. Thus, because road investments impact the cost of transport, in general, lowering transport costs leads to increased deforestation. However, the context in which road investments are made is important and even at this broadscale some broad differences in new road impact occur. We see that prior forest access and prior forest clearing have a powerful influence on the estimated impacts of new roads on forests. New roads appear to have lower immediate impacts if prior development is either very high or very low, while between those two endpoints, a fall in transport cost has its greatest immediate impact on deforestation.

This variation in broad patterns invites us down in scale to learn more about the contexts and the types of roads placed in them. The larger-scale analysis suggests that as the road-generating processes differ, at regional or village scale, so will the relationship of roads to clearing. That said, analyses at these smaller scales also confirm the general importance of transport cost for land use. Finally, we step back to consider evidence of road impacts on people's incomes, to flag the importance of nonlocal influences, including interactions within Amazonian ecosystems, and to emphasize that empirical analyses of roads such as those discussed here are relevant for future roads policies.

2. TRANSPORT COSTS AFFECT FOREST

2.1. Across Basins and Decades

We begin with a long view in space and time, i.e., looking across all of Brazil, over several centuries. It is not always recognized that transport costs have always been a central factor in defining patterns of development. For example, the Brazilian hinterland's adverse soil, relief, climate, vegetation, and hydrology limited development by making transport prohibitively costly [*Silva*, 1949; *Summerhill*, 2003].

From Rio Grande do Sul to Bahia, the dense forests of the Serra do Mar, intense rains in summer, and slopes, with almost 1000 m of altitude change in 100 km from the coast, made travel and settlement of the Central Highlands unattractive, until gold was discovered in the eighteenth century. The few navigable rivers flowed west, creating quite a long detour and corresponding increase in transport costs. Moving to the northeast region of Brazil, the Borborema Mountain Range along with both the poor soils and the arid climate combined to make economic settlement beyond the narrow coastal strip unsustainable. Finally, in Amazonia, although river navigation was and is the main form of transport, the impenetrable vegetation for a long time restricted human settlements to the riverine strips of land [*Goulart*, 1959; *Dean*, 1995].

During the sixteenth and seventeenth centuries, technology for the long-distance transport of goods was essentially restricted to Indian and African slaves' shoulders. Horses and carts were inadequate for the steep slopes of the Serra do Mar, for instance. Mules were first introduced as substitutes for slaves during the gold discoveries in the eighteenth century. The railroads, introducing wheels for the first time in Brazilian history, together with cultivation of coffee, were one of the key driving factors behind expansion of the agricultural frontier as well as the industrialization of the central-southern region of the country during the last quarter of the nineteenth and first half of the twentieth centuries.

Trucks and the development of the road network pushed the agricultural frontier in a northwesterly direction toward the Amazon basin during the second half of the twentieth century. The main factors behind these shifts were the rise of the domestic auto industry and the priorities and subsidies to road transportation within government budgets and public tariffs [*Barat*, 1978]. From 1960 to 1975, there was a massive expansion of roads in all regions of the country. The Brazilian road network expanded from 440,000 to 1,418,000 km (IBGE, various issues). Following this trend, road build- Q3
ing was a cornerstone of the regional development strategy for Brazilian Amazonia. First came the Belém-Brasília Highway, completed in 1964 before Operação Amazônia. This highway created the first time overland connection between Amazonia and the rest of the country. An immediate consequence of this road building was the migration to northern Goiás, southeast Pará, and southern Maranhão. Extensive cattle raising spread in a disorganized fashion, despite official efforts to regulate rural settlements [see, e.g., *Mahar*, 1989; *Mueller*, 1983].

During the 1970s, massive investments in axial routes (Cuiabá-Porto Velho completed in 1970, Transamazônica with 2200 km in 1974, and Cuiabá-Santarém in 1976) gave greatly improved access to the hinterlands. *Almeida* [1992] estimates that, in this period, road investment reached $4 billion. This was complemented by colonization projects and agricultural research. From 1974 to 1986, National

Integration Plan and Land Redistribution and North/Northeast Stimulus Program together invested approximately $13 billion [*Diniz*, 1995]. As the agricultural frontier reached the flatter Central Highlands, opportunities for mechanization opened. The main beneficiaries of this were soybean farmers and cattle ranchers.

In 1984, the highway linking Porto Velho to Brasília was paved as part of the World Bank-funded Polonoroeste program. The Polonoroeste included three new settlement projects, with the largest one in Machadinho, in the northeastern corner of the state of Rondônia. The occupation of Rondônia proceeded through the 1970s into the 1980s despite the Brazilian Institute of Colonization and Agrarian Reform's (INCRA's) loss of control over the colonization process [*Monte-Mór*, 2004]. INCRA's roles were limited to the selection of settlers, land distribution, and design and construction of urban and rural areas in the new projects: roads, rural parcels, urban nuclei, and public buildings [*Monte-Mór*, 2004; *Barbieri et al.*, 2009].

Eventually, these road investments slowed down, and the responsibilities were decentralized, with states and municipalities taking more active roles. Overall, these investments in components of the Amazonian transportation system, enabled by initial federal investments, lowered transportation costs between Amazonia and the rest of the country [*Simmons et al.*, 2007; *Walker et al.*, 2009]. For example, *Walker et al.* [2009] document that by 1995, about a third of the Amazon basin (in the south and east) could be reached from São Paulo by ground transportation in less than 50 h, whereas in 1968, only a tiny strip of the southeastern margin had this degree of accessibility.

When road building is financed by federal agencies, the decisions by states and municipalities are subordinate. However, once major axial roads are built by the federal government, there is political pressure for the expansion of smaller roads. Such pressures can be practically impossible to resist at the state and local levels.

2.2. Transport Costs Matter Locally Too

Broad patterns or associations across space may not always hold as we look more closely. Yet even at the "micro" or household level, transport costs are critical in many different theories about land use. Thus, we might expect transport to be locally influential, too. Several case studies are considered below, and they all confirm this view.

In fact, Brazilian Amazonia is the source of famous images linking local transportation investments to local deforestation patterns, e.g., the "fishbone" pattern of clearing in colonization projects. Generally, the form of "spatial architecture" of the roads will influence the "geometry" of the remaining forest, with clearing occurring closer to the roads [see, e.g., *Alves*, 2002; *Arima et al.*, 2005, 2008]. Thus, different kinds of networks produce different deforestation patterns. Landscapes often exhibit a patchwork mosaic of land cover types, with the urban and agricultural land uses tending to be closer to roads, while primary and secondary forests are farther away from roads.

2.3. Multiple Transmission Mechanisms

Some local stories or models suggest that the impacts of roads are straightforward and intuitive. New investments lower transport costs and thereby raise farm-gate prices received by producers for outputs. At the same time, input prices are reduced. Both of those changes increase the profit from agriculture.

However, more than one type of output can be produced by a given household, and some outputs are better produced on forest land than on cleared land (see *Andersen et al.* [2002] for discussion on the value of standing forest in Brazilian Amazonia). The drop in transport costs could also increase the profits from production of those forest outputs. Thus, for a new road to increase deforestation, the gain in profits for the outputs from the cleared land must be greater than the gain in profits from the forest products.

Other types of outputs are produced in cities, on land that is already deforested [see *Andersen et al.*, 2002]. For example, in a city, significant outputs of services could be produced in an area whose value in agricultural production might be considerably lower. Given this spatial variation in types of production, individuals choose not only what to consume but also to which types of production they will dedicate their time. New roads could lead to urban migration, potentially counteracting other effects on agriculture in terms of total forest impact. Analogously but within agriculture, new roads could, in principle, yield spatial concentration with more intensive production arising on less land. These mechanisms are all important given the regional importance of urbanization.

Yet the impacts of roads on urbanization are complex and have many linkages to deforestation. Analyzing them requires integrating across scales, spatially and temporally. *Barbieri et al.* [2009] cast Amazonian rural-urban migration as actors maximizing opportunities given many constraints and opportunities, which are determined in part by infrastructure development: "in both Brazilian and Ecuadorian cases, urbanization (…) may be a typical response not only to socioeconomic, demographic and land use changes in the frontier, but also to structural changes in the national and global economy." Many possibilities for road impacts can arise within such dynamics.

2.4. Average Forest Impacts at Basin Scale

Both the large- and small-scale summaries above suggest that where there are new roads, there will also be more clearing. That is indeed what empirical study at basin level finds, at least on average given the variation in the impacts, over space and time, which is discussed more below. For discussion of differences across countries in the settings in which deforestation occurs, see, for instance, *Geist and Lambin* [2001].

Consistent with macroscale and microscale anecdotes above, the empirical evidence at various scales across Amazonia suggests that greater access due to roads raises rates of deforestation. Systematic simple organization of basin-scale, municipio-level data on forest, roads, and other factors driving land use, from *Reis and Guzman* [1992] and *Pfaff* [1999] on, suggests that more roads yield more clearing.

Chomitz and Thomas [2003] considerably increase the number of observations by using census tract data instead of counties. There are 10 to 20 times more observations in the census tract data than in the county data set. They find results consistent with earlier works, though they note that their and others' average estimated road impacts seem relatively low (see also G. D. de Luca, World Bank Development Research Group, Development and deforestation: A review, manu-
Q4 script in preparation, 2007) on this, and for a comparison with perhaps typical assumptions, see, for instance, *Laurance et al.* [2001]).

Q5 Following *Chomitz and Thomas* [2003], A. R. Pfaff et al. (Roads and deforestation in the Brazilian Amazon, submitted, 2006, Available at: www.duke.edu/~asp9; hereinafter referred to as Pfaff et al., submitted manuscript, 2006) revisit this issue using census tracts, and observations of road and forest changes over time. The change over time, and census-tract resolution, permit county-specific statistical controls to improve estimates. Focusing on 1976–1987 deforestation rates, using lagged 1968–1975 new road investments, they confirm that new roads increase deforestation on average. Further, while allowing that new road impacts can vary with prior development (measured as prior deforestation), by breaking this large sample into prior-development categories, they find that all significant impacts are increases in clearing.

It is worth noting that the total impact of a road will extend beyond the first decade after the investment has been made. Actors will respond to a road investment over time, with the rate of response, in part, a function of the availability of other production inputs. Some actors may respond with additional investments, such as in health or educational infrastructure that complements the road in attracting migrants. *Pfaff et al.* [2006] and D. A. Conde and A. Pfaff (Duke University, Sequenced road investments and clearing of the Mayan forests, manuscript in preparation, 2007) show, for instance, that the earlier investments in new roads significantly influence deforestation in the future, controlling for later investments.

It is also worth noting that the total impact of a road will extend beyond its census tract or even its municipio or county. *Pfaff* [1999], for instance, suggests that higher road density in a county affects rates of deforestation in adjacent counties. Census-tract data permit examination of such spatial spillovers within a county. In principle, a new road could spatially concentrate economic activity within a county, perhaps even lowering deforestation in some tracts. *Pfaff et al.* [2007] extend the previous analysis from *Pfaff et al.* (submitted manuscript, 2006) of 1976–1987 deforestation following lagged road investments. The robust result is that deforestation increases in census tracts within 100 km of any census tract receiving new roads. This supports prior results and indicates a higher total impact.

3. ROAD LOCATION AFFECTS ROAD IMPACT

3.1. Pristine, Highly Developed, and In-Between

While average results are informative, few new road investments are average in all dimensions. Unpaved roads differ from paved: paving from scratch differs from paving over a previously unpaved road. As important as anything, the first road offering access to an area differs from additional roads. *Chomitz* [2006] spans many locations and policy issues in emphasizing the importance of setting.

Andersen et al. [2002] make this explicit by considering the effects of prior development, measured as prior deforestation. With around 250 observations (conglomerates of counties), they estimate an interaction between roads and prior clearing, assuming that higher prior deforestation will always raise or always lower road impact. They find it lowers the impact, i.e., that when prior deforestation is higher, the forest impacts of a new road will always be lower. Further, they extrapolate from this estimated constant trend [see also *Weinhold and Reis*, 2008], concluding that for high enough prior deforestation, reducing transport cost will reduce clearing.

Pfaff et al. (submitted manuscript, 2006) use 6000 data points to find support for this idea, but not for that result. More observations, for census tracts, permit a split of the data into prior-deforestation categories. As do *Andersen et al.* [2002], they find significant increases in clearing when roads are placed into locations where less than half of the original forest has been cleared (which represent the great majority of census tracts). Unlike Andersen et al., they find road impacts are higher for the next highest level of prior clearing, (50–75% of original forest has been cleared). From 75% up, impact is insignificant. Thus, road impact is smaller with highest or lowest prior development and is largest in between. This supports the contention that prior development matters. Yet it refutes a simple trend and is never negative. As just noted, extrapolating that trend can yield negative estimated impacts otherwise not found. The findings of Conde and Pfaff (manuscript in preparation, 2007) for Mayan forest in Mexico, Guatemala, and Belize support these results. Deforestation rates never fall after investments in new roads, and refuting the simple linear trend, clearing increases are lower in the pristine areas than in the areas of middling prior development.

Pfaff et al. [2006] then used road data over time to measure prior development using prior roads. To examine empirically whether this could matter, *Pfaff et al.* [2006] split new paved road investments into those following prior unpaved roads in a census tract and those in census tracts where new investment was not paving previously unpaved roads. They find that new paved road investments in places with prior unpaved do not have significant impacts on clearing, controlling for the impacts of prior paved roads too. With the same controls, new paved road investments without prior unpaved raise deforestation. Thus, while again the new roads never lower clearing, these results, using prior roads to measure prior development, support the idea that a road can have lower impacts given high development.

C. I. Delgado et al. (Duke University, New roads are not all made equal: REDD-relevant evidence on the influence of prior development from a deforestation frontier in the tri-border region of Brazil, Peru and Bolivia, manuscript in preparation, 2008) find the same result for the Interoceanic Highway in western Brazilian Amazonia and Peru, which is also near to and influences deforestation in Bolivia. When first constructed, as an unpaved route, the highway clearly raises deforestation rates in all three countries. However, its paving in Brazil after 2000 does not appear to influence local clearing.

Using three categories of prior development, from Pfaff et al. (submitted manuscript, 2006), and using prior roads to measure prior development, from *Pfaff et al.* [2006], *Pfaff and Robalino* [2009] apply pixel data for the entirety of Brazilian Amazonia. This provides another significant jump in observations, allowing the distance to the closest prior road to be measured as a prior-development control in studying a new road's impacts and allowing matching methods to be applied for better causal inference. Their results support the idea by Pfaff et al. (submitted manuscript, 2006): highest initial road impact in middle ranges of prior road distance; lower initial impacts when the closest prior roads are either very far, in isolated frontiers without conditions that support production, or very close, where the existing development given prior access can generate clearing dynamics with impact distinct from road effects.

This pattern of impacts varying across space, as a function of levels of prior development, suggests that the spatial pattern of emerging networks will affect development's impacts on forest. For instance, if the shortest path for a development goal is through middling prior development, then considering longer alternative paths along existing transport routes can involve a trade-off between higher road costs and lower deforestation. Whether that trade-off is attractive may be affected by carbon payments.

Based on the first-decade impacts cited here, one might posit the same trade-off for longer paths through pristine areas. However, while the first-decade increases in clearing for those areas may be lower than increases in regions of middling prior development, recall that total impact of a new road includes the long-run shifts brought on if additional investments follow the new road (and *Pfaff et al.* [2006] show that in Brazilian Amazonia, many new roads follow on old roads). Thus, the longer-run impact of opening up access to a pristine area could be considerably larger. In addition, if species habitat (as opposed to carbon storage) were a leading forest concern, then the fragmenting impacts of cutting through pristine habitat could dominate even in the short run (consider, for instance, the estimated impacts of new roads on jaguar habitat by *Conde Ovando* [2008]).

3.2. Where Are Roads, Why, and So What?

Roads are not located by blindfolded planners randomly throwing darts at maps. Rather, such significant infrastructural investments are usually driven by specific motivations. Those may be identifiable from historical documents. However, often such documents may not exist, or may not represent the key details of meetings, or even intentionally may not reveal all. Here we must substitute statistical associations and our own interpretations for such documents.

The reason for doing so is that motivation matters. Specifically, a lack of understanding of why a road was located can confound the estimation of the causal forest impact of new roads. We assume that road planners had more information at their disposal than we have as analysts. Thus, we are likely to not be able to account statistically for some factors that mattered. For instance, if planners aim a road at the place most likely to boom in agricultural production, and we do not observe all of the factors that made it so, we might assign such factors' impacts to roads.

Simplifying and formalizing this, D. Weinhold et al. (London School of Economics, Land use and transportation costs in the Brazilian Amazon, manuscript in preparation, 2006)

Q6 extend the work of *Andersen et al.* [2002] by examining statistically whether some roads appear to follow upon prior deforestation. They find this is the case. Thus, a significant portion of road investments may be following on some prior development, which may signal to road planners that various factors will facilitate more output.

Along these lines, see that a significant fraction of all the roads in Brazilian Amazonia are near a city. In several cases, this is linked to INCRA's sponsored colonization pattern known as urbanismo rural, which established the city as the "loci" of social and economic organization in several parts of Amazonia [*Barbieri et al.*, 2009]. A stated rationale was "bringing the town to the country" through linking rural parcels to urban areas via a network of local roads. This was a central component of a strategy to effectively occupy Amazonia [*Barbieri et al.*, 2009]. *Browder and Godfrey* [1997], considering settlement in Rondônia, suggest that this reproduced in the forest an infrastructure and abandonment found in slums of more-developed areas in Brazil.

For our purposes, given the results above that the impacts of roads on forest vary with context, where in fact roads are placed clearly affects their actual and estimated impacts. Thus, if past new roads were often placed in locations where their impacts actually were relatively low, analysis at the regional level might find, erroneously, that impacts are always low. Yet commentators could still be correct to claim that a particular new road would lead to a significant rise in deforestation.

4. ROAD TYPES AND PROCESSES

4.1. Official Versus Unofficial

Roads are varied in Amazonia. One might distinguish by construction (e.g., paved versus unpaved) or other engineering specifications, but another useful distinction is between the "official" and the other "unofficial" roads [*Brandão and Souza*, 2006; *Perz et al.*, 2005, 2007a, 2007b]. Official roads, or "primary" or "development" roads, are interregional highways built or financed by national or state governments. They appear on official maps and run for hundreds of kilometers connecting cities in different parts of the country or even in different countries. Examples in Brazilian Amazonia include well-known highways such as the Transamazon, the Cuiabá-Santarém (BR-163), and the BR-364 through Rondônia. The main reasons for building official highways include regional integration, to facilitate economic development by facilitating access to global markets, as well as geopolitical objectives, such as securing national borders.

Official roads have received considerable attention as large-scale infrastructure projects that were often initiated with very little public debate. Past official road projects in Amazonia in the 1960s and 1970s are linked to considerable deforestation and rural violence in conflicts over land [*Goodland and Irwin*, 1975; *Schmink and Wood*, 1992]. Thus, it is not surprising that new official road projects in the region have been substantially criticized concerning their prospective impact [see, e.g., *Laurance et al.*, 2001], including specific debate about road paving [*Nepstad et al.*, 2002].

In terms of their total impacts, it has been noted that official roads form sparse networks [*Arima et al.*, 2005]. They are few in number and run in parallel hundreds of kilometers apart with few intersections (though the intersections and the effectiveness of the network would increase under current new road plans). At least with the current network, that could leave large blocks of forest intact. However, as was stated above, road investments and access tend to lead to follow-on investments including other new roads. Thus, indirect impacts of official roads accessing pristine areas may be considerable.

In particular, official roads may stimulate construction of unofficial roads. "Secondary" or "settlement" or "logging" roads, depending on who constructs them, are created by nonstate actors such as loggers and colonists. They are local in extent and often do not appear on official maps. The main purpose for building them is to access natural resources. This can be simply for local livelihoods, though complexities and conflicts may arise, and we discuss governance below.

Unofficial roads are thus specifically for resource exploitation and underlie economies of natural-resource-based communities in frontier areas. Indeed, another term for unofficial roads is "endogenous roads" as their location directly follows from local opportunities for greater output. They may even be directly funded by profitable local extraction and end when profitability does.

Many official road projects involve upgrading rather than new construction (e.g., the well-known Avança Brasil project includes significant paving over of unpaved roads). Unofficial roads, in contrast, are now being rapidly constructed. Interpretation of satellite images allows maps of such roads [*Brandão and Souza*, 2006]. Analysis of central-western Pará, a frontier area, reveals rapid expansion. From 1990 to 2001, unofficial roads grew from 5042 to 20,769 km. During that time, the extent of official roads was fixed. By 2001, unofficial roads comprised over 80% of the total road network in the area. Such mapping elsewhere across Brazilian Amazonia also reveals extensive unofficial road networks [*Lentini et al.*, 2005, pp. 78–79].

4.2. Logging and Unofficial Roads

Perhaps the key actor in unofficial road building in Amazonia is the logging firm [*Grogan et al.*, 2002; *Arima et al.*, 2005, 2008]. Loggers build roads to reach high-value timber, raising profits by minimizing distances, while avoiding steep hillsides and rivers, which require expensive bridges. Thus, loggers build roads through landscapes along topographic contours [see *Arima et al.*, 2005].

Loggers build roads of varying quality. Roads to large areas for multiyear exploitation are often high quality for reliable passage, whereas short-term-access roads are of low quality. There are temporal cost trade-offs here: more expense in road building can lower maintenance. This has important ramifications. Dense logging road networks tend to be temporary, abandoned when profitable timber is exhausted, while roads to larger timber stands remain for many years.

A related investment by those loggers with scale in mind is in larger trucks [*Stone*, 1998]. So-called "Romeo and Juliets," i.e., double-trailer large trucks, are often early adoptions by loggers regardless of logging quality. Government investments affect such decisions [*Bauch et al.*, 2007]. Paving investments that lower transports costs permit logging to expand further into the forest. Government's role may even affect who makes decisions. *Lima and Merry* [2003] and *Bauch et al.* [2007] note a trend to subcontract transport, possibly to avoid bureaucracy for movement of logs.

Exhaustion of the timber near markets impels road extensions. Profits from initial timber extraction help to fund these extensions. Thus, to the extent they yield profitable timber extraction, unofficial roads will be built [*Perz et al.*, 2007a, 2007b]. The result is an extensive logging road network in many areas, up to 200 km from urban centers. In terms of impact, even if logging is selective, the areas with such networks exhibit extensive forest degradation [*Nepstad et al.*, 1999].

4.3. Colonization and Unofficial Roads

Frontier colonization areas also exhibit unofficial road building, though following a logic somewhat different from that of the loggers. Along such official roads as the Transamazon and BR-364, the state built feeder roads, which perpendicularly intersected the highway every 5 km, forming the "fishbone" architecture. The feeders ran up to 10 km in both directions from the primary roads but then in-migration led to demand for land beyond this. Thus, colonists began to unofficially extend the feeder roads [*Walker*, 2003]. Their focus was land tenure and rights to provide a basis for family livelihoods.

To facilitate state recognition of the land claims, colonists chose routes following the state design for the official road network. This worked, and it also motivated additional road extension [*Walker*, 2003]. Recently, the state has sought to recognize new colonization areas as a way of prohibiting further road building that would enter protected areas. However, such official road recognition has only further motivated road extensions and additional informal colonization [*Perz et al.*, 2005, 2007a].

This strategy's success has relied on colonists' ability to form political pressure groups. State decentralization in Brazil during the 1990s made municipal governments more important for many functions including road maintenance. Consequently, promises of road maintenance arose in political campaigns in many parts of Amazonia, with votes-for-roads deals being cut. While the political ecology literature emphasizes inequalities, contestation, and conflict over natural resources [e.g., *Schmink and Wood*, 1992; *Hall*, 1989], some cases of unofficial roads illustrate the potential for cooperation and negotiation in building roads for access to resources.

4.4. Colonist-Logger-Indigenous Interactions

Cooperative political ecology is also evident in relations between colonists and loggers with respect to road building. A challenge for logging road building in Brazil is that land claims must be for permanent productive land use, while loggers often extract timber and move on. The presence of colonists offers a solution. Colonists with established land claims but poor roads can make deals with loggers to sell timber on their lots to loggers in return for road building and/or maintenance. Migrants seeking to acquire land make such deals for unofficial roads that reach unclaimed land. Colonists gain road access or maintenance, while loggers receive legal cover.

Yet unofficial roads can also generate social tensions and reveal conflicts, such as over the route for a new road. For instance, while loggers seek to minimize costs and avoid rivers, colonists seek roads alongside the front of their lots, usually in straight lines. Loggers seeking to build roads through a lot held by a colonist in order to reach timber in a more remote area may thus face difficult negotiations [*Perz et al.*, 2007a]. The extension of unofficial roads also sometimes breaches indigenous reserves and state forests, creating conflicts over land tenure. Demarcation of the Cachoeira Seca do Irirí indigenous territory to the south of the Transamazon Highway is controversial because unofficial roads built by loggers into the indigenous territory have allowed colonists to informally settle there [see *Perz et al.*, 2005, 2007a].

5. SPECIFIC ROAD CASES

5.1. Transport and Land Use in Acre

5.1.1. Projeto de Colonização Humaitá. This project was established in 1981 in Porto Acre in the state of Acre on

60,334 ha, which straddle the Rio Acre. The state capital of Rio Branco is accessible along 35 km of paved road (AC-010). Unlike most government-sponsored colonization projects in Amazonia, which were on public lands, Humaitá was a re-distributive land reform project on private land. Owners of the rubber farms were willing to sell off some land, in part due to the decline of the rubber economy.

Its design is a radial road network around a central village, and originally, it was divided in 951 lots (ZEE 2000:38), all implemented by the INCRA. The radial design provides a good connection between the secondary roads and the main paved road to Rio Branco, but like "fishbones," the design did not take account of the watershed drainage system.

The land use strategies of agriculture and mixed husbandry depend on all-weather roads in the Humaitá region. Most agricultural products are taken to market during the rainy season, when the condition of unpaved roads is often poor. Mixed husbandry is composed mainly of dairy products and fish. Several farmers reported changing land use strategy after losing their crops or milk production because of poor access to urban centers and markets. Both types of outputs are also dependent on access to electricity, which is likely to be correlated with road network conditions. Lack of market access is probably the biggest factor keeping families in "subsistence farming," in keeping with von Thünen's link between income per area and urban proximity [*Dunn*, 1970; *Walker et al.*, 2009].

Paving of BR-317 will eventually link Acre to the Pacific Ocean as part of *Avança Brasil*, to facilitate shipping of central Brazil's agricultural production to international markets (Asia in particular) and to enhance Amazonian economic development [*Nepstad et al.*, 1999]. This connection is expected to boost the economy and to change land cover along BR-317 [*Brown et al.*, 2002].

5.1.2. Road impacts. Transportation costs are highly significant in explaining the land use choices of farmers in Humaitá settlement. At greater distances and transport costs, one finds more subsistence and extractivism; with lesser transport costs, more land is in agriculture and in mixed husbandry. A multinomial logistic regression for 63 farmers shows a significant effect on land use strategies.

Roads also matter for lot turnover and land consolidation. During the early stages of the frontier's development, settlers who lack infrastructure are isolated from markets and services. They may abandon their lots or may sell them at low prices to investors. During more advanced stages of frontier development, with infrastructure and land markets, farmers face an incentive to sell, as rising land demand raises the price of land. An examination of transport costs (in time) and total land area (a proxy for lot consolidation) finds a highly significant positive link. Thus, more land consolidation appears to have occurred further from urban centers [*Ludewigs*, 2006].

As the settlement's life continued, difficulties in access to urban centers in remote areas of Humaitá led to a number of farmers being willing to sell their lots at lower prices than would be obtained in more accessible areas. Note that returns to investments in land purchases in these areas have been favorable with cattle ranching or land speculation, providing a shelter against inflation. Land investors favored contiguous lots that could be consolidated into larger properties, which facilitate cattle ranching. Yet lots served by better quality roads and closer to urban centers had sufficiently higher profits in agriculture that colonist farmers were willing to move to Humaitá.

5.1.3. Road demand and supply. What socioeconomic and environmental conditions reinforce the importance of roads? The agricultural calendar, based on the seasonal rainfall cycle through the year, leads the harvest time of most agricultural crops to fall during the rainy season. This is also the time of the year when road quality is worst, given the negative impact of rainfall on the maintenance of road conditions.

Thus, road maintenance is important [*Nelson*, 1973]. It has been shown that the frequency of heavy traffic plus factors such as soil type, relief, and the geography of the drainage system all influence the road conditions that maintenance needs to address. However, the allocation of road maintenance expenditure is linked not only to the condition of roads but most importantly to the political influence of farmers and rural producer associations. Land investors connected to the government can attract maintenance. Well-organized producer associations can, too. This is a clear case in which the potential for output can affect road investments, which can then confound impact estimates; at the least, evidence from the places that have more roads may not apply to where there are few.

Participation of both public and private stakeholders in various land programs may help improve road construction and maintenance. Promising examples of public-private partnerships in roads have been reported for the Santarém region (*Nepstad et al.* [2004] and *Lima et al.* [2006] note that a single logging company can create and maintain over 700 km of agricultural access roads in INCRA settlements). These may more effectively attend to farmers' demands for better road infrastructure and land titling. They also have increased the legal commercialization of timber. An increased efficiency of resource use raises the chance that settlers will remain in their lots.

5.2. Roads and Transamazon Smallholders

Merry et al. [2006] show that for smallholder settlements on the Transamazon Highway, the greater the distance to a city, the lower the settlers' land value (following the observation of *Walker et al.* [2002] that high-value systems tend to be found closer to the Transamazon Highway than low-value, or subsistence, systems). For each additional kilometer from the city, per hectare values decline by R$2.19 (or approximately $1.00). This result is roughly consistent over three settlement regimes studied-purchased, formally settled by INCRA, and informally settled. These results support the contention that distance plays an important role in land values.

In the difficult conditions along the Transamazon Highway, one might well expect that the quality of the road is paramount for the outcomes generated. Poor roads could soon disappear or become impassable in the wet season. The portion of the road that is "improved," i.e., covered with gravel, varies considerably in this area, and thus, such a hypothesis can be tested. *Merry et al.* [2006] find in fact that the quality of the road, in terms of just dirt versus with gravel, does not significantly affect land values. Such "all-weather dirt highways," with gravel, currently comprise only 22% of total average distance, perhaps too little to affect land values in these settlements.

Merry et al. [2006] also consider the relationship of these settlement regimes to the roads. For instance, on average, individuals attain lots 3 years after the road was built. However, *Merry et al.* break this down by regime to reveal significant differences. Formal settlers arrived almost simultaneously with the roads. Informal settlers arrived on average 2.3 years later, while those who purchased their lots did so on average 4.8 years after the establishment of the road. These clear differences convey the typical trend in this area of initial roads with the formal settlement, then informal settlement alongside informal road extension, be that by the settlers or by loggers, and then a formalization of the land market as more formal buyers of the land entered the area.

5.3. Roads, Population Mobility, and Deforestation in Northern Ecuadorian Amazonia

5.3.1. Oil exploitation and initial settlement. Northern Ecuadorian Amazonia (NEA) is a sparsely populated tropical lowland rainforest and an area of extraordinary biodiversity [*Myers et al.*, 2000; *Bilsborrow et al.*, 2004]. Altitude varies from the Andean foothills to about 200 m above sea level at the eastern border with Peru. Soil is more fertile than in most lower Amazonian areas of Peru or Brazil, with pockets of volcanic (black) soils, though quality is highly variable, and there is much poor red soil. Unlike Brazilian Amazonia, NEA has a year-round growing season with rain occurring in all 12 months. This leads to slash-and-mulch clearing (leaving cut trees to decompose) with little burning. Also in this area, unlike Brazilian Amazonia, large-scale commercial agriculture, ranching, and logging have never played major roles, with most forest cleaning occurring at the hands of small farmers [see also *Brondizio et al*., this volume].

Initial colonization, starting in the 1960s and through the 1980s, is closely linked with the discovery and exploitation of oil in Sucumbios province, near what would become Lago Agrio (Nueva Loja). Oil has become the most important source of export earnings in the country. Since the 1960s, oil companies have constructed roads into the forested lowlands in order to lay pipelines and to connect wells to the network, which pipes oil over the Andes to Esmeraldas for export.

A major consequence of oil exploitation was the establishment of a network of roads by the oil companies. This greatly facilitated settlement. Previous research in Ecuador [*Rudel*, 1983; *Southgate et al.*, 1991] and elsewhere (e.g., *Almeida* [1992] on Brazil, *Heckandon* [1983] on Panama, *Kaimowitz* [1997] on Bolivia) has found road access to be a dominant factor in land clearing. The road infrastructure in NEA was improved as a result of some expansion and some paving of primary roads, as well as the construction or expansion of secondary roads.

In thinking about the impacts of roads on forests, we note that *Bilsborrow et al.* [2004] and *Barbieri et al.* [2006] show that in contrast to Brazil, Indonesia, and other countries, NEA settlement was spontaneous, not government-sponsored. Migrants settled along oil roads, with successive arrivals claiming land plots behind the farms along the roads. Most came from the Sierra region of rural poverty, extremely concentrated landholdings, and "minifundia," which acted as a strong population push (versus any pull from abundant, cheap land in the NEA). The colonists were poor and arrived without capital to invest in their plots. Thus, oil roads opened vast forest areas to settlers, facilitating deforestation in NEA. Forest cover in the study area fell, from essentially 100% in 1970 to 59% in 1990 and 45% in 1999 [*Bilsborrow et al.*, 2004]. Some deforestation was due to the creation of farm subdivisions during the 1990s along roads. But road expansion also occurred. In 1999, 51% of households reported some road construction or improvement near their houses since 1990.

5.3.2. Second-generation colonists and urbanization. The 1990s brought a second important wave of deforestation linked to an out-migration, mostly of sons and daughters, from pioneer migrant settler households to other rural areas of Ecuadorian Amazonia [*Barbieri*, 2006; *Barbieri et al.*, 2006]. A 1999 field survey found many new land subdivisions associated with pioneer colonists' children demanding land upon reaching adult age. They occupied and cleared intact forest in the plot or moved away to another forest area in Amazonia or to the incipient urban areas in NEA. Overall, population mobility and redistribution are now dominant demographic factors in regions such as NEA, as fertility and mortality have fallen considerably, as has natural population growth [*Barbieri*, 2006].

Given this demographic dynamic, the relatively extensive road network was a key factor in deforestation, facilitating migration to other rural areas though also to urban areas [*Barbieri*, 2006]. For instance, the 1999 survey found that subdivisions arose along roads and near towns, given the importance of labor mobility. Note that even the urban migration could be part of an ongoing process of agricultural production causing deforestation, if families diversify income to address multiple sources of risk and thus keep farming [see, e.g., *Barbieri*, 2006; *Barbieri et al.*, 2006; *Barbieri and Carr*, 2005; *Barbieri et al.*, 2005].

In keeping with the subdivisions developing close to the roads, *Barbieri* [2006] shows that longer walking distance from the household to the nearest road decreases the odds of rural-urban migration and of local off-farm employment, for both the old and the newer cohorts of colonists. These local transport costs appear to significantly hinder interactions between various locations.

These deforestation pressures continue to the present. High fertility, new immigrants, the expectation of further expansion of the oil industry (with recent discoveries of large new deposits and the beginning of construction of a second trans-Andean oil pipeline) and consequently the expansion of road networks all point to increasing pressures on forest in NEA. *Mena et al.* [2006] find that the Cuyabeno Wildlife Reserve, one of the most important protected areas in Ecuador, and within NEA, is threatened following the permission to exploit oil given to the Brazilian oil company Petrobras. Existing and planned roads to the Cuyabeno Reserve have recently become a major facilitator of settler colonization in the areas within or nearby the reserve.

6. BROADER SOCIOECONOMIC CONTEXTS

6.1. Local Road and Development Benefits

To this point, our almost exclusive focus has been the impacts of new roads upon deforestation. Yet one must suspect that there is a reason why people put in all the effort it takes to build roads other than the widespread clearing of forest, which per se is rarely, if ever, mentioned as the goal (though land titling policies rewarding land "improvement" came close to such a direct incentive). Speaking plainly, while certainly the motivations for roads have differed across space and time, it is likely that some actors associated a new road's construction with some form of local and regional benefits.

For instance, the notion that a road's socioeconomic impacts can be positive holds at the level of the household and of the village. Both official and unofficial roads can provide access to natural resources, facilitate market access for rural producers plus the integration of economic sectors, and reduce costs of spatial mobility for people, capital, and also information [*Owen*, 1987; *Vance*, 1986]. Thus, roads clearly can be central to economic development and to social well-being.

Unofficial roads are instrumental in local economies. Logging firms provide work for many from frontier communities. Large sawmills employ up to 300 employees per firm. The sector also indirectly generates employment in tractor repairs, trucking of sawn wood, and sales of wood products. Beyond jobs, roads built by loggers improve the access of rural populations to local markets, where they can sell produce, and to urban services such as education and health care. Rural communities thus view logging roads as crucial for improving quality of life [*Perz et al.*, 2005].

That said, the socioeconomic impacts are not all rosy. Changes in access may well yield social conflicts over land and other natural resources, as well as debate concerning their impacts on preexisting livelihood strategies, including, for instance, those based on threatened resources [*Brown et al.*, 2002; *Reid and Bowles*, 1997; *Schmink and Wood*, 1992]. These outcomes are certainly not caused exclusively by roads per se. However, at least we can say that the development outcomes in new frontiers have both highs and lows, not only over time but also in terms of distribution across groups.

Returning to a broad view across space for such empirical evidence, consider *Andersen et al.'s* [2002] analysis of census data for Amazonia at county level. In short, they find that over decades, the gains from agricultural production and ranching in Amazonia have risen. Their results suggest both learning-by-doing by individual farmers and that an important factor was the adaptation of cultivars and the technologies provided by EMBRAPA's agricultural research Q7
(*Cattaneo* [2001, 2005] also supports the importance of such innovations in agriculture).

Andersen et al. [2002] estimate the value of cleared land in Amazonia using three methods: observed land prices, site studies of agriculture in both Pará [*Almeida and Uhl*, 1995] and Acre [*Vosti et al.*, 2001], and simulations from their own county-level deforestation regression modeling that relies upon the census data on past land usage. One useful perspective on all such estimates, they add, is that in a region with abundant land and varying scarcity of labor and capital, one might expect the per-hectare returns to vary widely and might also expect that overtime labor and capital would become less scarce, while land would become scarcer.

Vosti et al. [2001] found that typical traditional-technology farms in Acre yield a discounted net present value of \$400 ha^{-1} (using a discount rate of 9%). That could be doubled with more intensive technologies, but many cannot afford the required outlays for labor and capital. *Almeida and Uhl* [1995] find that in Pará, the net present value of land with sustainably grown perennial crops is about \$5000 ha^{-1} (though they are using a discount rate of 6%).

The simulations based on county census data by *Andersen et al.* [2002], of course, also vary with the discount rate chosen. Q8 Adding the rural and urban changes in gross domestic product (GDP) associated with the new roads constructed during the period 1970–1995, and using a 2% rate of discount, they find a per-hectare net present value of cleared land to be \$5676 (similar to Almeida and Uhl, though they note that there are questions about how best to add the rural and urban outcomes). They also note that urban gains are relatively constant, while rural benefits increased over time.

Tying into the issue of context, *Andersen et al.* [2002] note that the gains in GDP from paved roads are higher when there is prior economic activity. Recalling from above that the clearing impacts of new roads in very highly cleared areas may be lower (perhaps especially when adding up the impacts that are likely to unfold over time with all responses to the roads, including new roads), these results for GDP impact may well suggest that the ratio of the GDP gain to the loss of forest could be maximized with a form of spatial zoning in which new roads intensify the development that has already been occurring instead of opening up relatively pristine areas for deforestation.

6.2. Nonlocal Influences on Transport Investments and Their Impacts

Almost all of the above concerned actions and consequences in Amazonia itself. Even more spatially specific, it concerned the local conditions in which a road investment occurs, and the resulting local impacts upon forest as well as employment and output. The exception, which was nonlocal, although still within the basin, was spatial deforestation spillovers to neighboring areas.

Yet spatial interaction can go in both directions. Much as a road in one locality can affect forest in other areas, socioeconomic shifts in other, nonlocal areas can affect the forest in places where local road investments occurred. They can affect the total amount of forest, taking prior road investments as fixed, and can affect the impacts of the road investments upon the forest.

Other countries provide examples of such interactions across space and time [*Pfaff*, 2000]. In the New England region of the northeast of the United States of America, as population spread and agricultural production increased, forests steadily vanished until the mid-1800s. Then, railroads linked the region to the Midwest, where the flatter and high quality agricultural land put steady downward pressure on New England agriculture returns. Local agricultural prices then fell. This external influence dominated forest outcomes in the region. Despite increasing population and output, New England forest increased.

That might not be surprising had no roads been built in New England. However, that was the case despite roads being built. While all else equal new roads can increase agricultural profits and push a few more parcels over the threshold to deforestation, a major downward shock to those profits implies that one could build many roads, and previously cleared land still would reforest. Thus, the direction of trade is critical. *Pfaff and Walker* [2009] apply this thinking to Amazonia.

Turning back to Amazonia, then, analogous to Midwest soil quality are externally determined prices in Amazonia: the Brazilian real's exchange rate and the prices of beef and soybeans. Also, as noted above, an analog to the introduction of rail in the United States of America that increased forest in the northeast is the introduction of agricultural innovation in Brazil that facilitated production and thus decreased Amazonian forest. Such factors can be dominant.

Cattaneo [2001] considers such innovation (which is the focus of his 2005 work cited above) as well as the exchange rate. His computable general equilibrium modeling suggested that a 40% devaluation of the "real" in real terms, at that time, in the long run would have led to a decrease of 12% in deforestation. More generally, changes in relative prices of imports and exports matter.

Whatever the level of the exchange rate, another important price is that of soy. Though Brazil is a large producer, for any level of Brazilian soy supply, many global factors such as the consumption of soy in China will significantly influence that price (for relevant discussion see, for instance, *Nepstad et al.* [2006] whose Figure 1 conveys temporal trends for the whole of Amazonia as well as M. del Vera Diaz et al. (An interdisciplinary model of soybean yield in the Amazon Basin, manuscript in preparation, 2007) whose Figure 1 locates soy centers). This key factor in the incentive to produce can affect not only deforestation given the transport infrastructure but also the plans to develop further infrastructure, such as for getting soy to travel through Belém headed eastward (*Fearnside* [2001] and *Nepstad et al.* [2002], for instance, provide further discussion of transport plans).

The importance of such influences makes predicting forest clearing rates a challenge. Even with perfect knowledge of local conditions, and further even with perfect control over local transport infrastructure and other policies, to perfectly predict both levels of deforestation and the impacts of new roads, one needs to consider the effects of such external influences.

7. BROADER ECOSYSTEMIC CONTEXTS

So far, we have examined all of the following: the local conditions, both biophysical and socioeconomic with a focus on roads, which affect local land uses and deforestation; the spillovers from those local roads to deforestation in nonlocal (e.g., neighboring) areas; and the effects of nonlocal socioeconomic changes on local forest outcomes.

That leaves out the impacts of nonlocal biophysical changes. Without question, shifts in hydrological and climate systems elsewhere in Amazonia and outside can bring shifts in hydrology, climate in any given Amazonian location [see *Silva Dias et al*., this volume; *Marengo et al*., this volume]. This spatial interaction can go in both directions, i.e., many Amazonian changes matter elsewhere too.

Stepping back, first, we should state explicitly that, in general, biophysical context strongly influences land use and deforestation. While this was not emphasized above, within the analyses of deforestation at all scales cited above, biophysical factors such as slope, rainfall total and distribution, and soil quality have repeatedly been shown to matter empirically, K. Anderson et al. (The effects of climate change on profitability and land use in Brazilian agriculture: A municipal cross-section analysis, Presentation at the XV Congresso Brasileiro de Agrometeorologia, 2007.) for some very recent work focused on climate impact, and see *Chomitz and Thomas* [2003] for evidence of such constraints.

Given such effects, and given further that deforestation can affect ecosystem function, the potential for iterative feedback between land use choices and ecosystem adaptations exists. That allows, in principle, for multiple equilibria in land use and ecosystem function. While such models are not yet well developed, an example of one piece is the exploration of land clearing's impact on the climate by *Moore et al.* [2007]. When such connections are empirically established, alongside further work on land use impacts of particular elements such as rainfall distributions, perhaps integrated modeling of land use and ecosystems could enhance predictions of impacts.

Finally, we must mention spatial pattern. To this point, we have focused explicitly only on the total amount of deforestation and the temporal pattern of clearing. Once some clearing and development have occurred, we suggested, the new road impacts on both deforestation and socioeconomic gains may be quite considerably altered.

Spatial pattern matters too (see, for instance, the works of *Laurance and Bierregaard* [1997] and *Bierregaard et al.* [2001]). For a given level of total forest loss, the general assertion is that when there are smaller, more irregular, and more isolated forest fragments remaining, then ecological function has been further impaired [*Laurance and Bierregaard*, 1997; *Bierregaard et al.*, 2001; *Laurance et al.*, 2002]. Such impairment is said to potentially generate not only biodiversity loss but also a biomass collapse and carbon emissions that would contribute significantly to climate change [*Gash et al.*, 1996].

Forest fragmentation links not only to such broad ecosystem changes but also to more local spatial interactions through fire. Degradation via fragmentation can raise ground surface temperatures and reduce precipitation, thereby elevating the risks of drought. Along with the increased litter fall from dying trees, this raises the likelihood of fires, which further increase forest vulnerability by modifying vegetation structure [*Cochrane et al.*, 1999; *Nepstad et al.*, 2001; see also *Meir et al*., this volume]. As do results above, these ecological points suggest careful attention to spatial targeting of new road location.

8. CONCLUDING REMARKS

8.1. Road Context and Road Impact

Our greatest emphasis has been on context. The impacts of new roads on forest loss and social gains depend on the conditions into which roads are placed. Conditions that matter include the various biophysical factors that affect land use, such as slope, rainfall, and soil quality. They also include external socioeconomic factors like national policies, exchange rates, and the price of soybeans.

Further, we emphasized, in particular, that those influential conditions include prior roads and deforestation. Where development has already come with investments and access for people, new roads may decrease forest less and raise production more than when entering pristine areas. Belief in such differences suggests careful consideration of where to invest further in transport.

There are limits to the precision of temporal predictions of new road impacts based on the past. Yet even relatively rough robust differences in the impacts of new roads across space could matter for planning over time. Additional first-order rationales derived from ecosystem science, such as about impacts of spatially fragmenting any given amount of forest, also seem relevant for road policy. Socioeconomic and ecological evidence both may support, for instance, leaving the standing forest in large tracts.

As to how to do that, certainly one step could be targeting investments along routes that are already established. Paving unpaved roads that have already generated clearing could, it seems, generate additional contributions to welfare with relatively lower marginal increases in deforestation. Yet we have seen that road investments may be followed by other investments including further new roads. Thus, steps to limit sprouting or spreading development could have value in addressing trade-offs between development and conservation goals. It has been suggested, for instance, that placing protected areas alongside roads (in a "road park") might limit road impacts. While little evidence exists to comment on this possibility, C. Delgado et al. (Might protected areas constrain road deforestation impacts? Chico Mendes Extractive Reserve and the Inter-Oceanic Highway, paper presented at Amazon in Perspective Conference, Inst. Nac. de Pesqui. da Amazônia, Manaus, Brazil, 2008.) analyze the Chico Mendes Extractive Reserve and find that, while it has been cleared more than other reserves in Acre, it is actually blocking considerable clearing given its location near the Interoceanic Highway.

8.2. Frontier Governance and Relative Impacts

The issue of predicted impacts has been raised in several useful illustrations of scenarios concerning future rates of deforestation in Amazonia [see, for instance, *Laurance et al.*, 2001; *Soares-Filho et al.*, 2006 and *Walker et al.*, 2007). Taken as a whole, the Amazonian forest scenarios appear to suggest that some form of enhancement of reserves or zoning or governance could have much larger impacts in, e.g., lowering forest loss, than would potential changes due to altering the planning of new roads.

This raises a few questions, including how best to count road impacts for spatial transport planning. When a new road penetrates a pristine area, as noted, there will be immense pressure for federal, state, and local complementary investments to improve local quality of life over time and space. Thus, however one delineates the marginal impact of each investment (which could be complicated), the long-run effect of the new road accessing a pristine area is greater, by far, than the initial years' local forest losses.

It also raises the question of what frontier governance is feasible. Modeling that generates glowing potential impacts of governance assumes, whatever level of prevention of deforestation is desired, can be attained and, implicitly, at reasonable cost. That may be the case for Costa Rica, but it may not be for the gigantic frontier of Amazonia. *Chomitz* [2006] emphasizes varied governance challenges.

Blending governance and roads, our discussions concerning the pressures driving unofficial roads highlight critical issues. On the one hand, these roads are crucial to livelihoods and communities' development in frontier areas. On the other, unofficial roads generate ecological losses as well as some social problems and, if local resource extraction is unsustainable, may only delay inevitable declines in frontier communities.

This means that for an optimal path, unofficial roads require effective governance. Environmental governance generally has received considerable attention in recent years, emphasizing state- and community-based models [*Perz et al.*, 2007b]. State-based models emphasize parks, tax breaks and incentives for sustainable resource use, and punishment of violators. They have had only mixed effectiveness within Amazonia, however, due to the large areas to be monitored and limited enforcement capacities.

For unofficial roads, the lack of state presence in Amazonia has produced a generation of local players used to relative autonomy and resistant to state-imposed regulations. This led to discussion of community-based approaches to environmental governance. They highlight the fact that people in Amazonia have managed natural resource for generations and are increasingly demonstrating an ability to mobilize and form local organizations. Yet community governance is hampered by local inequalities and the potential for capture by powerful families, as well as by a limited capacity to respond to external threats or large-scale processes [*Perz et al.*, 2007b].

Hybrid governance models might combine state capacity and oversight with community-based participation and responsiveness to local exigencies. The Instituto de Pesquisa Ambiental da Amazônia has sought to work with communities along BR-163 to engage in zoning along the corridor [*Nepstad et al.*, 2002]. Stakeholder workshops have sought to link data on past land use and projections of future scenarios to planning [*Alencar et al.*, 2004]. Another example is the "MAP Initiative" in southwestern Amazonia where Q9 the Interoceanic Highway is being paved [*Iniciativa MAP*, 2007; *Brown et al.*, 2002]. This trinational effort has focused on cross-border exchanges among stakeholders on roads, climate, and other prospective changes in the region. It has led to grassroots activities with some state support to plan for and to mitigate the impacts of paving official roads and expansions of unofficial roads. In thinking about future road impact, we must understand not only official spatial development plans and the broader contexts in which new road investments may occur but also the critical local contexts.

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