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Article

Trans-Boundary Infrastructure and Changes in Rural Livelihood Diversity in the Southwestern Amazon: Resilience and Inequality

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Abstract: Infrastructure has long been a priority in development policy, but there is debate over infrastructure impacts. Whereas economic studies show reductions in poverty, social research has documented growing income inequality. We suggest that a focus on livelihoods permits a bridge between the two literatures by highlighting decisions by households that may capture economic benefits but also yield social inequalities. We therefore take up two questions. First is whether new infrastructure allows households to diversify their livelihoods, where diversity begets resilience and thus affords livelihood sustainability. Second is whether households with more diverse livelihoods exhibit greater increases in livelihood diversity, which would widen livelihood inequalities. We take up the case of the Inter-Oceanic Highway, a trans-boundary infrastructure project in the southwestern Amazon.

Findings from a rural household survey for the first question show a strong effect of accessibility on increasing livelihood diversity in areas receiving infrastructure upgrades, an indication that infrastructure fosters household resilience. However, results regarding the second question indicate that households with more diversified livelihoods also exhibit larger increments in diversity, which implies growing livelihood inequality. There remains a need to account for inequalities in livelihood diversity, since less diversified households benefit less from new infrastructure and remain more exposed to risks to their livelihoods.

Keywords: infrastructure; livelihood; resilience; sustainability; Amazon; Bolivia; Brazil; Peru

1. Introduction

In the opening years of the 21st century, a hallmark of national development initiatives around the world is global economic integration [1,2]. In this context, trans-boundary infrastructure projects that span national frontiers have become a policy focus. Trans-boundary infrastructure seeks to complement other instruments of economic integration, such as trade agreements, by providing the on-the-ground facilities to permit cross-border commerce.

The focus on trans-boundary infrastructure has however reignited old debates over the wisdom of infrastructure projects in general. For present purposes we note the literatures on the economic and social impacts of infrastructure. Economic appraisals have highlighted the benefits of infrastructure, primarily in terms of economic growth and poverty reduction. Macroeconomic studies of infrastructure impacts have documented positive and significant findings regarding economic growth, especially for developing countries [3], including in Latin America [4] and the rural sector [5]. Complementing this work is a microeconomic literature on roads and poverty in developing countries. Numerous empirical studies have documented increased incomes and poverty reduction near roads, whether via analysis of sub-national administrative units [6,7], communities [8,9], or households [10,11].

That said, there is a distinct literature on the problematic social impacts of new infrastructure. The common focus of social critiques concerns differential benefits among distinct social groups, resulting in growing inequalities of incomes or wealth. Some studies have documented increased inequality as a result of persistent poverty among poorer groups in areas receiving infrastructure [12]. Conversely, social research has highlighted differential benefits to higher status social groups [13,14] and districts closer to new infrastructure [15,16], often as the result of a lack of broad participation in infrastructure planning [17]. There are also concerns that newcomers make legalistic claims to natural resources in order to discredit traditional claims by indigenous groups and other local peoples. This disrupts traditional livelihoods, as in frontier areas such as the Amazon [18,19].

Increasing inequalities raise doubts about the sustainability of the economic benefits of infrastructure in affected regions. However, it remains difficult to square up the positive results in economic literature on infrastructure impacts and the negative appraisals in the corresponding social literature. We therefore assert that a focus on livelihoods permits construction of a bridge between the two literatures by offering a means of understanding the processes behind the findings reported. A focus on livelihoods takes a step back from only looking at outcomes such as poverty or income inequality to consider choices and

mechanisms about activities that lead to such results. Livelihood systems of households involve manifold decisions in response to opportunities and constraints, such as those presented by infrastructure, markets and policies. Focusing on livelihood decisions, which become manifest in livelihood activities adopted, permits analysis of the means by which households may capture the benefits noted in economic literature but also exhibit the inequalities highlighted in the social literature. Hence, livelihoods may benefit from infrastructure, but to differing degrees among different households, which would be reflected in inequalities in livelihoods themselves.

1.1. Change in Livelihood Diversity and Household Resilience

Rural livelihood systems provide a useful focus for evaluating the benefits and problems stemming from infrastructure as they relate to questions of sustainability. Rural livelihoods can change over time as opportunities and constraints shift, including changes due to modifications in infrastructure. Incorporation of the time dimension via the focus on change unavoidably raises the question of livelihood sustainability, especially in periods of rapid change, such as during and after implementation of infrastructure projects. Further, rural livelihoods depend in part on natural resources, which relates livelihood decisions not only to economic considerations like markets and infrastructure, but also to environmental issues such as resource management as related to the maintenance of ecosystem services. Hence, analysis of livelihood change is not only relevant to questions of sustainability of livelihoods in themselves, but also to related issues of environmental sustainability.

A key characteristic of livelihoods in light of sustainability concerns diversity. Rural livelihood systems involve some combination of on- and off-farm activities to produce incomes [20,21]. Within each category are specific activities, such as agriculture and forest extractivism among the on-farm activities. Further, within a given activity are specific products, such as particular crops and animals that make up agriculture. The sum of on- and off-farm products and activities thus encompasses a livelihood system, where the number of products and their relative importance characterize the diversity of a household's livelihood.

More diverse livelihoods are associated with higher incomes as well as greater household capacity for risk management [20,21]. The classic example of how livelihood diversification raises household income is when rural households previously engaged in on-farm activities, such as agriculture, diversify by adding off-farm activities such as wage work. However, the key reason for diversifying livelihoods is to secure households against external risks over which they may have no control. Having more livelihood activities may require more labor effort and greater investments of land and capital, but diversification brings the benefit of buffering against the loss of income from certain activities if they become unprofitable or unviable.

In light of these considerations, diversity, whether in livelihoods or other types of systems, such as ecosystems, has frequently been invoked as a hallmark characteristic of system resilience [22,23]. Resilience refers to the capacity of a system to exhibit stability or persistence in the face of change, to adapt creatively to externally-induced shocks, or to exhibit self-organization. Research on resilience has highlighted the importance of diversity for flexibility in adaptation to change. Hence, whereas diversity is important for resilience, in turn, resilience constitutes a keystone for sustainability, since resilience highlights a suite of mechanisms that support system sustainability.

Geographers and other social scientists have defined "social resilience" as the capacity of social groups to respond to externally-induced shocks [24]. Vulnerability to external shocks is especially important for social resilience [25]. Notably, this is the case for integration initiatives such as new infrastructure, which can catalyze rapid changes due to incorporation of households into market networks that exhibit rapid price swings. Further, among natural resource-dependent households, there are ever-present risks of other shocks, such as those imposed by extreme climatic events like droughts and floods.

Applied to livelihood systems, resilience often refers to their diversity, a proxy for their sustainability insofar as the loss of one livelihood source can be buffered by others. The resilience literature highlights the value of redundancy and complementarity among system components, whether among species in ecosystems [22,23] or activities in livelihoods [24,25]. Social science research on resilience has therefore highlighted livelihood diversity as a means of accruing greater benefits to social groups as well as reducing vulnerability to external shocks [20,26–28]. Livelihood diversity thus begets resilience by providing more options for households to accumulate resources, manage uncertainty, and adapt to rapid change. As a result, households with more diverse livelihoods have greater alternative options for sustaining themselves, especially in the face of change and uncertainty.

Resilience is also a concept that highlights change dynamics, which makes it useful for interpreting livelihood changes. In the presence of external shocks, including those wrought by infrastructure change, it becomes very useful to evaluate changes in livelihood diversity. The key interpretive issue then is how to understand an increase or decrease in livelihood diversity in light of household resilience. In a resilience perspective, an increment in livelihood diversity is favorable since it suggests a broader array of livelihood sources and thus improved resilience and sustainability. In contrast, a decline in livelihood diversity would be more problematic since that would imply a reduction in livelihood options and thus greater household vulnerability.

1.2. Infrastructure Connectivity in Frameworks for the Analysis of Household Livelihood Diversity

Frameworks for understanding differences in livelihood systems often highlight both household characteristics as well as external factors. Ellis [20] underscores the importance of household asset endowments, such as land, labor, and capital as components of household capacities that afford livelihood diversification. Bebbington [29] differentiates among distinct capitals, including natural, cultural, institutional, financial, and social, to elaborate on the array of distinct household assets. The general expectation in such "household capability" models is that greater household assets, whether in land, labor or various capitals, permit households to take on more enterprises and thereby diversify their livelihoods and accrue benefits therefrom. At the same time, discussions of livelihoods also underscore the importance of external factors such as policies, markets, and climatic events [20]. Here we focus on the issue of regional integration via infrastructure.

Since we focus on household livelihoods, it is important to evaluate the impacts of infrastructure at the household level. We therefore invoke the concept of connectivity in order to assess infrastructure impacts on household livelihood diversity. The concept of connectivity stems from a long line of thought in economic geography, from foundational work by von Thünen, Christaller, and others. Connectivity is key in more recent literature on location theory [30,31] and transport geography [32,33]. We follow

elements of these lineages by appropriating connectivity as regards accessibility among specific locations in transportation networks [34]. In the present paper connectivity therefore refers to the degree to which rural households are linked to markets.

We focus on "access connectivity" as captured by travel times, which reflect distance from household to market, as well as infrastructure quality in terms of paving status and thus travel speed. Households that are more distant and/or use unpaved roads to reach markets are thus considered less connected in terms of accessibility because they have longer travel times. Conversely, rural households in places closer to markets and/or with paved roads exhibit greater accessibility via shorter travel times. Hence, during the course of improving infrastructure, connectivity is likely to improve via reduced travel times as part of process of regional integration. In turn, households with greater access connectivity can be considered more integrated into market networks.

1.3. Research Questions and Theoretical Expectations

We thus invoke the concepts of connectivity and resilience to frame an analysis of the effects of infrastructure on changes in rural livelihood diversity [27,28]. Whereas connectivity reflects market accessibility and thus regional integration, the concept of resilience provides an interpretive framework for understanding changes in livelihood diversity. With this framework, we ask two research questions about change in livelihood diversity. Figure 1 provides a visualization of the key relationships at hand, and highlights our two main research questions (RQs).

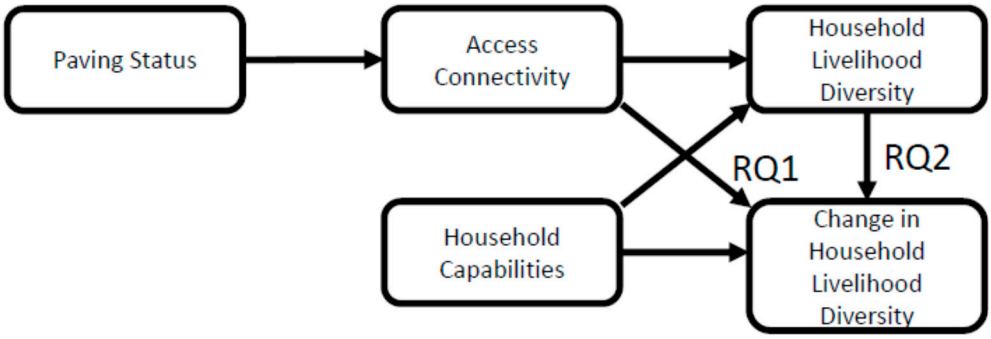

Figure 1. Conceptual framework with key relationships between connectivity, livelihood diversity, and change in diversity.

Our first research question (RQ1) concerns the effect of access connectivity on change in household livelihood diversity. Location theory from von Thünen forward makes clear that accessibility will affect transport costs and thus the profitability of productive activities. However, depending on the specific productive activities and the risk preferences of producers, improved accessibility could permit diversification (an increase in livelihood diversity) or specialization (a decrease). This is an important question, for the shifts in the profile of activities in livelihood systems reflect decisions by households as to their prospects to improve their well-being. Improved infrastructure may make heretofore unprofitable activities viable, permitting households to add or expand livelihood activities. Households seeking to reduce livelihood risks and improve their well-being will thus diversify their livelihoods [20,21].

That said, there is also good reason to believe that new infrastructure may instead foster livelihood specialization, particularly when said infrastructure crosses national boundaries and thereby permits integration of heretofore separated markets. Arguments for trans-boundary infrastructure programs highlight the complementarities in comparative advantages among countries, such that specialty products are particularly likely to find new markets in other countries [1,35]. On this account, local producers along trans-boundary highway corridors may find significant opportunities to expand production in selected activities, but not others. Hence, new or expanded activities become important at the expense of others, and livelihood diversity may decline as producers specialize.

In sum, the specific processes entrained by infrastructure improvements could result either in a rise or decline in household livelihood diversity, with ramifications for household resilience. In a resilience interpretive frame, improved connectivity could bring benefits via livelihood diversification or threats in the form of specialization. The implications in terms of sustainability thus also become evident: reduced livelihood diversity due to specialization in a few high-income activities might be economically beneficial in the short term, but this would also expose households to downstream livelihood risks should one or more such activities be threatened. Indeed, regional integration itself may threaten local livelihoods by exposing households to downstream shocks. Hence in a resilience perspective, it is favorable if improved connectivity leads to increases in livelihood diversity, which provides households with more options to sustain their livelihoods. A finding that connectivity fosters increased livelihood diversity would provide an explanation for positive impacts of infrastructure seen in the economic literature, at least for developing regions.

Our second research question (RQ2) concerns the relationship of pre-existing livelihood diversity to change therein. Households may respond to new infrastructure, but modifications in household livelihoods likely also depend on their extant livelihood diversity [20]. As was the case for the relationship of infrastructure to change in livelihoods, there are countervailing arguments about the relationship between extant diversity and subsequent changes in livelihoods. One argument is that the relationship is likely to be the inverse. If we consider the full range of possible livelihoods from very specialized to very diverse, households with little diversity would be likely to add or expand activities for the sake of increased income as well as risk management. By contrast, rural households with moderate livelihood diversity might be able to increment activities activity periodically, and those with highly diversified livelihoods would be hard-pressed to do so. The underlying assertion is that households with more diversified livelihoods are likely to be near the limit of what their asset portfolios permit. Hence, at low levels of livelihood diversity, we would anticipate an increase in diversity, but at higher levels, we would expect smaller gains, no change or perhaps even a decrease.

There is also the argument that households with more diversified livelihoods will be more able to increase their portfolio of activities. This is because such households not only have more assets and thus the wherewithal to be diversified in the first place, but also because their pre-existing diversity itself indicates their entrepreneurial ability. Thus, more diversified households would be the ones that can diversify yet further.

These two arguments are important for the debate among literatures on infrastructure impacts and interpretation in light of resilience and sustainability. The upshot of the first argument is to anticipate increased diversity among the least diversified households, with less change among more diversified households. The eventuality would therefore be a decline in the inequalities among households in terms

of their livelihood diversity, which would confirm the aggregate benefits purported in the economic literature and disconfirm the inequalities underscored in the social literature. This would also be very favorable in terms of resilience and sustainability, due to the increased overall diversity along with the decrease in inequality in livelihoods. Conversely, the second argument leads to very different implications. If the most diversified households are indeed also those which exhibit the biggest increments in livelihood diversity, then inequalities in livelihoods will widen. Per the earlier discussion, even if inequalities in livelihood diversity reflect specialization to capture larger present economic benefits, there remains the problem of exposure to risks and thus doubts about resilience and sustainability. Just as increased livelihood diversity is attractive in a resilience interpretive frame, so is reduced inequality via changes in livelihood diversity.

1.4. Study Case

To evaluate these questions, we take up the case of the Initiative for Integration of Regional Infrastructure in South America (IIRSA) [2,35]. IIRSA was constituted by a meeting of South American presidents in 2000. The goal of IIRSA is to improve trans-boundary infrastructure in South America in order to facilitate trade between neighboring countries. IIRSA constitutes a spatial strategy for cross-border commerce by targeting specific national frontiers for investment. IIRSA meetings have included multilateral development banks and led to agreements to fund numerous projects [2,35].

We focus on a key IIRSA project, the Inter-Oceanic Highway (IOH) [35]. The IOH was a priority under the first five-year phase of IIRSA. As the name suggests, the IOH ultimately links Atlantic ports in southern Brazil to Pacific ports in Peru [2]. Investment in the IOH under IIRSA centered on the "Peru-Brazil axis of integration" in the southwestern Amazon, where road paving was still necessary to provide infrastructure to support cross-border commerce [2].

In particular, attention has centered on the heart of the southwestern Amazon, the tri-national "MAP" frontier (Figure 1) where Madre de Dios, Peru meets Acre, Brazil and Pando, Bolivia [36,37]. It is in this tri-national frontier that IIRSA has focused for paving of the IOH. Paving was crucial to expand commerce because in the Amazon, transit on unpaved roads during the rainy season is virtually impossible. Paving the IOH in the southwestern Amazon thus not only reduced travel times, but also permitted year-round transit. Notably, the status of highway paving differs among the three sides of the MAP frontier. Whereas in Acre, the highway was paved by the end of 2002 by the Government of Brazil, in Madre de Dios, paving proceeded during 2006–2010 under IIRSA. By contrast, while the Government of Bolivia has announced intentions to pave highways in Pando, most roads there remain unpaved. Hence Pando serves as the "before paving" case, Madre de Dios as the "during paving" area, and Acre as the "after paving" case.

Along the IOH and other road corridors in the MAP frontier, there are a large number of rural communities and some local and regional market towns, shown in Figure 2. Livelihoods in rural households of the MAP frontier encompass a combination of forest extractivism (such as non-timber forest products (NTFPs)), crop cultivation (whether annual crops or perennial (tree) crops), and livestock husbandry. Off-farm income sources include wage labor, remittances, pensions, family businesses, and rents. Livelihood diversity varies among rural households across the MAP frontier, and access connectivity related to highway paving influences livelihood diversity [28]. Those findings beg the

research questions posed here, concerning connectivity and livelihood diversity as they both affect changes in livelihood diversity.

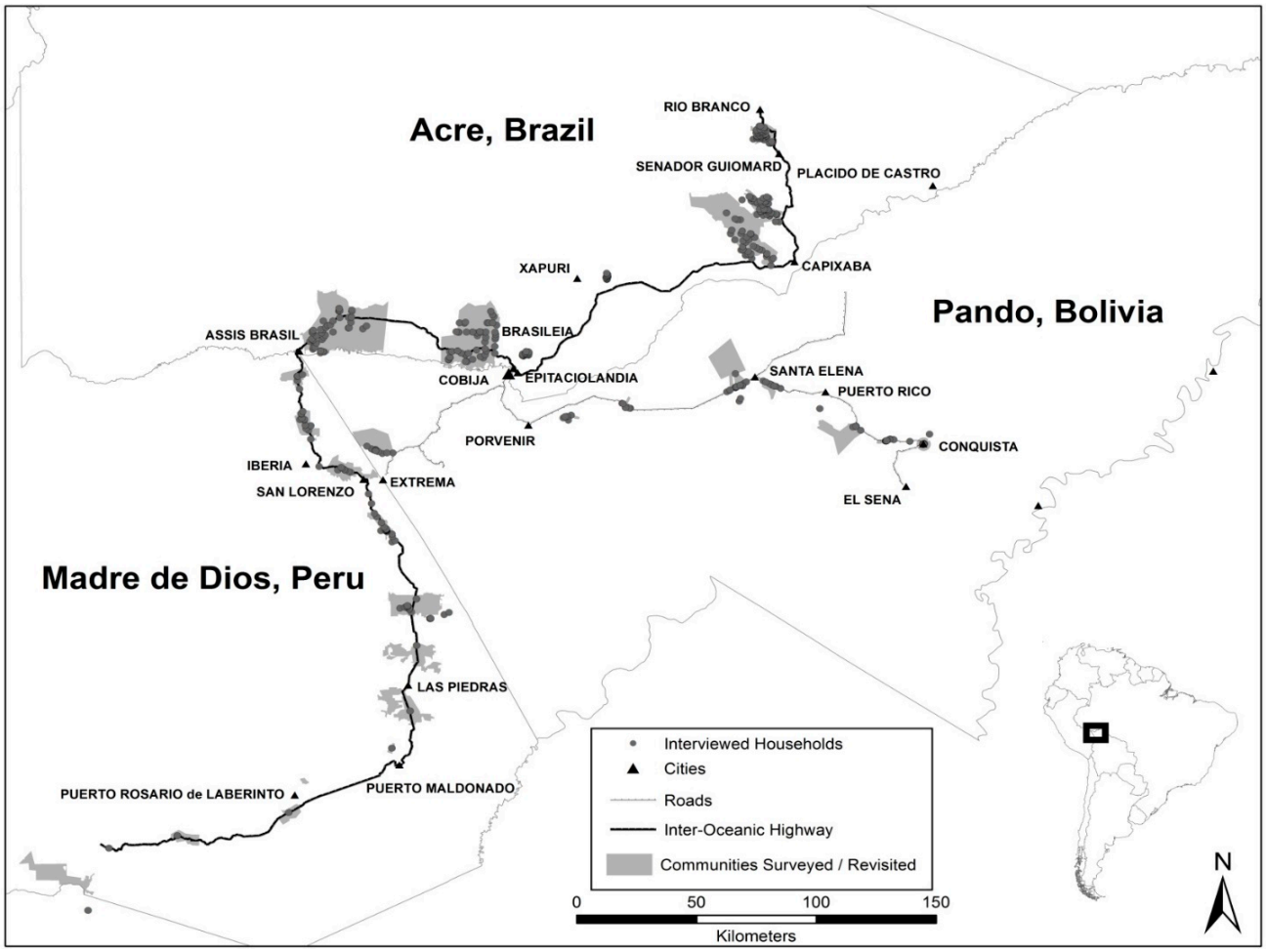

Figure 2. Map of the tri-national MAP frontier (Madre de Dios/Peru, Acre/Brazil, and Pando/Bolivia) with the Inter-Oceanic Highway, other key roads, and the locations of communities and households surveyed.

2. Methods and Materials

2.1. Design, Sampling and Questionnaires

We draw on information from a tri-national survey of rural households along highways in the MAP frontier. Faculty and students at the University of Florida (UF) coordinated the data collection effort via partnerships with counterparts at the Amazonian University of Pando (UAP) for fieldwork in Bolivia, the Federal University of Acre (UFAC) for fieldwork in Brazil, and the National Amazonian University of Madre de Dios (UNAMAD) for fieldwork in Peru.

The first phase of our data collection involved a survey of approximately 300 leaders from roughly 100 communities across the MAP frontier [27]. Specific definitions of rural communities vary across MAP because land tenure regimes vary among countries. In Pando, Bolivia, communities refer to communal land tenure units (*predios comunales*) consisting of nucleated settlements where member families use the surrounding lands. In Madre de Dios, Peru, communities are constituted by local

associations of member families with private individual land parcels. In Acre, Brazil, communities vary in definition, including agricultural settlement projects, agro-extractive projects, agroforestry poles, and extractive reserves. We sampled communities geographically, selecting communities at differing locations along the IOH and other highways in the region. Consequently, our sample included communities encompassing a broad range of characteristics in terms of their land tenure, population size, paving status, and livelihoods.

For the second phase of the data collection, we revisited a representative subset of communities in order to conduct household interviews. We selected roughly one in four communities for revisits based on their location and their paving status. In each community, we sought to pursue random sampling as feasible. In Madre de Dios and Pando, random sampling was viable insofar as lists of member families were available. In Acre, we worked from cadastral maps of individual properties and sampled properties systematically based on property numbers. In all cases, we worked from population estimates provided by community leaders in the first phase to establish sampling ratios such that smaller communities had larger ratios to ensure adequate representation.

In 2008, teams from UF and UAP visited eight communities in Pando and conducted 164 household interviews. Also that year, personnel from UF and UNAMAD visited 12 communities in Madre de Dios and conducted 312 household interviews. In 2009, UF and UFAC faculty and students visited seven distinct tenure areas in Acre (among agricultural settlement projects, agro-extractive projects, and agroforestry poles) and conducted 266 household interviews. Figure 1 shows the locations of the communities and households we interviewed in the MAP frontier.

We developed a questionnaire based on previous questionnaires applied in the study region. We sought to make the questionnaire as comparable as possible across the three sides of the frontier, while ensuring that each version of the instrument would be culturally appropriate in local argot and institutionally relevant given distinct land tenure regimes. The questionnaire was translated and/or reviewed by native speakers from the respective side of the MAP frontier prior to application.

The questionnaire included sections on household location (including GPS coordinates and information on roads traveled to reach markets), migration history, family labor, assets owned, social capital (via organizational memberships), capital inputs for productive activities, resource tenure (including private and communal land and rentals), health and well-being, and future plans. These sections provide data related to household capacities and market connectivity. In addition, the questionnaire featured items on agricultural activities (annual and perennial crops, livestock and related products such as milk), forest extractive activities (including NTFPs), and off-farm income sources (such as wage jobs, retirement pensions, and others). These sections permit measurement of livelihood diversity and change.

2.2. Measuring Change in Livelihood Diversity

Discussions relevant to the measurement of livelihood diversity come from various disciplines including ecology [38], economics [39], and sociology [40]. Conceptually, diversity encompasses two dimensions. "Structural diversity" refers to the number of categories present (*i.e.*, specific products of livelihood activities). A household livelihood system is more structurally diverse if a household pursues more different types of activities and produces more different products. By contrast, "distributive

diversity" refers to the relative distribution of units among the categories present (*i.e.*, the amount of each product generated from each activity). Hence, a household livelihood system is also more diverse if a household produces similar quantities of many products from numerous different activities.

We employ three complementary measures of diversity: the number of products (*S*), the 6th Gibbs-Poston index (*M6*), and the inverse of the Herfindhal concentration index (1-*H*). Discussions of the details for calculating these measures appear elsewhere [28,41]. *S* is a purely structural measure of diversity and is simply the sum of the number of products and activities in a household's livelihood system. *S* is useful because it is easy to interpret and serves as a benchmark for comparing with distributive measures of diversity. Gibbs and Poston's [40] *M6* captures both structural and distributive aspects of diversity: it increases as the number of products and activities grows, and also when units produced are more evenly distributed among those products and activities. That said, *M6* takes values other than integers, making interpretation somewhat less clear. The Herfindhal index *H* is itself an index of "concentration," the inverse of diversity, so by taking 1-*H* one obtains a measure of diversity. We chose 1-*H* because it is a distributive measure that is also sensitive to structural diversity, placing it between *S* and *M6* in terms of capturing structural and distributive aspects of diversity. Overall, *S*, *M6* and 1-*H* provide a suite of measures of varying sensitivity to structural and distributive diversity.

To measure livelihood diversity, we use reported production amounts for on-farm activities as well as binomial data for off-farm income sources. For the on-farm activities, one or more of the households sampled across the MAP frontier reported one or more of 11 annual crops, 18 perennial crops, five livestock products, and four types of extractive products. For all of these products, we created 0/1 binomial measures of whether a given household engaged in that activity. This permits measurement of structural diversity of on-farm activities. In addition, for all but two on-farm products, we collected reported amounts produced (in kg). Calculation of production values required conversions from various local measures of weight and involved extensive consultations with counterparts, community leaders and other key informants. Reported values constitute estimates of production, and are thus subject to errors. We mitigated such problems by using interviewers who often came from the communities visited, and were thus familiar with local production practices and units of measurement. Interviewers also asked respondents to figure production in more than one way, which permitted more accurate estimation. For crops and forest extractive products, we focused on production amounts in the last harvest. For livestock, we used data on animals born in the previous year. We assumed 250 kg/head of cattle, 50 kg/head for pigs, and 1 kg/head for chickens to calculate amounts produced. This permits measurement of distributive diversity of on-farm activities in terms of production. In our analysis of distributive diversity, we focus on production rather than income. We considered modeling income diversity since we have data on amounts sold. However, local price data vary in availability and quality among products and countries. In past analyses of livelihood diversity with production as well as income, findings did not vary greatly [41]. We therefore stayed with analysis of livelihood diversity in terms of production. Finally, we drew on data indicating whether households gained income from off-farm activities: fishing, mining, logging, retirement pension, rentals, remittances, small business, wage work, and "other" activities. Timber extraction may be on-farm or on other lands such as concessions. We asked about amounts of timber extracted, but logging is often illegal and many respondents did not admit to timber harvesting, so we discount reported values. All such activities were therefore measured in 0/1 binomial terms, which permits evaluation in terms of structural though not distributive diversity. Hence, we can

observe both structural and distributive livelihood diversity for on-farm activities, but only structural diversity for off-farm activities.

Measuring change in diversity introduces some complications. Some diversity measures are more sensitive to change than others, and some measures are more sensitive when diversity is very high or very low [38–41]. There is also the issue of differentiating structural changes from distributive changes. We therefore made the decision to measure structural change in diversity separately from change in distributive diversity. This is advantageous, since it permits a clear decomposition of different types of changes in household livelihood systems. Whereas distributive changes signal shifts in the relative importance of pre-existing activities, structural changes are more risky since they indicate dropping pre-existing activities or picking up new ones.

To measure change in household livelihood diversity, we drew from questionnaire data on pre-existing activities at the time of the surveys, as well as information about plans for changes in those activities in the next year. Using reported plans for changes is not the same as a panel design involving revisits in order to permit calculations of change over time. However, pursuing a panel presents its own complications, notably the difficulty in securing follow-ups in a rural frontier area. Nonetheless, use of reported plans raises questions of data validity. In our case, that problem was significantly mitigated by the timing of our field visits. Whereas the agricultural year in the Amazon begins in May with the onset of the dry season (when forest clearing occurs), and proceeds from there (to burning at the end of the dry season in October, planting thereafter, and harvest early the next calendar year), our field visits occurred between June and August. This was to ensure access during the dry season to households in rural communities along unpaved secondary roads that become very difficult to transit in the rainy season. Hence many household decisions about clearing and planting had already been made, entraining commitments of family labor, land and capital assets. In turn, those decisions also affect decisions about forest extractivism and off-farm activities over the same period. As a result, reported "plans for the next year" were in many respects already being implemented in practice at the time of our survey interviews.

To observe changes in livelihood activities, we asked households a battery of questions about plans in the current agricultural year regarding on- and off-farm activities. We included questions on plans for 18 different activities: three on NTFPs (castaña nuts, rubber, and "other"), two on crops (annuals and perennials), two on livestock (cattle and "other"), and one each on wage work, hunting, fishing, fish farming, mining, logging, land rentals, remittances, small businesses, and two "others." For each, response options were closed-ended, and included "start" and "stop" for possible structural changes, and "increase" and "decrease" for distributive changes. We also included response options for "no change" and "no interest".

From these questions we tallied up the number of activities for which respondents indicated structural changes (start/stop) and distributive changes (increase/decrease). These counts constitute continuous measures of plans for changes in household livelihoods. Further, we differentiated plans to start or increase activities from plans to stop or decrease them. We calculated gross changes by summing plans to start and stop as well as increase and decrease; this provided a measure of total changes planned. Similarly, we calculated net changes by subtracting activities for which there were plans to stop from those for which there were plans to start; we also took the number of activities for which there were plans to increase and subtracted activities slated for decreases. These measures thus provide

system-wide indexes of changes in livelihood diversity for each households surveyed, and are thus appropriate for interpretation in terms of resilience and sustainability.

2.3. Explanatory Variables in the Analysis of Change in Livelihood Diversity

With these measures of change in household livelihood diversity, our analysis proceeds in two parts. First, we conducted a comparative analysis of livelihood diversity and change among rural households across the three sides of the MAP frontier. This permits a bivariate analysis of the importance of access connectivity as well as livelihood diversity for change in diversity, for three distinct stages in the paving process: before, during and after. This offers a preliminary indication of the direction of the relationships of regional integration and extant livelihoods with changes in livelihood diversity at the household level. Second, we constructed multivariate models of change in livelihood diversity at the household level. In the models, we feature access connectivity and livelihood diversity, and use a suite of household capability variables as statistical controls. This affords a much more refined analysis, which permits evaluation of the effects of connectivity and livelihood diversity on change in household livelihood diversity while controlling for the effects of household assets.

2.3.1. Connectivity

To evaluate access connectivity, we seek to capture both distance to market and paving status of the IOH in terms of spatial measures via travel time and temporal measures via time since paving. To calculate travel times to markets, we used GPS points for household and market locations along with GIS coverage of road maps, along with estimates of travel speeds on paved highways (90 km/h), unpaved highways (60 km/h), and unpaved secondary roads (30 km/h). The GPS points and road coverage permitted measurement of distances along roads from houses to markets, and multiplied by travel speeds, the product yields total travel times. We calculated travel times from each household to the nearest market town as well as the regional capital.

In addition to travel times, we also measure access connectivity in terms of years since highway paving. We know when specific segments of the IOH were paved in Acre and Madre de Dios. We therefore calculated the difference between year of interview and year of completion of paving. We made this calculation even for households who received paving after the time of interview for some places in Madre de Dios, reasoning that paving was ongoing during interviews, and households may well have been modifying their activities in anticipation of the completion of paving. We anticipate that the impacts of integration emerge during paving and grow with time since paving [42]. Households in communities with "older" paving may have more diverse livelihoods if they take advantage of new market opportunities. Of course, households may have less diverse livelihoods if paving instead prompts specialization.

2.3.2. Household Capabilities

We also drew from the questionnaires to develop measures of household capabilities to serve as controls in the multivariate models where we feature connectivity and livelihood diversity. Household capabilities include land, labor and various capital assets. Indicators of land assets include areas cleared and land under forest cover. Given the importance of cleared land for agriculture and

forested land for extractivism, these measures account for distinct natural capitals. Lands held by households differ among the three sides of the MAP frontier due to the differing tenure regimes. There are different types of lands in our sample for Acre, including from agro-extractive reserves with 300–500 ha per family mostly under forest, to agricultural settlement projects with 50–100 ha each and less forest, to agroforestry poles with only 5–10 ha and little forest cover. In Madre de Dios, households had agricultural land parcels of approximately 50 ha with a mix of forest and cleared land. In addition, some households also had *castaña* concessions, usually of 500 ha and forested. In Pando, rural communities were demarcated by providing member families 500 ha each, most in forest for *castaña* harvesting. Households with greater land assets should exhibit greater livelihood diversity since land represents a key resource for various on-farm activities and products.

Household labor is crucial to livelihoods in rural areas of the Amazon, since capital is typically scarce. We therefore measure the number of adults (men and women ages 15–64) as well as children (under age 15) and elderly family members (ages 65+), as well as absent family members and (in Acre) days of labor hired. We differentiate age groups since the productive contributions of adults are likely to be higher than for children or the elderly. For purposes of modeling, we also consider a squared term for adults, as larger families may allocate labor differently than smaller ones, resulting in a non-linear relationship. Greater labor availability should result in greater livelihood diversity given the importance of labor for productive activities in rural households. Families with more adults and (to a lesser extent) elderly, absent family members and days of labor hired should exhibit greater livelihood diversity. Children may increase livelihood diversity, depending on how families allocate child time between educational and productive activities.

We also consider various capitals, following Bebbington [29]. We begin with cultural capital, which reflects experience in the MAP frontier. In Bolivia, Brazil, and Peru, the Amazon has a distinct environment and history and, thus, Amazonian communities have distinct identities and knowledge bases concerning resource management. We therefore consider region of birth, place of birth and years of local residence. We measure region of birth in terms of origin in the Amazon *versus* other portions of each country. In Madre de Dios, we distinguish between birth in Madre de Dios and the rest of Peru, since Madre de Dios is tied to the rest of Peru primarily via the Andean highlands. Similarly, in Pando, we differentiate between birth in Pando or the neighboring lowland department of Beni and the rest of Bolivia, since Pando and Beni are distinguished as "northern Bolivia" [43]. In Acre, we differentiate between Brazil's "North" (Amazon) region and the rest of the country. In each case, origins in the Amazon region will likely lead to greater livelihood diversity, as outside migrants often arrive in the Amazon focusing on agricultural activities and neglecting forest extractivism. We also consider place of birth in terms of rural and urban areas. While rural birthplaces are likely to relate to knowledge of extractive and agricultural activities, urban origins may indicate exposure to off-farm activities. We also consider years of residence on the argument that more time in the Amazon permits learning about local productive activities and market opportunities [44]. This may beget innovations in livelihoods and result in greater diversity.

We also recognize the importance of financial (productive) capital for livelihoods. We consider the importance of owning a chainsaw, a form of capital that can increase household labor productivity in terms of clearing land for agriculture. Households with chainsaws may thus exhibit greater livelihood diversity. In addition, given our focus on regional integration, we accounted for the role of truck

ownership for livelihoods. Truck ownership permits hauling of produce or other people, which facilitates generation of additional income streams.

The models also account for institutional capital, that is, tenure status and financial support from external organizations. Differences in tenure across the MAP frontier influence rules concerning resource use and, thus, livelihood strategies. This is especially the case in Acre, where use rules differ among agricultural settlements, agro-extractive settlements and agroforestry poles. We anticipate that livelihood diversity may be greater in agro-extractive settlements because they are designed to encourage extractive and agricultural activities, whereas agricultural settlement projects focus on agriculture and agroforestry poles are small-scale systems. Beyond land tenure types, in Acre and Madre de Dios, private individual landholdings have different land titling designations. Parcels may be untitled, tentatively designated, or definitively titled. In Pando, lands are communally titled, so it makes no sense to differentiate titled and untitled lands at the household level, especially since the land tenure agency INRA had already issued titles to all of the communities we visited. Per economic theory, having a title confers tenure security, which motivates longer-term planning of activities [45] and thus potentially more diverse livelihoods. Beyond tenure status, institutional capital refers to whether a household had received formal credit from a bank. Credit constitutes capital beyond household assets and is generally intended to facilitate the addition or expansion of livelihood activities, thus incrementing livelihood diversity.

Finally, the models account for social capital, that is, the relations of trust that beget social support which may offset scarcities of other inputs to productive activities. We focus on social capital in the form of organizational memberships. We asked respondents a series of questions concerning different types of organizations in which they are members, ranging from community associations to religious organizations, producer cooperatives, sports clubs, and others. We measure social capital in terms of the number of different kinds of organizations in which a household reported membership. This seeks to capture access to different sources of information and support, which in theory should increase livelihood diversity.

We implemented the models in Stata v. 13.1 [46]. All models involve weighted least squares (WLS) regressions that include weights on observations to account for differing population sizes and varying sampling ratios among communities. Each household is weighted in accordance with how representative it is among the rural communities we visited across the MAP frontier. This ensures that inferential tests from the models are based on how representative each household is in the study region. The models use robust standard errors to account for heteroskedasticity. We focus on models of net change in structural and distributive diversity. This simplifies the exposition and reflects the fact that few households reported plans to stop or reduce activities, while still accounting for overall changes in livelihood diversity and permitting possible observation of declines in diversity.

Inclusion of livelihood diversity as an explanatory factor in models of planned changes in diversity complicates the estimation. This is because models of livelihood change account for the effects of household capabilities, which were also used in previous work to model livelihood diversity [28]. To avoid multicollinearity and identification problems, we therefore took the results of the livelihood diversity models and calculated the residuals as the difference between the observed values for livelihood diversity and those predicted on the basis of access connectivity and household capabilities. The residual values thus capture variation in household livelihood diversity aside from that accounted for by the other

covariates. The residuals are thus likely to include a random component as well as a non-random component of unexplained variation in livelihood diversity, which may be important for modeling change in diversity.

3. Results

3.1. Change in Livelihood Diversity Before, During and After Paving

The first part of our analysis considers the relationship between household livelihood diversity and change therein, as potentially modified by paving status. Table 1 presents descriptive statistics for indicators of livelihood diversity at the time of surveys as well as planned changes in livelihoods for the households interviewed. All values in results reported reflect weights applied to the observations to correct for differing sampling ratios employed among communities. We present means with standard deviations in parentheses. Structural diversity is greatest in household livelihoods in Pando, with Acre second, and then Madre de Dios. These findings suggest greater structural diversity before highway paving (as in Pando) and after paving (as in Acre) than during paving (in Madre de Dios). Similar findings appear for structural change: new activities, total change and net gains in planned activities are also greater (or more positive in the case of net change) in Pando and Acre than in Madre de Dios. There is very little reporting of plans to stop activities in any side of the frontier. Evidently rural households in a region receiving new infrastructure are optimistic about their ability to add new activities. Also intriguing are the low correlations between structural diversity at the time of interview and planned structural changes; there are insignificant negative correlations observed in Acre and Pando, but significant positive correlations in Madre de Dios. Thus, households with more structurally diverse livelihoods were not generally daunted relative to households with few activities in planning to add more activities. Indeed, in Madre de Dios, where structural diversity was lowest but new infrastructure was being built, households with more diverse livelihood systems tended to be those planning to initiate the most additional activities.

Table 1 also reports findings for distributive diversity and change in household livelihoods. Here the differences among the three sides contrast somewhat with those seen for structural diversity. For both *M6* and 1-*H*, Acre exhibits the greatest distributive diversity, followed by Pando and then Madre de Dios. These findings still suggest greater livelihood diversity before paving (Pando) and after paving (Acre) than during paving, but the order differs from that seen for structural diversity. This confirms the importance of the distinction of structural and distributive diversity. Findings for distributive change follow the same order: households in Acre reported plans for increases in more activities and the largest net gain in distributive diversity, followed by Pando and then Madre de Dios. Correlations between distributive diversity and planned change are significant, often large, and always positive. Hence, households with livelihood systems more evenly distributed among activities also planned greater increases in their activities, throughout the MAP frontier. That said, correlations are strongest in Madre de Dios, followed by Acre and then Pando. This suggests that households with more diversified livelihoods in terms of distribution were also planning greater increases in distributive diversity. This implies a near-term increase in the differentiation of livelihood diversity among rural households in the MAP frontier. This is especially the case in Madre de Dios, where distributive diversity was lowest overall.

Table 1. Structural and distributive measures of livelihood diversity and planned changes in livelihood activities, rural households in Madre de Dios/Peru, Acre/Brazil and Pando/Bolivia, 2008–2010.

	Madre de Dios	Acre	Pando
Structural Diversity			
Total Products/Activities (*S*)	7.53 (4.08) [1]	8.64 (4.17)	11.64 (5.67)
Structural Change			
New Activities Planned	0.97 (1.17)	1.81 (1.45)	1.78 (1.76)
Activities to be Ended	0.10 (0.32)	0.11 (0.35)	0.00 (0.00)
Total Change in Activities	1.07 (1.24)	1.93 (1.46)	1.78 (1.76)
Net Change in Activities	0.88 (1.19)	1.70 (1.52)	1.78 (1.76)
Correlations of Structural Diversity (*S*) with			
Total Change in Activities	0.18 ** [2]	−0.11 +	−0.04
Net Change in Activities	0.12 *	−0.08	−0.04
Distributive Diversity			
Inverse Herfindhal (1-*H*)	0.39 (0.30)	0.46 (0.28)	0.41 (0.27)
Gibbs−Poston *M6*	2.98 (1.78)	3.95 (2.18)	3.36 (1.64)
Distributive Change			
Activities to be Increased	1.69 (1.35)	2.49 (1.62)	2.38 (1.55)
Activities to be Decreased	0.03 (0.19)	0.07 (0.29)	0.19 (0.62)
Total Change in Distribution	1.71 (1.37)	2.56 (1.64)	2.57 (1.69)
Net Change in Distribution	1.66 (1.35)	2.42 (1.65)	2.19 (1.66)
Correlations of Inverse Herfindhal (1−*H*) with			
Total Change in Distribution	0.47 **	0.39 **	0.24 **
Net Change in Distribution	0.46 **	0.37 **	0.21 **
Correlations of Gibbs−Poston *M6* with			
Total Change in Distribution	0.52 **	0.46 **	0.23 **
Net Change in Distribution	0.32 **	0.43 **	0.18 **

[1] Observations are weighted to reflect sampling ratios and relative sizes of communities from which households were selected; [2] + $p < 0.15$, * $p < 0.05$, ** $p < 0.01$.

3.2. Multivariate Models of Changes in Livelihood Diversity

The second part of our analysis involves multivariate models of change in livelihood diversity. This requires assessment of the infrastructure connectivity and household capabilities variables. Table 2 presents descriptive statistics for measures of the connectivity and capabilities for the three sides of the MAP frontier. Table 2 shows differences in travel times across the MAP frontier. In part, longer travel times reflect larger distances, as in Acre, where the capital, Rio Branco, is at one end of the highway and up to 330 km from some communities. However, longer travel times also reflect the status of road paving, as in Pando, where households only range up to 250 km from the capital, Cobija, but must travel on unpaved roads. We also consider an interaction term to evaluate whether travel times to the nearest market are affected by travel times to the capital. Integration may have non-linear effects on rural livelihoods, such that being farther from the capital may modify the effects of distance to the nearest market.

Table 2. Connectivity and capability measures, rural households in Madre de Dios, Acre and Pando, 2008–2009.

	Madre de Dios	Acre	Pando
Access Connectivity			
Travel Time to Capital (Minutes)	93.12 [1]	182.95	175.54
Travel Time to Nearest Market (Minutes)	24.39	27.31	85.54
Time to Capital × Time to Nearest Market	1418.28	5208.84	15,943.90
Years since Highway Paving	−2.02	12.8	N/A
Land/Natural Capital			
Ha Cleared Land	9.26	23.94	14.78
Ln Ha Cleared Land	1.61	2.61	1.48
Ha Forested Land	98.85	44.80	476.31
Ln Ha Forested Land	2.15	2.67	3.99
Access to Other Castaña Forest (0 = No, 1 = Yes)	0.05	N/A	0.16
Labor			
Number of Adults in Household (Ages 15–64)	2.77	2.72	2.33
Adults Squared	9.94	9.27	6.84
Number of Children in Household (Under Age 15)	1.43	1.18	2.19
Number of Elderly in Household (Ages 65+)	0.14	0.23	0.18
Number of Absent Family Members	1.14	1.53	0.94
Days of Labor Hired	N/A	23.99	N/A
Ln Days of Labor Hired	N/A	1.83	N/A
Cultural Capital			
Region of Birth (0 = Other Region, 1 = Same Region)	0.33	0.75	0.92
Place of Birth (0 = Rural, 1 = Urban)	0.40	0.20	0.34
Years of Residence	20.4	15.47	14.36
Financial/Productive Capital			
Chainsaw Ownership (0 = No, 1 = Yes)	0.40	0.43	0.30
Truck Ownership (0 = No, 1 = Yes)	0.01	0.06	0.05
Institutional Capital			
Agricultural Settlement Project (0 = No, 1 = Yes)	N/A	0.78	N/A
Agro−extractive Settlement (0 = No, 1 = Yes)	N/A	0.17	N/A
Provisional Title (0 = No, 1 = Yes)	0.22	0.44	N/A
Definitive Title (0 = No, 1 = Yes)	0.47	0.46	N/A
Formal Credit (0 = No, 1 = Yes)	0.16	0.29	0.05
Social Capital			
Number of Types of Organizational Memberships	0.58	1.22	0.79

[1] Observations are weighted to reflect sampling ratios and relative sizes of communities from which households were selected.

Table 2 also shows descriptive statistics for indicators of household capabilities. Average cleared land area was greater in Acre due to the importance of pasture for cattle ranching there. By contrast, forested land areas were greater in Madre de Dios and especially Pando, where many families had access to forest reserve lands such as concessions and communal territories. Labor assets were on average similar among households on the three sides, with multiple adults and children, some elderly, and some absent family

members. Cultural capital varied in some ways in the sample, with most household heads having been born in the Amazon in Acre and Pando but not in Madre de Dios. Most household heads came from rural origins, and they reported lengthy durations of residence (15–20 years) in their communities of residence. Financial capital was low overall and varied to a limited extent, as somewhat more households in Acre had chainsaws and owned vehicles. In terms of institutional capital, most households in Acre were in agricultural settlements, and most households in Acre and Madre de Dios had some type of land tenure document. More households in Acre had received formal bank credit than households elsewhere. Similarly, with respect to social capital, households in Acre belonged to more voluntary organizations than their counterparts elsewhere in the MAP frontier. Table 2 thus indicates differing profiles of household assets across the study region.

Our multivariate analysis incorporates the variables from Tables 1 and 2 in models of change in household livelihood diversity. We present models of both structural and distributive change in diversity. For each, we implemented a "base" model with indicators of access connectivity and the household capability measures. This yields results to address our first research question on the relationship of accessibility and change in livelihood diversity. The other models add the effect of livelihood diversity at the time of surveys. Those models generate results that address our second research question on the effect of extant livelihood diversity on change in livelihoods. We include various indicators of livelihood diversity (*S*, *M6*, and 1-*H*) to consider potential differences in the effects of structural and distributive diversity.

Table 3 presents the results for Pando, Bolivia, which largely lacked highway paving at the time of surveys. We include two models of net structural change in household livelihood diversity, the base model and the model with residuals of *S*, and three models of net distributive change, namely the base model plus models that add residuals of 1-*H* and *M6*. Models in Pando are generally weak, barely achieving statistical significance overall. Few variables exhibit even weakly significant effects on structural change in livelihood diversity in the base model, though the addition of residuals of *S* yields some significant effects such that households with heads born in Northern Bolivia planned to add more activities. The models of distributive change are only slightly stronger, and have some unexpected findings. The base model shows a positive effect of travel time to Cobija (and the IOH) on plans for increasing distributive diversity. This finding addresses the first research question and indicates that households less integrated to the IOH (with less access connectivity) exhibited larger plans to increase their livelihood diversity. The model with the residuals for 1-*H* is stronger, and the effect of 1-*H* is highly positive. This result is relevant to the second research question and suggests that households with more diversified livelihoods also reported more ambitious plans for further diversification. Both findings arise from models of distributive changes in livelihoods; these relationships are weaker for structural changes.

Table 4 presents the same suite of model specifications for Acre, Brazil, where paving was complete by the time of surveys. Models of structural change in household livelihood diversity were relatively weak. The only significant household capability variables refer to land title status, with households holding preliminary and definitive titles reporting fewer plans to expand structural diversity. This is an intriguing finding, as it implies that titling and, thus, tenure security make risk management via diversification less important. We do not interpret this finding as implying that that households will specialize in the sense of reducing diversity, since virtually no households reported plans to stop or reduce more activities than those for which they reported plans to start up or increase. Neither access

connectivity nor structural diversity mattered for plans for changes in structural diversity. In contrast, the models of distributive changes in livelihood diversity were stronger and significant. Plans to broaden the distributive diversity of livelihood systems were more pronounced among households originating in Brazil's north region and especially in rural areas. In contrast to the structural change model, distributive change is positively affected by holding preliminary (but not definitive) titles. Where paving was complete, access connectivity mattered less than cultural and institutional capital for changes in distributive diversity. There are however strong, positive effects of the residuals for 1-*H* as well as *M6*. Households that already had more distributively diverse livelihoods planned much greater distributive expansions than households with less diverse livelihoods. This implies an increased differentiation in household distributive diversity in the presence of improved infrastructure. Overall, the findings for Acre also indicate stronger relationships of explanatory variables and distributive rather than structural changes in livelihoods. Further, the results indicate that after paving, access connectivity does not matter much for change in livelihoods. In contrast, the diversity of extant livelihoods has a strong positive effect on plans to increase distributive diversity.

Table 5 presents the models for Madre de Dios, Peru, where paving was underway during fieldwork, such that some households had paving but others did not. Models of change in household livelihood diversity in Madre de Dios were generally stronger than elsewhere and always significant. At the same time, models of change in structural diversity were not as strong as for distributive diversity. We modified the specification for access connectivity to include time since paving but not travel time to nearest market since the first yielded stronger models. Indeed, the specification presented shows very strong results for access connectivity on change in both structural and distributive diversity. Households with shorter travel times as well as longer times since paving reported bigger plans to structurally and distributively diversify their livelihoods. Further, there is a negative interaction between travel time to capital and time since paving: households with shorter travel times and also with paving longer reported yet greater plans for diversification. Hence, regional integration via improved access connectivity has strong effects on plans for changes in livelihood diversity where highway paving is underway. While livelihood diversity overall in Madre de Dios was lower than elsewhere in the MAP frontier, there are stronger findings for the effects of access connectivity on change in diversity during highway paving than before or after. Beyond connectivity, few variables were important for change in structural or distributive diversity. Notably, structural diversity itself failed to register a significant effect on planned structural change, while distributive diversity had strong, positive effects on planned distributive change. These findings indicate that net of the effects of connectivity and household capabilities, households with greater distributive diversity also planned larger increases in distributive diversity in the presence of highway paving.

Table 3. WLS Models of connectivity and livelihood plans among rural households in Pando, Bolivia, 2008–2009.

	Net Structural Change		**Net Distributive Change**		
	Base	*S*	Base	1−*H*	*M6*
R^2	0.07	0.16	0.18	0.17	0.15
F test	0.51	2.06 *	1.59 +	1.99 *	1.62 +
Valid n	147 [1]	141	147	117	117
Connectivity					
Travel Time to Capital (Minutes)	−0.001 [2]	0.000	0.012 *	0.000	0.000
Travel Time to Nearest Market (Minutes)	−0.004	−0.003	0.013 +	−0.002	−0.002
Time to Capital * Time to Nearest Market	0.000	0.000	−0.000 +	0.000	0.000
Land/Natural Capital					
Ln Ha Cleared Land	0.054	0.047	0.148	0.086	0.086
Ln Ha Forested Land	−0.033	−0.031	0.093	0.124 +	0.124 +
Access to Other Castaña Forest (0 = No, 1 = Yes)	−0.431	−0.543	0.387	0.253	0.253
Labor					
Number of Adults in Household (Ages 15−64)	0.045	0.028	−0.199 +	−0.143	−0.143
Number of Children in Household (Under Age 15)	0.113	0.129	0.235 *	0.213 +	0.213 +
Number of Elderly in Household (Ages 65+)	−0.019	−0.036	0.459	0.203	0.203
Number of Absent Family Members	−0.11	−0.106	0.011	0.024	0.024
Cultural Capital					
Region of Birth (0 = Other Region, 1 = Northern Bolivia)	0.683	1.083 *	−0.601	−0.602	−0.602
Place of Birth (0 = Rural, 1 = Urban)	−0.007 +	−0.008 +	0.011 *	0.007	0.007
Years of Residence	0.001	0.001	0.011	0.006	0.006
Financial/Productive Capital					
Truck Ownership (0 = No, 1 = Yes)	−0.065	0.123	−0.004	0.502	0.502
Chainsaw Ownership (0 = No, 1 = Yes)	0.016	0.016	0.003	0.000	0.000
Institutional Capital					
Formal Credit (0 = No, 1 = Yes)	0.041	0.011	−0.039	−0.185	−0.185

Table 3. *Cont.*

	Net Structural Change		Net Distributive Change		
Social Capital					
Number of Types of Organizational Memberships	0.247	0.309 +	0.065	0.171	0.171
Livelihood Diversity					
Structural Diversity Residual (r_S)		0.017			
Inverse Herfindhal Residual (r_{1-H})				1.521 *	
Gibbs−Poston *M6* Residual (r_{M6})					0.154

[1] Observations are weighted to reflect sampling ratios and relative sizes of communities from which households were selected; [2] + $p < 0.15$, * $p < 0.05$, ** $p < 0.01$.

Table 4. WLS Models of connectivity and livelihood plans among rural households in Acre, Brazil, 2009–2010.

	Net Structural Change		Net Distributive Change		
	Base	*S*	Base	1−*H*	*M6*
R^2	0.17	0.17	0.16	0.28	0.32
F test	1.3	1.25	2.14 **	29.51 **	27.97 **
Valid n	235 [1]	228	235	192	192
Connectivity					
Travel Time to Nearest Market (Minutes)	0.011 [2]	0.009	0.013	−0.007	−0.007
Travel Time to Capital (Minutes)	0.005 +	0.005	0.002	−0.001	−0.001
Time to Capital * Time to Nearest Market	0.000	0.000	0.000	0.000	0.000
Land/Natural Capital					
Ln Ha Cleared Land	−0.035	−0.046	−0.019	−0.035	−0.035
Ln Ha Forested Land	0.063	0.072	0.201	0.323 +	0.324 +

Table 4. *Cont.*

	Net Structural Change		Net Distributive Change		
Labor					
Number of Adults in Household (Ages 15–64)	0.09	0.093	0.06	−0.119	−0.119
Adults Squared	−0.019	−0.02	−0.004	0.025	0.025
Number of Children in Household (Under Age 15)	0.175	0.154 +	0.105	0.160 +	0.160 +
Number of Elderly in Household (Ages 65+)	0.282	0.279	−0.101	−0.245	−0.245
Number of Absent Family Members	−0.032	−0.034	0.015	0.071	0.071
Ln Days of Labor Hired	0.024	0.025	0.003	0.010	0.010
Cultural Capital					
Region of Birth (0 = Other Region, 1 = Northern Brazil)	0.120	0.127	0.528 +	0.575 +	0.575 *
Place of Birth (0 = Rural, 1 = Urban)	0.001	0.001	0.001	−0.019 **	−0.020 **
Years of Residence	−0.020	−0.020	−0.005	−0.010	−0.010
Financial/Productive Capital					
Truck Ownership (0 = No, 1 = Yes)	−0.817	−0.861	−0.175	−0.125	−0.125
Chainsaw Ownership (0 = No, 1 = Yes)	−0.004	−0.004	−0.002	0.006	0.006
Institutional Capital					
Agricultural Settlement Project (0 = No, 1 = Yes)	0.572	0.597	0.098	0.001	0.001
Agro-extractive Settlement (0 = No, 1 = Yes)	0.203	0.266	0.609	0.396	0.396
Provisional Title (0 = No, 1 = Yes)	−1.273 *	−1.227 *	0.529 +	0.799 *	0.799 *
Definitive Title (0 = No, 1 = Yes)	−1.579 **	−1.527 **	0.175	0.139	0.139
Formal Credit (0 = No, 1 = Yes)	0.150	0.146	0.305	0.210	0.211
Social Capital					
Number of Types of Organizational Memberships	0.077	0.074	0.278 +	0.377 +	0.377 +
Livelihood Diversity					
Structural Diversity Residual (r_S)		−0.035			
Inverse Herfindhal Residual (r_{1-H})				1.950 **	
Gibbs-Poston *M6* Residual (r_{M6})					0.326 **

[1] Observations are weighted to reflect sampling ratios and relative sizes of communities from which households were selected; [2] + $p < 0.15$, * $p < 0.05$, ** $p < 0.01$.

Table 5. WLS Models of connectivity and livelihood plans among rural households in Madre de Dios, Peru, 2008–2009.

	Net Structural Change		Net Distributive Change		
	Base	S	Base	H	M6
R^2	0.16	0.17	0.27	0.37	0.39
F test	3.26 **	3.04 **	5.74 **	11.07 **	11.58 **
Valid n	304 [1]	285	304	257	257
Connectivity					
Travel Time to Capital (Minutes)	−0.008 ** [2]	−0.009 +	−0.013 **	−0.013 **	−0.013 **
Years since Highway Paving	0.407 **	0.378 **	0.340 **	0.404 **	0.404 **
Time to Capital * Years since Paving	−0.004 *	−0.004 +	−0.007 **	−0.008 **	−0.008 **
Land/Natural Capital					
Ln Ha Cleared Land	−0.014	0.001	0.055	0.042	0.041
Ln Ha Forested Land	0.057	0.073	0.307 **	0.287 **	0.287 **
Access to Other Castaña Forest (0 = No, 1 = Yes)	0.129	−0.008	0.166	0.176	0.176
Labor					
Number of Adults in Household (Ages 15–64)	−0.283 +	−0.133	0.206	0.100	0.100
Adults Squared	0.033	0.005	−0.029	−0.017	−0.017
Number of Children in Household (Under Age 15)	0.091	0.071	−0.055	−0.075	−0.075
Number of Elderly in Household (Ages 65+)	−0.493 **	−0.421 **	−0.333 +	−0.391 +	−0.391 +
Number of Absent Family Members	−0.021	−0.037	−0.038	−0.072	−0.072
Cultural Capital					
Region of Birth (0 = Other Region, 1 = Madre de Dios)	−0.114	−0.021	−0.16	−0.248 +	−0.248 +
Place of Birth (0 = Rural, 1 = Urban)	−0.002	−0.001	0.006	0.001	0.001
Years of Residence	0.008 +	0.007	−0.003	0.002	0.002

Table 5. *Cont.*

	Net Structural Change		Net Distributive Change		
Financial/Productive Capital					
Truck Ownership (0 = No, 1 = Yes)	0.706 +	0.934 *	−0.189	−0.212	−0.212
Chainsaw Ownership (0 = No, 1 = Yes)	0.304 +	0.209	0.007	0.097	0.097
Institutional Capital					
Provisional Title (0 = No, 1 = Yes)	0.0230	0.042	0.350 +	0.368	0.368
Definitive Title (0 = No, 1 = Yes)	−0.119	−0.004	0.574 *	0.546 *	0.546 *
Formal Credit (0 = No, 1 = Yes)	−0.240	−0.356 *	0.305 +	0.277	0.277
Social Capital					
Number of Types of Organizational Memberships	0.155 +	0.152 +	−0.172 +	−0.110	−0.110
Livelihood Diversity					
Structural Diversity Residual (r_S)		0.019			
Inverse Herfindhal Residual (r_{1-H})				1.927 **	
Gibbs−Poston *M6* Residual (r_{M6})					0.375 **

[1] Observations are weighted to reflect sampling ratios and relative sizes of communities from which households were selected; [2] + $p < 0.15$, * $p < 0.05$, ** $p < 0.01$.

4. Discussion

This analysis goes beyond prior work on infrastructure impacts, including in the Amazon, in several noteworthy respects. Most previous work on infrastructure impacts in the Amazon has focused on the environmental impacts, usually in terms of deforestation [47–49]. Previous work on the economic and social impacts of infrastructure has generally been framed in terms of wealth/poverty or inequalities. This paper pursued a complementary and arguably more inclusive avenue by focusing on household livelihoods. Rural livelihoods are based in large measure on natural resources but also incorporate other activities. Livelihoods also permit a broader appraisal understanding of household decisions about economic activities than narrower measures such as wealth or income. At the same time, livelihoods still afford an evaluation of household inequalities. This is especially important, because livelihoods constitute a means of evaluating household capacity to provide for families as well as an index of the ability of households to buffer against shocks, including the loss of some livelihood activities. On that note, we adopted a resilience frame for interpreting change in livelihood diversity, which is innovative but appropriate since resilience thought highlights diversity as an important means of reducing vulnerability to shocks. Further, we took up a systematic quantitative approach to evaluating change in diversity. This complements most livelihoods research and permitted analysis of the extent to which connectivity and pre-existing livelihood diversity in turn influence planned changes in diversity.

The findings indicate strong shifts in household livelihood diversity in the MAP frontier in the presence of infrastructure improvements in the form of the IOH. The comparative analysis of change in structural and distributive diversity among rural households showed that paving status (before, during, after) is important. Household livelihood diversity was greater before paving (in Pando, Bolivia) and after paving (in Acre, Brazil) than during paving (in Madre de Dios, Peru). Similarly, planned changes in livelihood diversity were greater before and after paving than during paving. We also found that the diversity of pre-existing livelihoods is related to planned changes in important ways. Correlations between structural diversity and structural changes were weak, except in Madre de Dios, where structural diversity was lowest. This implies a growing differentiation in structural diversity during highway paving, where households with more structurally diverse livelihoods were also the ones planning to add the most new activities. Correlations between distributive diversity and distributive changes were stronger overall than for structural diversity and change. However, again correlations were strongest in Madre de Dios, where distributive diversity was also lowest. Hence, there is evidence of differentiation in household livelihood diversity in terms of distribution during highway paving. While household livelihood diversity was lower in Madre de Dios, and while planned changes were smaller among households there than elsewhere, pre-existing livelihoods have stronger effects on planned changes during highway paving than elsewhere.

The multivariate models built on the comparative findings by evaluating differences among individual households and controlling for household capabilities. Three key findings arise from the models. First, household capabilities had relatively little to do with planned changes in livelihood diversity. For the most part, households with more land, labor or capital did not vary systematically in their plans for either structural or distributive changes in the diversity of their livelihoods. Second, access connectivity was not important for planned changes in livelihood diversity among rural households before paving (in Pando) or after paving (in Acre). However, accessibility during paving (in Madre de Dios) mattered

greatly for change in household livelihood diversity: households with shorter travel times and more time since paving reported bigger plans to add new activities (structural change) as well as broaden their activities (distributive change). Put differently, the relationship of connectivity to change in livelihood diversity is tighter during highway paving than before or after. Third, the diversity of pre-existing livelihoods was usually important for plans for changes in livelihood diversity. Specifically, distributive diversity was important for planned changes in diversity, and this relationship held across the MAP frontier. Regardless of paving status, households with more distributively diverse livelihoods also tended to have bigger plans to broaden their portfolio of activities. The multivariate models thus confirmed the bivariate correlations indicating that in the presence of new infrastructure in a given region—whether before, during, or after paving—livelihood diversity becomes increasingly differentiated and thus unequal.

These findings permit conclusions for the study region with regard to the two research questions posed earlier. With regard to the first question, the findings show that access connectivity prompts plans to increase livelihood diversity, with the caveat that this is the case during highway paving as seen in Madre de Dios. This conclusion arises from the largely insignificant findings before paving in Pando and after paving in Acre. Hence, during the process of integration, livelihood diversity increases consonant with advantages of accessibility. Concerning the second research question, the findings from all three sides of the MAP frontier indicate that extant livelihood diversity has a strong positive effect on plans to further increase diversity, with the caveat that this applies more to distributive than structural diversity.

The two conclusions in turn bear implications for debates over the economic and social wisdom of new infrastructure in light of resilience and sustainability. Previous analysis of rural households in the MAP frontier indicated that households with greater access connectivity also exhibited less diverse livelihoods [28]. Households that were more integrated were thus more vulnerable to external shocks and in that regard less resilient. This analysis adds several key points to those findings. Regardless of household livelihood diversity at the time of surveys, households throughout the MAP frontier reported plans to add or expand activities, thus building their capacity for resilience. This was most evident among households in Madre de Dios, where households had the least diversified livelihood systems. While such results are encouraging, the findings also showed that households with more diversified livelihoods also planned to broaden their activity portfolios more than less diversified households. This suggests increasing inequalities in livelihood diversity among households. Going forward, differences in household livelihood diversity look to be greater than they were at the time of interviews. Hence, while overall household resilience in terms of livelihood diversity was rising during highway paving, there also appear to be growing inequalities in household resilience.

The findings thus confirm both previous economic work indicating that infrastructure improvements bring benefits and social science research indicating increasing inequality. Insofar as they can add or broaden the distribution of activities in their livelihood systems, households can better manage risk and improve their well-being. But insofar as more diversified households are better able to diversify than others, differential livelihood diversification increases inequalities in livelihood diversity and, thus, risk exposure to livelihoods. A focus on livelihood diversity thus reconciles the seemingly contrary conclusions from the economic and social literatures by capturing in the same metrics both the benefits and problems of infrastructure impacts. A focus on livelihoods thereby bridges the economic and social

science literatures on infrastructure, and helps account for why there are positive as well as negative socioeconomic consequences of highway paving, via the dynamics in livelihood systems.

Consequently there is a need to account for differential exposure to risk and therefore vulnerability in planning for infrastructure impacts. Of particular importance is the identification of community locations and households with less diversified livelihoods for support in the context of infrastructure projects. Targeted policies for poverty reduction have been proposed previously for areas receiving infrastructure investments [50,51]. This research underscores the need for programs designed to support livelihood diversification as a means of improving household well-being while also reducing vulnerability.

These findings contribute to research on infrastructure impacts and livelihood studies in several respects. Firstly, they offer a rare glimpse of the relationship of changing infrastructure on overall change in household livelihood systems. Most previous work on infrastructure and livelihood change has tended to focus on narrower indicators such as the dynamics of individual activities or products. Secondly, this analysis provides an equally rare peek at the relationship of pre-existing livelihoods to changes therein. Prior research has also usually focused on individual activities or products. Thirdly, this paper revealed that while accessibility might correspond to less diverse livelihoods at a given time, greater accessibility also corresponds to larger planned increments in livelihood diversity. Hence, the static relationship of accessibility and livelihood diversity is not the same as the dynamic relationship. Fourth, under conditions of new investments in infrastructure, there is growing inequality in livelihood diversity. This is a policy concern because infrastructure integrates regions, which can be good for economic growth, but it also differentially exposes households to vulnerabilities to external shocks.

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Author Contributions

Stephen G. Perz led the design of the study, analysis and writing of the manuscript; Flavia L. Leite and Lauren N. Griffin contributed to the analysis and provided support during writing; Jeffrey Hoelle and Martha Rosero provided support during writing; and Lucas Araujo Carvalho, Jorge Castillo and Daniel Rojas supported the design of the study, review of field instrument, site selection, and logistics for fieldwork.

Conflicts of Interest

The authors declare no conflict of interest.

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