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Research Paper

Bringing economic development for whom? An exploratory study of the impact of the Interoceanic Highway on the livelihood of smallholders in the Amazon

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ABSTRACT

Significant research efforts have been devoted to characterizing smallholding productive systems and assessing the relative contribution of small-scale farming to global food production. However, there is a noted paucity of studies addressing the determinants of and contributors to income generation of smallholders around the world, particularly in the Amazon forest. Moreover, while road development in the Amazon has been heavily discussed, the impacts of infrastructure projects, such as road paving, on smallholders' livelihoods remain uncertain. Here we explore the relevance of agriculture, livestock rearing and collection of non-timber forest products (NTFP) as income providers of smallholders in the Amazon forest in Madre de Dios-Peru, after the paving of Interoceanic South Highway (ISH), a large infrastructural project connecting Acre state in Brazil with Cusco in Peru. We interviewed 62 smallholder families in an area of 403 km^2 along the road from Iñapari to Mazuko near the tri-national border of Brazil, Perú and Bolivia. We applied a multinomial statistical model to estimate the proportion of annual net revenue related to each productive system from selected predictor variables. Our results show that smallholders' net revenue originates from a mix of productive systems including agriculture (rice, corn), livestock rearing (cows) and others (poultry, pigs, sheep) as well as NTFP extractivist activities (Brazil nut). Average net revenue is of USD 35.2 $\pm$ 25.7 $ha^{-1}yr^{-1}$ suggesting that economic returns to smallholders remain low even after the paving of ISH. This indicates that connection with markets alone is not sufficient to increase rents of smallholder families.

1. Introduction

Although there is a large body of literature on small scale farming, there is still a fragmented view on the diversity of economic activities that comprise smallholder livelihoods, often including agriculture, livestock rearing and Non Timber Forest products (NTFP) extractivist activities (Duchelle et al., 2012; Wunder, Angelsen, & Belcher, 2014). Studies often focus on a limited number of products such as fibers (Pisani & Scrocco, 2016), crops (Wunder et al., 2014) and different NTFP chains (e.g. Brazil nut) (Escobal & Aldana, 2003). Furthermore, while there is abundant literature on the role of agriculture as a source of income (FAO, 2014; Rapsomanikis, 2015), the importance of forest resources has been less explored (Wunder et al., 2014). The work by the Poverty Environmental Network (PEN) has gathered evidence on the fact that forests significantly contribute to the net revenue of rural livelihoods, particularly in the tropics (Wunder et al., 2014). Here we refer to family forest livelihoods as those smallholders in the Amazon that reconcile forest and agricultural activities often in complex Agroforestry Systems (SAFs). We thus seek to explore the contribution of these activities (agriculture, livestock rearing, and NTFP extractivism) to the net revenues of smallholders' in the Amazon.

Small scale farming is prominent across Latin America and the Caribbean (LAC) where there are about 15 million smallholdings, occupying an area of about 400 million ha (Berdegué & Fuentealba, 2011). We identified that average annual income of smallholders in Latin America, particularly in the Amazon, is low, regardless of the

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estimation method (Table S1). Estimates for Brazil alone report 4.8 million smallholders (about 84% of the total number of farmers) occupying 353 million hectares with incomes averaging USD 104 $ha^{-1}year^{-1}$ (FAO & INCRA, 2000). In Bolivia, there are about 654 thousand smallholdings that occupy 42.8% of the total area of agricultural land (UDAPE, 2015), with an average annual income per household of USD 1040 (Duchelle, Almeyda-Zambrano, Wunder, Börner, & Kainer, 2014). In Ecuador, there are 843 thousand smallholders, representing 88% of the total agricultural area with annual income ranging from USD 2028 to USD 12,651 (Salazar, Ramos-Martin, & Lomas, 2016). In Peru, smallholders account for 97% of the total agricultural area, producing 70% of total national food with, on average, an annual income of USD 2460 per year/household, equivalent to USD 52 $ha^{-1}yr^{-1}$ (MINAGRI, 2015) (Table S1).

Interoceanic South Highway (ISH) paving was promoted through the Initiative for the Integration of South American Regional Infrastructure (IIRSA) created in August 2000 (Carciofi, 2012; Van Dijck, 2013). This road was paved in 2002 in Brazil, while in Peru most of the construction occurred between 2003 and 2005, becoming only fully operational in 2010 (Dourojeanni, 2006; Mendoza et al., 2007). Previously, it was a poorly maintained dirt road, often inaccessible during the rainy season. The paving of this road was expected to foster fresh socio-economic opportunities to neighboring rural households in the region, particularly to inland areas such as the Madre de Dios department in Peru (MDD) (Fig. 1), despite resulting in considerable deforestation (Almeyda-Zambrano, Broadbent, Schmink, Perz, & Asner, 2010; Soares-Filho et al., 2006). Historically isolated from the rest of the country, MDD is currently a rapidly expanding frontier in the Amazonian lowlands, specifically along the ISH that connects Brazil and Peru (Perz et al., 2016). In the announcement of the construction, the Brazilian President argued that the Interoceanic Highway "has the merit of assisting the populations that are marginalized and often forgotten. It is this integration that we seek: a process that unites us and makes us closer, but that also distributes, in a more balanced way, its benefits" (PR, 2005, p. 1). In the MDD region, smallholders' net revenue in 1999 (before the paving of the Interoceanic Highway) ranged from USD 14 to 43.6 $ha^{-1}yr^{-1}$ averaging USD 33 $ha^{-1}yr^{-1}$ (Escobal & Aldana, 2003).

In this exploratory study, we aim at providing new insights on the economic impacts of road paving on the livelihoods of 62 forest dependent smallholders along the ISH in MDD (see Section 2.1). Through a combination of field survey data and statistical modeling, we explore how well the regional and international connection offered by the ISH was able to boost socioeconomic development and, if so, bringing economic development for whom? We particularly aim at exploring if there was improvement of the smallholders' net revenue in relation to the 1999 estimate by Escobal and Aldana (2003) (see Section 2.2). To this end, we assess the contribution of agriculture, livestock rearing and NTFPs to the income generation (net revenue) of smallholders in the Madre de Dios region (see Section 2.2.1).

2. Methods

2.1. Case study and data collection

We focus our study in the department of Madre de Dios, Peru, where

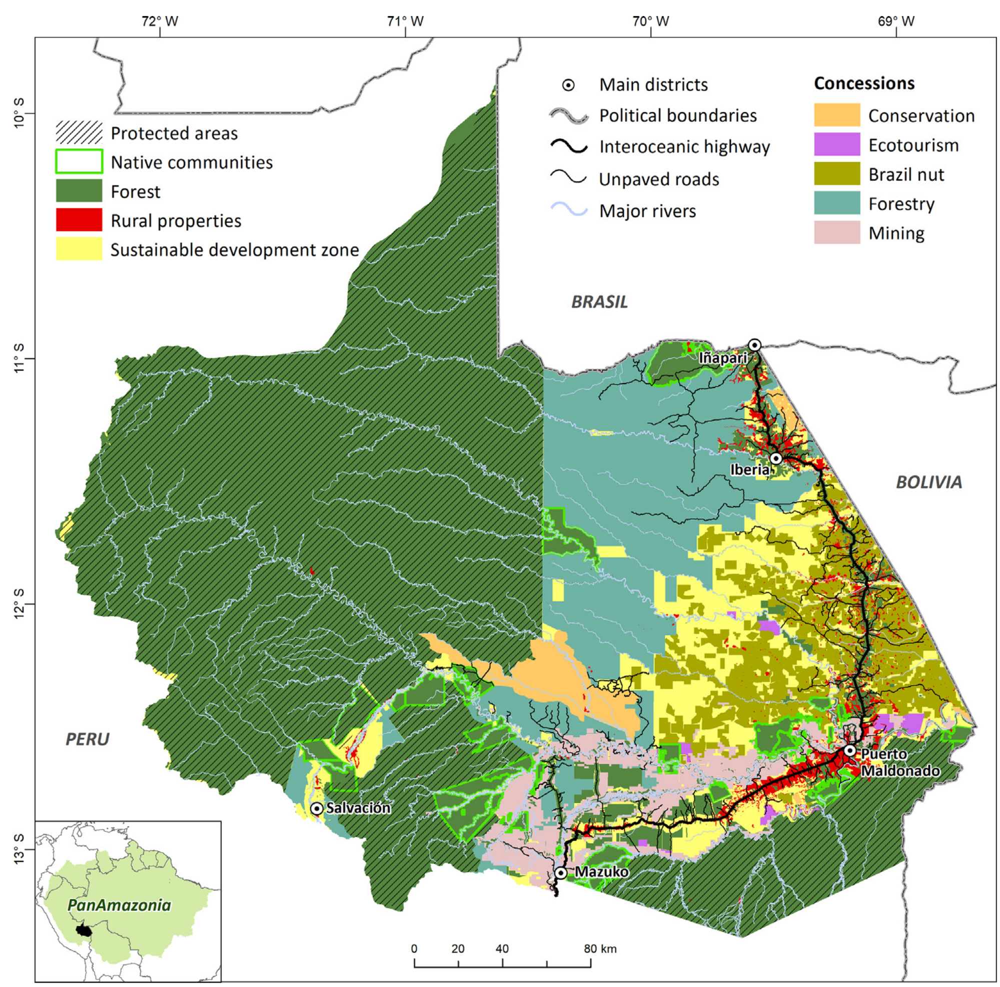

Fig. 1. Land use in Madre de Dios.

most of the ISH extent is located (Fig. 1). MDD is the third largest Department in Peru covering 85,300 km^2 and representing 7% of the Peruvian territory (GOREMAD, 2010). Roughly protected areas cover 60% of the region, agricultural areas comprise 16%, while 23.5% is designated to productive uses by means of long-term concessions (up to 40 years) for Brazil nut collection (500–1000 ha each concession), and timber extraction (5000–40,000 ha) (Evans, Murphy, & de Jong, 2014). MDD has experienced a rapid increase in rural population in recent decades. Migrants from various parts of Peru and other South American countries have been attracted to MDD for gold mining and agriculture in anticipation of the paving of ISH. The demographic dynamics resulted in an unprecedented land use change in the region, mainly surrounding the ISH, with the development of thousands of small farms in the heart of the Amazon forest (Fig. 1). This in-migration is mainly located in the buffer zone of 30 km either side of the ISH, where about 65% of the smallholdings can be found, closer to the capital Puerto Maldonado, the main regional market.

We began our study by organizing meetings with representatives from both governmental and non-governmental organizations. During these meetings we collected data for characterizing landholdings in the region, including land use categories and geographical and biophysical variables (Table S2). Organizations contacted were: Gobierno Regional de Madre de Dios (GOREMAD), Instituto Nacional de Recursos Naturales (INRENA), Dirección Regional de Agricultura (DRAMDD), Servicio Nacional de Sanidad Agraria (SENASA), Asociación para la Conservación de la Cuenca Amazónica (ACCA), Fundación Peruana para la Conservación de la Naturaleza (ProNaturaleza) and Organismo de Formalización de la Propiedad Informal (COFOPRI). Logistic support to conduct field surveys was provided by SENASA (National Agrarian Health Service). We attended meetings of farmers' unions and training sessions held by SENASA. In these events, we were able to interview smallholders visiting SENASA headquarters and solicited contacts for other smallholders to enlarge our "snowball" sample (Suri, 2011). These individuals were then contacted by SENASA field experts who guided our research team to conduct the survey. Our sample was not random, hence sample bias needs to be acknowledged and accounted for when conducting the statistical analysis (see Section 2.2.1).

The fieldwork was carried out in November and December 2010, and began in Iñapari (at the border with Brazil) and ended in Mazuko (at the border with the departments of Puno and Cusco, Peru). This covered 403 km, the total stretch of the ISH within the MDD department. We conducted 62 semi-structured interviews (interview sheet, Supplementary materials, page 5) to collect data on household characteristics including age, gender, and education level of the smallholder. We also characterized their productive systems, including size of the plot, farming infrastructure, crops and livestock, prices and costs of productive systems, transportation costs, and labor employed on the property, among other data.

2.2. Income generation of smallholders: net revenue

In order to estimate smallholders' income, we first calculated gross income and then subtracted production and transportation costs to calculate net revenue. Production data, market prices and production costs were gathered in the interviews (Table 1). We calculated gross income by multiplying prices of each product by the quantity produced in each household. In this case, we calculated gross income for agricultural products, livestock production (meat and poultry) and NTFPs. From the gross income, we subtracted transportation, labor and input costs in order to estimate net revenue. We calculated net revenue (R) for the year 2010 (Table 1) following Eq. (1):

$$R = \sum_{n=i} [(\omega n * \rho n) - (\mu n + \gamma n + \tau n)]/\pi \quad (1)$$

where, $\omega n * \rho n$ is the gross income for each product n, ωn is the quantity produced, and ρn is the market price of the product. The gross income of each product is subtracted by the costs of its production: μn, labor costs, γn, input costs, and τn, transportation cost. Examples of input costs vary according to the specificities of production systems including seeds, fertilizers, pesticides and the depreciation of equipment. Transportation costs are calculated to each individual product (average value per ton using an average distance of 65 km to the nearest market), Σ is the sum of net revenue from all products that is divided by the total area of each type of production system (annual crops, perennial crops, pasture and forest) (π) (see Table 1).

Table 1
Prices and costs of the products as of 2010.

Products[1] *Annual crops*	Price *(USD/kg) Average*	Production costs *(USD/ton/year)* average	Transportation costs[2] *(USD/ton/km)* average
Rice	0.42	169.34	0.73
Maize	0.32	145.10	0.72
Manioc	0.43	122.02	0.67
Coffee	1.00	185.15	0.71
Beans	1.02	205.23	1.00
Perennial crops	*(USD/kg)* average	*(USD/ton/year)* average	*(USD/ton/km)* average
Banana	0.15	32.30	0.41
Orange	0.30	95.30	1.00
Alligator pear	0.47	57.76	1.20
Papaya	0.36	70.76	0.76
Tangerine	0.43	80.30	0.92
Lemon	0.44	84.37	0.71
Pineapple	0.42	30.42	0.90
Cucumber	0.44	23.45	0.17
Tomato	0.43	32.56	0.14
Pumpkin	0.15	20.45	0.17
Livestock	*(USD/kg/ head) average*	*(USD/head/year)* average	*(USD/head/km)* average
Cattle	2.7/321.4	96.42	0.34
Chicken	3.2/9.8	17.11	0.02
Pigs	3.4/64.2	100.95	0.17
Sheep	3.67/89.2	350.45	0.25
Non-timber forest products	*(USD/kg)* average	*(USD/ton/year)* average	*(USD/ton/km)* average
Brazil-nut	2.21	14.31	0.82
Cupuaçu	1.89	28.92	0.71

Source: Data from the interviews.
[1] The daily wage is USD 7.5 (on average, 3 external workers are hired for 60 days).
[2] Considers an average distance to market of 65 km and average costs of transport (paved and unpaved roads).

2.2.1. The role of different productive systems in the generation of smalholders's net revenue

We evaluated the contribution of the different productive systems (agriculture, livestock and NTFP) to the annual net revenue of the 62 smallholders through a statistical model implemented using *glmnet* package in R suite. In general, the annual net revenue for each family comprises a mix of productive systems such as agriculture, cattle rearing, NTFP extractivism, and others (Table 1). Agriculture comprises the annual crops including rice and corn, and perennial crops such as fruits. Extractivist activities comprise the collection of Brazil nuts and cupuaçu, while livestock refers to cattle breeding for beef. The category "others" refers to poultry, pigs and sheep. We therefore estimate the annual net revenue for each productive system for each individual smallholder family. The annual net revenue for each productive system comprises the response variables. Property features and production costs are predictor variables to estimate the proportion of the annual net revenue from each productive system. The predictor variables are distance to paved roads (km), forest area (ha), area of annual

Table 2
Socioeconomic profile of smallholders.

Statistical variables (N = 62)	Minimum	Maximum	Mean	Std. Deviation
Gross income (Thousand USD/year)	0.20	27.7	5.4	5.8
Total cost (Thousand USD/year)	0.04	25.3	3.2	4.4
Labor costs (Thousand USD/year)	0.04	14.2	1.7	2.5
Input costs (Thousand USD/year)	0.1	8.0	1.0	1.7
Transportation costs (Thousand USD/year)	0.1	4.2	0.4	0.7
Distance to market (km)	1	222	43.0	49.5
Resident population (N°)[1]	1	9	4	2.0
Total area (ha)	10	470	73.2	70.6
Forest area (ha)	1	410	42.7	59.0
Area of annual crops (ha)	0	30	8.2	8.3
Area of perennial crops (ha)	0	25	5.6	7.0
Area of fallow agricultural land (ha)	0	35	4.2	7.5
Pasture area (ha)	0	86	12.4	19.5
Net income (USD/ha/year)	**0**	**82.0**	**35.2**	**25.7**

Source: Data from the interviews.
[1] Other socio-demographic characteristics on the families can be found in Table S3.

Table 3
Production of smallholders.

Statistical variables (N = 62)	Minimum	Maximum	Mean	Std. Deviation
p[1]				
Annual crops (kg/year)	0	30,000	4676	5661
Perennial crops (Kg/year)	0	72,000	5671	13,717
Animals[2]				
Cattle (Kg/year)	0	50,000	1874	6632
Chicken (kg/year)	0	4800	105	613
Pigs (Kg/year)	0	1280	60	223
Sheep (Kg/year)	0	500	20	84
NTTPs				
Brazil-nut (Kg/year)	0	6500	190	870
Cupuaçu (Kg/year)	0	15,600	343	2037

Source: Data from the interviews.
[1] All agricultural products and their produced quantities are listed in Table S4.
[2] We consider the live weight of the animal and the respective utilization rate: cattle (average on 500 kg per animal and 20% rate of utilization); chicken (average on 2 kg per animal and 80% rate of utilization); pigs (average on 80 kg per animal and 80% rate of utilization) and sheep (average on 50 kg per animal and 20% rate of utilization) – average values – as collected in the interviews.

agriculture (ha), area of perennial agriculture (ha), area of fallow agricultural land (ha), pasture area (ha), labor costs, input costs and transportation costs (Tables 2 and 3).

Let Y_i be the total annual net revenue for the i property, $i = 1, \cdots, 62$, and Y_{ij} is the annual net revenue related to the j productive systems, $j = 1, 2, 3, 4$, listed previously, $Y_i = \sum_j Y_{ij}$. Let p_{ij} be the proportion, or share, of the total annual net revenue related to the j productive system. p_{ij} can be denoted as a function of the predictor variables using a multinomial logistic function, as proposed by Zhu (2004) (Eq. (2)).

$$p_{ij} = \frac{\exp(\beta_{0j} + \beta_{1j}x_{1i} + \cdots + \beta_{9j}x_{9i})}{\sum_{j=1}^{4} \exp(\beta_{0j} + \beta_{1j}x_{1i} + \cdots + \beta_{9j}x_{9i})} \tag{2}$$

Each productive system is represented by a set of coefficients, $\beta_{0j}, \beta_{1j}, \cdots, \beta_{9j}$ which need to be estimated. Furthermore, each coefficient β_{kj}, $k = 1, \cdots, 9$, is associated with one predictor variable. Positive coefficients β_{kj} comprise variables that positively contribute to a larger proportion of the j productive system in the annual net revenue. Similarly, negative coefficients comprise variables that decrease the proportion of the j productive system in the annual net revenue. Given p_{ij}, the annual net revenue related to each productive system is calculated as $Y_i \times p_{ij}$. The proposed model resembles a statistical multinomial model (Collet, 2003; Mosimann, 1962), in which a given a total number of outcomes, say Y, the proportion of Y in pre-defined categories are modeled. Consequently, the coefficients are estimated by maximizing the log-likelihood of the multinomial distribution. The log-likelihood of the multinomial distribution is as follows.

$$l(\{\beta_{0j}, \beta_{9j}\}_{j=1}^{4}) = \frac{1}{n}\sum_{i=1}^{n}\left[\sum_{j=1}^{4} y_{ij}(\beta_{0j} + \beta_{1j}x_{1j} + \cdots + \beta_{9j}x_{9j}) - \log\left(\sum_{j=1}^{4} e^{\beta_{0j} + \beta_{1j}x_{1j} + \cdots + \beta_{9j}x_{9j}}\right)\right] \tag{3}$$

where n is the sample size. With Eq. (3) it is possible to investigate separately the correlation between the proposed predictor variables and the annual net revenue related to each productive system. Nonetheless, it is worth mentioning that the available sample size is small. In addition, some productive systems have few, non-zero observations. For example, extractivism has only 10 non-zero observations, which represent 16% of the data. In general, a property contains multiple productive systems, therefore sharing resources. Finally, as opposed to measuring the amount of kilograms produced in each productive system, we rely instead on evaluating the financial impact of each productive system in the annual net income of each property, thereby achieving a common financial response for each productive system.

The statistical properties of the multinomial distribution can be applied to continuous data, such as the smallholders net revenue by using quasi-likelihood models (McCullagh & Nelder, 1989; Wedderburn, 1974). Therefore, the multinomial logistic model applied in this work relies on the properties of the quasi-likelihood theory.

Our statistical model estimates the coefficients related to each productive system to provide statistical inference. There is, however, evidence that the sample is biased thus standard statistical inference is compromised. An alternative is to use cross-validation techniques (Friedman, Hastie, & Tibshirani, 2001) in order to select the most predictive models, given the sample. This alternative has been used by Costa, Huang, Moore, Kulldorff, and Finkelstein (2011) to select covariates when using small biased samples. Using cross-validation methods, a subset of the sample, named as the validation set, is initially taken out. The remaining sample is named as the training set. Statistical models are estimated using the training set. In sequence, the validation set is used to calculate predictive statistics. This procedure is repeated several times in order to generate different training and validation sets. The statistical model with the best predictive statistic is selected. Further details of cross-validation techniques are found in Friedman et al. (2001). In addition, the elastic net penalty function (Friedman, Hastie, & Tibshirani, 2010) is included in the maximization equation as follows:

$$P_\alpha(\beta) = (1-\alpha)\frac{1}{2}\sum_{k,j}\beta_{kj}^2 + \alpha\sum_{k,j}|\beta_{kj}| \tag{4}$$

Eq. (4) aims at selecting coefficients during the maximization problem. The penalty parameter α controls the number of coefficients, β_{kj}, which are estimated as zero. Eq. (3) combines the ridge regression penalty (Hoerl & Kennard, 1970) and the lasso regression penalty (Tibshirani, 1996). Further details about the elastic net penalty are found in Friedman et al. (2010). Thus, the coefficients of the proposed multinomial model are estimated by maximizing the penalized log-likelihood as in Eq. (5).

$$\hat{\beta}_{kj} = \arg_{\beta_{kj}} max\{l(\{\beta_{0j}, \beta_{9j}\}_{j=1}^{4}) - \lambda \cdot P_\alpha(\beta)\} \tag{5}$$

The *leave-one-out* cross validation (Friedman et al., 2001) is applied in this work. Given the sample of size $n = 62$, each observation is used

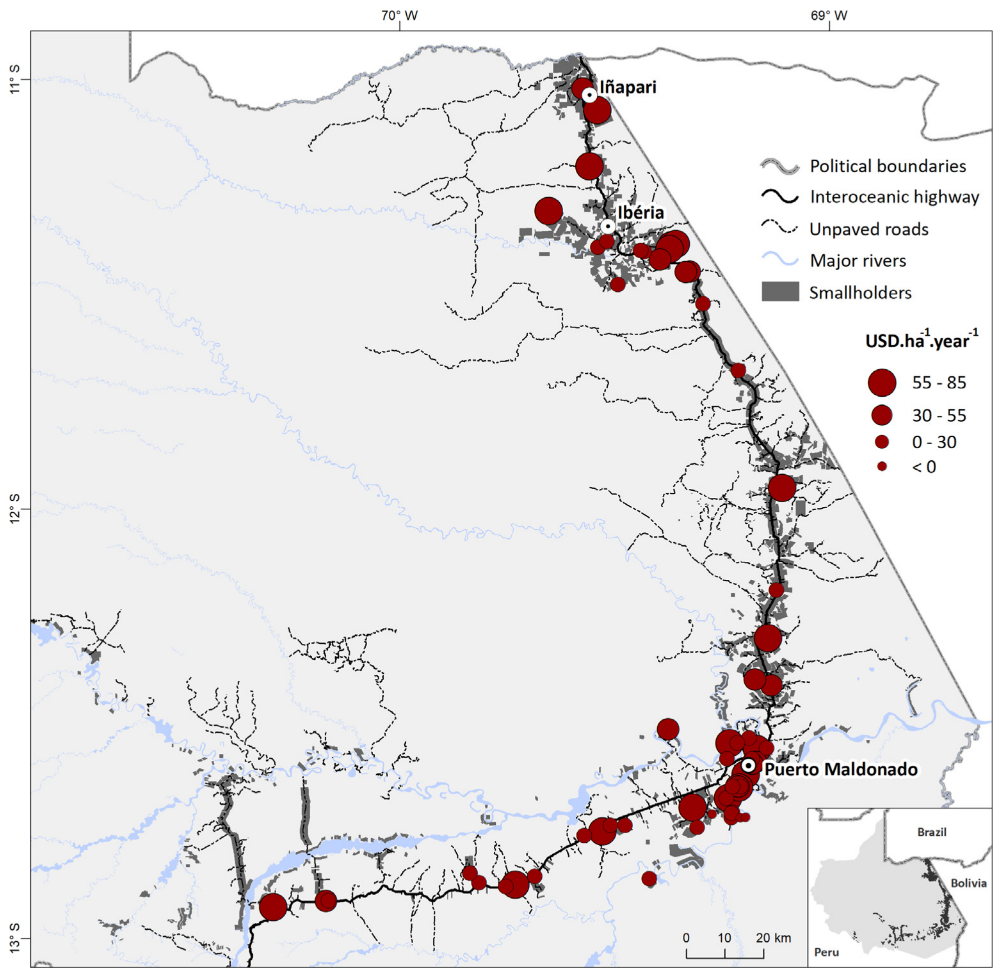

Fig. 2. Net revenue of the 62 families.

as a validation set. Therefore, 61 observations are used as training sets. This procedure is repeated 62 times, each time one different observation of the sample is used as the validation set. Let $\widehat{Y}_{(i)}$ be the estimated annual income of property i which was used as the validation set. The predictive error is denoted in Eq. (6). In addition, the *leave-one-out* cross validation is applied to select the penalty parameters λ and α. Briefly, the predictive error is applied to a grid of λ and α values. The λ and α values with the minimum predictive error are selected.

$$PRESS = \sum_{i=1}^{n} (Y_i - \widehat{Y}_{(i)})^2 \quad (6)$$

3. Results

3.1. The role of different production systems in the generation of stakeholders' net income

The average size of landholdings for the 62 families we interviewed is 73.2 ± 70.6 ha, to whom we estimate an average net revenue of USD 35.2 ± 25.7 $\text{ha}^{-1}\text{yr}^{-1}$. Fig. 2 shows the spatial distribution of net revenues of smallholders across the study area. Fig. 2 shows that along the Interoceanic Highway, higher rents tend to concentrate near major urban centers, i.e. Porto Maldonado and Iberia.

On average, families in our sample are composed of 4 individuals (see Table S3 for details of sociodemographic characteristics of interviewees). In the landholdings, forest areas are the most representative land use occupying on average 42.7 ± 59.0 ha, followed by pastures 12.4 ± 19.5 ha, and annual cropping 8.2 ± 8.3 ha (Table 2). The highest production cost of our interviewees is associated to outsourced labor, whose expenses are on average USD 1.7 ± 2.5 thousand per year. Transport costs were found to be the lowest USD 0.4 ± 0.7 thousand per year, likely due to proximity of the landholdings with the nearest retail outlet (on average 43 km) (Table 2). Transport costs reflect the average of what is spent by interviewees considering both paved and unpaved roads. For example, the average cost of transportation of rice using paved roads is of 0.63 USD/ton/km and the average transport costs of rice by unpaved roads is 0.83 USD/ton/km. Thus, we calculate the average transport costs for rice as the mean between 0.63 USS/ton/km and 0.83 US$/t/km, that is, 0.73 USD/ton/km (Table 2).

Regarding to property rights, we found that 57% of the families interviewed acquired the property by purchase, but without public deed. About 34% acquired the property for concession for agricultural use, 7% purchased it with public deed and 2% for possession. Other relevant information is that that 70% of the smallholders do not hold certification for their products and 36% claimed not to pay taxes on the land.

Although forest areas occupy 57% of the landholding (42 out 73 ha, on average), for the vast majority of our interviewees (88.7%), income comes only from agricultural land with an overwhelming reliance on agriculture productive systems (see next section). On average, more than 5500 kg of perennial crops are produced per year, especially banana, pineapple, cucumber and avocado (Tables 3 and S4). Among annual crops, rice and maize stand out with an average of 4600 kg per year each. Beef production reaches more than 1500 kg per year. Finally, extractivist activities consist of collection of cupuaçu (avg. 340 kg per year) as well as Brazil nut (avg. 190 kg per year) (Table 3).

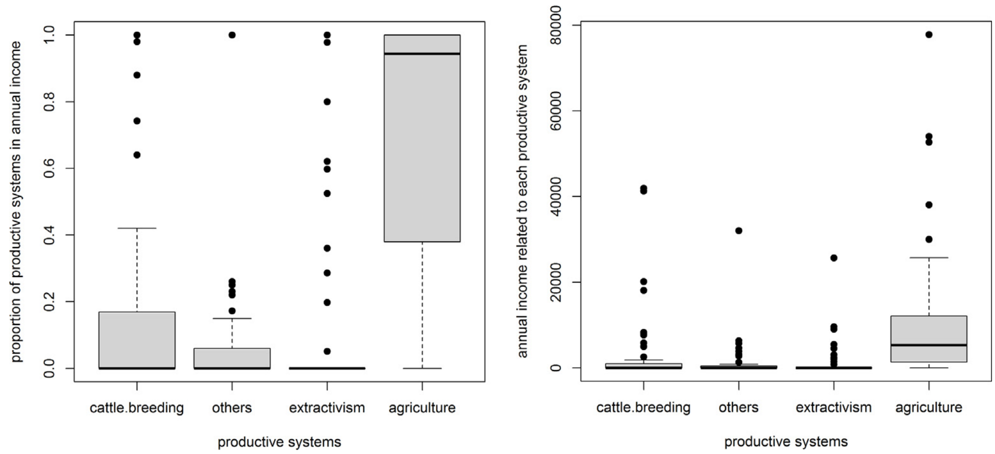

Fig. 3. (a) Boxplot of the proportion of productive systems in the annual income of the properties. (b) Boxplot of the annual income of the properties for each productive system.

3.2. Share of the net revenue from different productive systems

Fig. 3(a) shows the proportion of each productive system in the annual net revenue of each landholding. Agriculture is the productive system that contributes the most to smallholders' net revenue. It is worth noticing that the median proportion for cattle breeding and other productive systems is zero, which means that at least 50% of the families do not raise any cattle, poultry, pig or sheep. Only a few interviewees in our sample have income from NTFPs extractivism (N = 10). Nevertheless, annual income share from extractivism is large for these families (Fig. 3(b)). In sum, annual net revenue from agriculture is the largest contributor to smallholders' annual income, followed by cattle breeding.

Table 4 shows the estimated coefficients of the multinomial regression model. Results are provided for all coefficients. Our results show that among the 9 predictors, only pasture area, transportation costs and input costs presented non-zero coefficients. For the agriculture productive system, the variable "input costs" is the major predictor. The larger the input costs, the larger the proportion of agriculture productive system in the property annual income. For extractivist activities, the transportation costs are the main predictor. Increased transportation costs result in a larger proportion of extractivist productive system in the property annual income. For the cattle breeding productive system, area of pasture is the main predictor. Larger pasture areas result in a larger proportion of cattle breeding productive system contribution to the smallholder annual income. Finally, for other productive systems (comprising chicken, pigs), no predictor was selected. Nonetheless, it worth mentioning that the multinomial model estimates the contribution of the different productive systems to the family annual net revenue. Since the proportions estimated in each productive system sum up to one, then it can be said that the lower the input costs, the transportation costs and the pasture area, the larger the proportion of other productive systems in the property annual income.

As described in Section 2.2.1, the proposed statistical model comprises a multinomial logistic function whose coefficients are estimated using one-leave-out cross validation and penalized maximum likelihood, as shown in Eq. (5). Using the elastic net penalty function (Friedman et al., 2010), some of the coefficients are estimated as zero. Cross-validation is applied to estimate the penalty parameter. Therefore, Table 4 shows all estimated coefficients (including zero), as described in Section 3.2. The proposed statistical methodology was required in order to deal with a small biased sample, as proposed by Costa et al. (2011).

The deviance (Pierce & Schafer, 1986), AIC (Sakamoto, Ishiguro, & Kitagawa, 1988) and BIC (Schwarz, 1978) statistics were used to compare the multinomial model adjusted only by the intercept, i.e., with no predictors, with the proposed multinomial model shown in Table 4. The multinomial model with no predictors presented deviance = 634,198, AIC = 634,378 and BIC = 634,386, whereas the proposed multinomial model with predictors presented deviance = 510,100, AIC = 510,280 and BIC = 510,288. Although larger values of the evaluated statistics (deviance, AIC and BIC) in all models indicate the presence of overdispersion (Cox, 1983), major differences between the evaluated statistics, with and without the selected predictors, suggest strong statistical significance of the predictors to estimate the contribution of the different productive systems to the annual income of the smallholders. For instance, the difference between the deviance estimated without and with predictors is 124,098. Based on the likelihood-ratio test (Casella & Berger, 2002) the difference can be compared with a Chi-Square distribution with k = 4 degrees of freedom or $\chi^2_{(\alpha=0.05,\mathrm{df}=4)} = 9.4877$. Therefore, a large difference between the deviance indicates strong statistical significance of the predictors, as previously mentioned.

Table 4
Estimated coefficients of the multinomial logistic model using leave-one-out cross validation and penalized log-likelihood maximization.

Coefficient	Productive Systems			
	Agriculture	Extractivism	Cattle breeding	Others
Intercept	0.002933	−0.592437	−0.151366	−0.434021
Distance to paved roads	0	0	0	0
Forest area	0	0	0	0
Area of annual agriculture	0	0	0	0
Area of perennial agriculture	0	0	0	0
Area of fallow agriculture land	0	0	0	0
Pasture area	0	0	0.027222	0
Labor costs	0	0	0	0
Input costs	6.0997E−05	0	0	0
Transportation costs	0	4.6470E−06	0	0

4. Discussion

In this exploratory study we found no substantial evidence that the new infrastructure has substantially improved the livelihood of smallholders in the Amazon. We found an average net revenue of USD 35.2 $ha^{-1}yr^{-1}$ for a sample of 62 smallholders along the ISH as of 2010. Our estimate is similar to that found for Mexico, corresponding of USD 34.7 $ha^{-1}yr^{-1}$ (Gravel, 2007), but lower than the values found for Ecuador (USD 67–421 $ha^{-1}yr^{-1}$), Chile (USD 50 $ha^{-1}yr^{-1}$), and Brazil (USD 104 $ha^{-1}yr^{-1}$) (Table S1). Most importantly, our result is only slightly higher than the annual net revenue of USD 33 $ha^{-1}yr^{-1}$ estimated in 1999, before the paving of the Interoceanic Highway by Escobal and Aldana (2003). Although we acknowledge that methodological differences may hinder a straight comparison among these studies, our results suggest that the paving of the Interoceanic Highway barely increased the income of smallholders along the road.

This result seems contradictory when confronted with expectations by policy makers over local development through large infrastructure projects such as highways (PR, 2005; Selamat, 2012) particularly the claim that "…(ISH) distributes, in a more balanced way, its benefits…" (PR, 2005, p. 1). What would explain this finding? In fact, an increasing number of studies have shown that the benefits that large infrastructure projects bring to society are unevenly distributed. Researchers have shown that even in developed countries, highways can negatively affect some areas while benefiting others by prompting economic growth of those that are closer to large urban centers, and reducing economic attractiveness of those that are farther away (Rephann & Isserman, 1994). In addition, lower transportation costs may benefit activities that depend on logistics involving large distances while decreasing economic importance of others by relocating markets (Chandra & Thompson, 2000).

Our results show that for the 62 families interviewed in this study, the generation of net revenue is dependent on a polycentric economy located around regional towns, hence a function of local transportation routes (rather than regional highways) and local demand for agriculture products through accessible markets (Fig. 2). This means that these forest livelihoods in the region still rely on regional market niches, where the traditional structure of local communities prevails and the economy tends to be informal, as a function of local demands. Hence, this reveals that smallholders barely extend their market access beyond their region, even in the presence of the recently upgraded ISH. Therefore, the supposed regional integration through the ISH was not quickly and directly reflected, as expected by the Peruvian Government, in the development of small-scale agriculture and family forests in MDD, whose land-use rents remain low (Table 2). This indicates that the potential connections with markets, virtually boosted by the newly paved ISH, are not sufficient to increase financial return to smallholders. Several issues such as land tenure, education and access to markets all serve as hindrances to the pursuit of improved income generation to the family forests in MDD. There is certainly need for upgrading government extension programs, including assistance and credit as well as education and professional training activities. However, more importantly, is that it is likely that isolated policy programs (education, tourism) as well as big infrastructural initiatives' (e.g. highway paving) are only selected components of a more complicated equation that defines economic development. If we assume development to be a process that triggers economic, social and cultural changes, which in turn enables stakeholders to move forward, allowing them greater opportunity to achieve their potential, then we can say that ISH did not seem to bring it to the majority of small scale farmers and family forests in MDD. Therefore, the question "development for whom?" still needs to be comprehensively explored in the context of the biggest tropical forest in the world.

In contrast to the small scale farmers, *commodity* producers have benefited from the Interoceanic Highway. This was true particularly for the timber industry and Brazil nut concessionaires, whose production increased by 9% and 26% between 2009 and 2011, respectively (INEI, 2015). Similarly, the Interoceanic Highway that is now 2600 km long and crosses ecologically rich tropical forests that concentrates a great number of endemic species (Mendoza et al., 2007; Myers, Mittermeier, Mittermeier, da Fonseca, & Kent, 2000) is increasingly important for regional development through ecotourism (Dourojeanni, 2006; Kirkby et al., 2010; Mendoza et al., 2007). In addition, to improve conditions for tourism in MDD, the highway allows the transportation of Brazilian products from the North and Middle-West of Brazil to Pacific ports such as Ilo, Matarani and San Juan (INEI, 2009). From those ports in the Pacific, agricultural products from inland Brazilian and Peruvian regions (such as MDD) can be exported to Asian markets. Therefore, the highway is indeed critical for decreasing the transportation costs of these "*commodities*" and is seen as an alternative route for exportation of industrialized and *in-natura* products, such as timber, nuts and minerals. The highway was also expected to benefit soybean and beef exports (Pfaff et al., 2009).

According to Bonifaz, Urrunaga, and Astorne (2008) the indirect benefits of the Interoceanic Highway due to lower transportation costs were expected to generate USD 24.0 million per year for loggers, and USD 1.5 million per year for Brazil nut collectors. However, our results suggest that this increase, if it in fact occurred, only benefited the middle-size to large-scale producers, such as timber and Brazil nuts concessionaires, while the net revenue of smallholders and family forests hardly increased. For instance, the production of their most important items, rice and maize, decreased by 29% and 11% between 2011 and 2012, respectively (GOREMAD, 2014).

There remain many obstacles before smallholders in MDD can overcome transaction costs imposed by those more complex markets made virtually accessible through the ISH. These transaction costs would be mainly related to land tenure issues (Perz et al., 2016; Scullion, Vogt, Sienkiewicz, Gmur, & Trujillo, 2014), one of the most important barriers to forest conservation and land use regulation in the region (Scullion et al., 2014). Land conflicts are clearly associated with the fact that MDD has been historically isolated from the rest of Peru, where public policies tend to focus on the central regions of the country (Perz et al., 2016). In this regard, large-scale producers, while benefiting from an increase in income prompted by the highway, have more access and lower transportation costs to once remote lands, a situation that may lead to increasing opportunities for land speculation and conflicts with traditional forest communities and small-scale farming settlers. As shown in our results, land tenure issues are in fact something of great concern along the ISH: more than half of our interviewees do not have a property deed. Lack of legal land titling in the Peruvian Amazon has been long criticized by scholars (e.g. Shoobridge, 1995). Additionally, MDD is known as a region with problems of land-use concessions overlapping and conflicts of land-use rights, which even threatens the attentionality of conservation efforts in the region (Chávez, Guariguata, Cronkleton, Menton, Capella, Araujo, & Quaedvlieg, 2010; Scullion et al., 2014).

One of the main obstacles preventing small farmers from benefiting from the highway is related to the characteristics of long distance markets. Large national and international markets are often more complex; they require a higher level of business formality and as such have a higher transaction cost. Without the improvement of basic education and support for the creation and professionalization of farmers' cooperatives, it is very unlikely that small farmers will reap the benefits. Another alternative is to bring higher income consumers by incentivizing tourism along the newly established routes, as already proposed by some certification schemes. Tourism could, by its turn, attract public and private funds, and as a result, add value to goods produced by smallholders. However, certification favors a narrow target group of farmers and it is often associated with high financial burdens for producer organizations (Bitzer, Glasbergen, & Arts, 2013). We need therefore to forge new solutions for associating forests with higher economic returns allied with infrastructure projects, if they are to provide any benefits for the local community. Unless roads also bring educational, health and local business development policies, only bulk buyers and land speculators will benefit from public investment in infrastructure (Swinton, Escobar, & Reardon, 2003). This indicates that the connection with markets alone is not sufficient to increase rents of small-scale agricultural production.

Agriculture and cattle ranching tend to be linked to higher contributions to income, though with larger environmental impact (Duchelle et al., 2014). In fact, small-scale agriculture plays a very important role in local and national food supply, which is clearly linked to food security in the country. By contrast, despite occupying 57% of the area of the landholding, forests contribute to a lesser extent to economic returns. It is necessary to forge new solutions for associating forests with higher economic returns. Imaginative incentive policies for good forest stewardship are therefore required (Swinton et al., 2003).

Pasture area, transportation costs and input costs are the most predictive variables to estimate the proportion of the four different productive systems in the annual income of the properties, reflecting the diversification of income sources and consequently income security. It becomes clear that if smallholders cannot count on specific policies targeting their productive systems, obstacles will remain when it comes to costs. Hence, large infrastructure projects can only benefit small-scale producers if accompanied by public policy aimed at increasing their access to production factors, information, and financial incentives. In order to design such policies, a better understanding of the dynamics of forest frontiers facing accelerated changes is also necessary (le Polain de Waroux et al., 2018).

Despite some methodological challenges (e.g. sample bias), our exploratory study contributed to the understanding of the dynamics of family forests in the Amazon surrounding large infrastructure projects such as highways. Further work, focusing on the social aspects of smallholders' livelihoods, such as social connectivity and the ways in which social ties contribute to reduce costs of production, will be a step forward for refining our results (Devereux, 2001; Kay, 2006). Smallholders are riddled with social linkages and inter-personal and inter-familial relations because they need to reciprocate and to share in times of threat. Through these organizations, families establish partnerships for the purchase of seeds and machinery in order to improve production. Certainly, these “safety nets” need to be accounted for in further economic assessments.

5. Conclusion

As to whether large infrastructure projects, such as highways, may produce greater development for tropical forests’ smallholders, we found no evidence that the newly paved ISH enhanced the net incomes of our sample of 62 smallholders in the Madre de Dios region, suggesting a lack of positive economic returns even in the presence of big infrastructure projects such as ISH. Land access issues, as well as social capital limitations (e.g. education), are crucial to understand the risks that smallholders in MDD face with the new economic dynamics prompted by the ISH. If smallholders cannot count on specific policies targeting their mix of productive systems, obstacles will remain when it comes to production costs. Hence, large infrastructure projects can only benefit small-scale producers if accompanied by a clear definition concerning for whom development is meant? This calls for a comprehensive approach including public and private policies aimed at increasing family forests access to production factors, transportation, access to markets, information, education and economic incentives that unfortunately were not yet in place in the MDD region.

The results of this work contribute to understanding the dynamics of small-scale farming in the biggest tropical forest in the world. The methods used both in data collection (semi structured interviews) and data analysis developed in this study, allow us to associate different production systems and land use patterns (crops, pasture, forest) to net revenues of family forests. These findings may significantly increase the ability to design, target and analyze development policies in the biggest tropical forest in the world. There are many obstacles and difficulties for producers to have access to factors of production, information, and to establish corporate agriculture. Our results show that small scale farming livelihoods are fragile as it is governance arrangements in these tropical frontiers. In this case, the challenges for small farmers to shape land use outcomes and obtain a differential capacity to capture income at the Amazon borders are still great.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.landurbplan.2019.04.025.

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