Tropical Deforestation in the Amazon: An Economic Analysis of Rondonia, Brazil

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Tropical forests are a unique environmental resource that provide numerous global benefits. Of the world's biomes, they provide the greatest biological diversity of plants and animals. It is estimated that these forests contain at least fifty percent of the world's animal species and almost seventy five percent of the world's plant species. Increased deforestation is likely to reduce this biodiversity and will result in many other negative impacts such as soil erosion, nutrient depletion, flooding, increased levels of greenhouse gases, disturbances in the carbon cycle and loss of forest products such as pharmaceuticals, timber and fuel.

In regions like the Brazilian Amazon, where the largest portion of the world's tropical forests is located, concern regarding deforestation has arisen because the current rate has accelerated to approximately 8000 hectares each year (Lui and Lu, 1992); (Dale and Pedlowski, 1992). The practice of agroforestry methods by farmers in some regions of the Amazon is thought to be a sufficient way to minimize the area of cleared forest while still allowing them to provide for themselves and their families. Therefore, minimizing the amount of land farmers use for agricultural production and ranching can reduce the amount of deforestation without a loss in total output (Caviglia and Kahn, 2001). To understand what factors drive farmers to deforest land, this paper uses empirical data to estimate different household land use alternatives in Rondonia, Brazil. Rondonia is chosen as the focus of this paper due to its accelerated deforestation rate and because data from this area is readily available. Based on the results presented, policy recommendations can be developed that may help to reduce deforestation levels.

2. DIVERSITY AMONG PRODUCERS

(a) Land use in the Amazon

The most commonly practiced agriculture methods in the Amazon include slash-and-burn, shifting cultivation and ranching. Slash-and-burn is the cutting and burning of forests to plant annual crops or provide pasture. It is thought to be inappropriate for this region because it strips the land of its nutrients. Moran et al. (1996) examine how human activities change the vegetation structure of the land. The authors analyze data from a combination of household surveys, soil and vegetation samples and satellite remote sensing data. Re-growth diversity of the land's invading species is found to be a result of the type of land clearing performed, the length of time the land is cultivated, and the intensity of cultivation. This implies that if less sustainable farming methods are used and coupled with intensive clearing methods such as slash-and-burn, the forest has a smaller chance of recovering to its former state. In some cases, re-growth or secondary forest can have the same structure as that of primary forests. However, biodiversity of plant and animal life in secondary forests may require a recovery period of many centuries, assuming recovery will occur (Moran et al., 1996); (Dale and Pedlowski, 1992).

Shifting cultivation (or swidden agriculture) is a farming method commonly used by indigenous households where farmers cut and burn the land, plant annual crops for a few years and leave it fallow for up to 10 years. During the fallow time the land becomes secondary forest growth and the soil can recover its nutrients. Tonilolo and Uhl (1995) suggest that producing annual crops using shifting cultivation methods results in low returns but is adopted by some farm families because it has low operation costs. A high level of capital investment is not required and operation costs in this situation is primarily labor (Toniolo and Uhl, 1995).

Ranching is thought to be an inherently unsustainable use of tropical land because it requires the clearing of trees. Without trees, the nutrients will easily wash away leaving infertile soil. As a result, this land use prohibits farmers from utilizing the same area for more than a couple of years. They tend to abandon the unproductive pasture and clear more forest area. Pasture creation can be a problem because an increasing amount of farmers have been expanding this practice, which is becoming a major contributor to increased deforestation. Ranching requires a substantial amount of capital for fences, the purchase of cattle and expenses to maintain cattle (Walker et al., 2000); (Dale and Pedlowski, 1992). This may impose barriers to farmers from entering the cattle market if they are resource poor and survive on a subsistence wage.

Agroforestry has more potential than slash-and-burn methods for reducing deforestation because this agricultural method depends upon the standing forest to generate income and supports a greater biodiversity. Sustainable methods such as agroforestry are methods that mix perennial and/or annual crops with existing trees. These methods can help reduce deforestation since they do not depend upon the removal of the tree canopy yet allow farmers to harvest on one land area for an extended period of time. Agroforestry is not a widely used technique in this region of the world because many farmers do not have access to planting materials or the financial capital to establish this type of farming system. This system allows farmers to produce a diverse composition of crops that are not all used for domestic consumption.

(b) Small producers and large producers

It is important to make a distinction between small and large producers since both have different impacts on deforestation and will react differently to various policies. This paper focuses solely on small producers. Small producers use a variety of agricultural methods; many do not rely solely on revenue from one type of production practice. Large producers usually specialize in a particular practice such as ranching on a much larger scale. Small producers in the study of Walker et al. (2000) are defined as individuals who received land grants between 50-100 hectares and large producers have a lot area of over 1000 hectares. The authors surveyed 132 small producers and collected data on the farming systems used, economic information and demographic information. As a result, ranching is shown to be a major component of deforestation (between 21 percent and 70 percent) and small producers are responsible for at least half of the area cleared for ranching.

3. EMPIRICAL ANALYSIS

(a) Description of variables used in this Model

The analysis in this paper utilizes household data collected in Ouro Preto do Oeste, Rondonia located on the western border of Brazil[*]. Rondonia has a population of approximately 92,000, 58 percent of whom live in rural areas. The region Ouro Preto do Oeste was established in the 1970's and is comprised of six municipalities. The farmers of this region are predominately small producers; the mean lot size of the observations is 62.6 hectares. The questionnaires were administered to 152 randomly selected farmers and include information on family characteristics, land use, production data and methods of deforestation. The method of regression used to model the effects of deforestation in this area is ordinary least squares.

To incorporate a broad spectrum of independent variables that could have an effect on deforestation, variables were chosen to represent family characteristics, farm characteristics and agricultural inputs. The list of variables used in the model is provided in Table 1. Independent variables that represent family characteristics include average age and education level of the household heads, years lived on the farm, number of children on the farm and number of bank accounts and loans held by the household.

Family characteristics such as these might have an impact on deforestation since families that remain on the lot for a longer period of time might deforest less. This is because they may pass on the land to future generations. A household that has several loans or bank accounts may possess the financial means to deforest the land at a larger scale. In this area, banks are not well established and require a relatively large accumulation of wealth to possess an account.

Variables that describe farm characteristics include distance of roads to the city center and road conditions during the rainy season. To avoid multicollinearity, the variable total distance of all roads to the city center is not included in the model with the sum of paved and unpaved distances. Instead, the variables representing paved and unpaved distances are included to test the significance of these variables on the dependent variable. Farm characteristics such as these can affect deforestation. If the distance to the city center or markets is small, farmers are likely to deforest more to sell agricultural goods at the market. Impassible roads may hinder farmers from selling their produce in the market as well.

Independent variables representing technological and agricultural inputs include the amount of chainsaws, cattle and workers a household owns and total income. The more technological inputs that a farmer owns the easier it may be to deforest.

(b) Empirical Model

Five different linear regressions are estimated to determine if the independent variables presented above have effects on specific land uses. These estimations include total deforestation (*TOTDEF*), pasture (*PASTURE*), agriculture (*AGRI*), forest (*FOREST*) and agroforestry (*AGRO*). The total area of each lot consists of total deforested land and standing forest. Total deforested land is divided between land devoted to pasture and agricultural land. The measure of standing forest includes agroforestry land uses. Like Pichon's (1997) study, this division of land use can be helpful in determining the factors that are influential in land use decisions, how land use affects the farmer's welfare and ultimately in the guiding of policy to reduce deforestation.

(c) Estimation of Total Deforestation

In the estimation of total deforestation the following regression equation was estimated:

Total Deforestation = f (*AVEAGE*, *AVEEDU*, *YRFARM*, *DISPROAD*, *DISUROAD*, *ADULTM*, *ADULTF*, *CHILD*, *INCTOT*, *ROADCON*, *CHAIN*, *CATTLE*, *WORKER*, *LOANS* and *BANKAC*)

The adjusted R squared measure for this model is 0.597, which is the percentage of variation in the data that is explained by the model adjusted for the number of total independent variables[1] (Table 2). It is a common measure of the relative strength of the regression model. The F statistic is 15.916 with a p-value of 0.000, which is the ratio of the hypothesis variance and unrestricted variance, also indicates the strength of the linear relationship. Generally a larger F value is associated with a strong model. Since the p-value is less than an alpha of 0.001, the model is significant with a 0.000 chance of error.

Distance of paved road to the city center (*DISPROAD*) is found to be significant and negative because the farther away the lot is from markets, the less incentive there is to deforest and produce food to sell in the market. Significant technological inputs on the farm include number of chainsaws (*CHAIN*) and number of cattle (*CATTLE*), both of which are positive. This is consistent with the results of Pichon (1997) and Walker et al.(2000). Significant family characteristics, such as average age of household heads (*AVEAGE*) and years lived on the farm (*YRFARM*) are also positively related to deforestation levels. These variables are likely to be significant because the longer the family remains on the farm, the more area they are physically able to deforest. The number of loans (*LOANS*) is significant and negative; however, Almeida's (1992) study suggests otherwise. The microeconomic theory maintains that the higher debt is a result of poorly structured markets. High debt leads to labor intensive farming that contributes greatly to over-deforestation. Perhaps in this study site, loans are used for purposes not related to deforestation.

Table 2
Total Deforestation Results

Variable	AVEAGE	AVEEDU	YRFARM	DISPROAD	DISUROAD	ADULTM	ADULTF	INCTOT
Coefficient	0.329387	1.144365	0.587411	-0.397663	-0.33054	1.347388	-1.21462	0.00017
P-value	0.041384	0.303125	0.030281	0.196505	0.00031	0.27025	0.315104	0.170885

Variable	ROADCON	CHAIN	CATTLE	WORKER	LOANS	BANKAC	CHILD	Intercept
Coefficient	1.052126	6.034427	0.149832	-4.149803	-6.901366	0.732253	1.10798	15.76325
P-value	0.574613	0.058107	2.53E-09	0.264756	0.029382	0.858294	0.159892	0.164462

		P-value
R Squared	0.637086	
Adj R Sq	0.597059	
F-stat	15.91629	4.05E-23

(d) Estimation of Pasture Land

In the estimation of pasture the following equation was utilized:

Pasture = f (*AVEAGE*, *AVEEDU*, *YRFARM*, *DISPROAD*, *DISUROAD*, *ADULTM*, *ADULTF*, *CHILD*, *INCTOT*, *ROADCON*, *CHAIN*, C*ATTLE*, *WORKER*, *LOANS* and *BANKAC*)

The F statistic in this study is 16.070 with a corresponding p-value of 0.000. The adjusted R squared for this model is 0.600, both suggesting a fairly strong model. Similar to the estimation of deforestation, the number of cattle, number of years lived on the farm and number of chainsaws is significant and positive (Table 3). The distance of paved roads to the city center, number of adult females on the farm (*ADULTF*) and number of loans is significant and negative.

Again, resembling the total deforestation results, the more technological inputs a farm can provide, the more area can be cleared and accessible markets give farmers incentives to raise more cattle.

Since this study pertains to small producers, it is important to recognize that ranching on a large scale is not always a viable option for small producers because it requires a substantial amount of capital and does not result in returns for a delayed period of time (Walker et al., 2000). However, if the family labor supply increases, it becomes more likely that farmers will adopt systems such as ranching. Walker and Homma (1996) focus their study on small producers and link land use choices to land cover outcomes. They suggest that land availability, off-farm employment, product price movement and quality of public infrastructure can all be factors that influence the production methods of small producers. Therefore, it is expected that number of workers employed and distance of roads to the city center will be positive and negative, respectively.

When comparing these results with studies measuring ranching decisions, Walker et al. (2000) find cattle and years on the farm to be significant and positive. Pichon (1997) discovers comparable results with education (*AVEEDU*), number of chainsaws, amount of total debt and number of cattle significant and positive.

Table 3
Pasture Results

Variable	AVEAGE	AVEEDU	YRFARM	DISPROAD	DISUROAD	ADULTM	ADULTF	INCTOT
Coefficient	0.253946	0.673306	0.468891	-0.481873	-0.364834	0.632949	-1.959721	8.80E-05
P-value	0.112127	0.541176	0.080618	0.115475	6.66E-05	0.601279	0.103607	0.474925

Variable	ROADCON	CHAIN	CATTLE	WORKER	LOANS	BANKAC	CHILD	Intercept
Coefficient	0.48276	5.672065	0.165074	-2.795148	-6.61752	1.274258	0.661276	23.51671
P-value	0.795236	0.072618	6.86E-11	0.448724	0.035285	0.754345	0.397081	0.037543

		P-value
R Squared	0.639301	

Adj R Sq	0.599518	
F-stat	16.06972	2.73E-23

(e)Estimation of Agricultural Land Use

In the estimation of agricultural land use, equation (3) was estimated.

Agriculture = f (*AVEAGE*, *AVEEDU*, *YRFARM*, *DISPROAD*, *DISUROAD*, *ADULTM*, *ADULTF*, *CHILD*, *INCTOT*, *ROADCON*, *CHAIN*, C*ATTLE*, *WORKER*, *LOANS* and *BANKAC*)

It is suspected that distance of roads to the city center may be significant and negative since farmers who have greater access to markets are more likely to plant annual crops to sell. Surprisingly, the regression analysis shows that distance of unpaved roads is insignificant, while total income and number of adult males, females and children is significant and positive (Table 4). Commonly, families in this area produce food for their own consumption; thus, a bigger family size demands greater agriculture production to survive. Agricultural production is also very labor intensive and therefore remains the limiting factor of production; non-family labor is not readily available to hire and increases production costs. The number of cattle is significant and negative since the more cattle a farmer owns, the less will be devoted to the amount of land used for agriculture. Average education was not a significant variable in this model; however, Pichon (1997) finds education to be significant and positive in the determination of the share of farm area allocated to food production. The F statistic for this model is 5.459 with a p-value of 0.000 and the adjusted R squared is 0.307. Although this model does not seem to be as sound as the previous two, there are some important significant results.

Table 4
Agriculture Results

Variable	AVEAGE	AVEEDU	YRFARM	DISPROAD	DISUROAD	ADULTM	ADULTF	INCTOT
Coefficient	0.075441	0.471059	0.11852	0.08421	0.034295	0.714439	0.745101	8.23E-05
P-value	0.112317	0.151635	0.13674	0.353291	0.195265	0.048698	0.037932	0.025759

Variable	ROADCON	CHAIN	CATTLE	WORKER	LOANS	BANKAC	CHILD	Intercept
Coefficient	0.569366	0.362363	-0.01524	-1.35465	-0.28385	-0.54201	0.446704	-7.75346
P-value	0.304011	0.697979	0.029455	0.217562	0.759433	0.654365	0.0556	0.021289

		P-value
R Squared	0.375804	
Adj R Sq	0.306959	
F-stat	5.458694	1.52E-08

(f) Estimation of Forest Land

In the estimation of the area remaining as forest the equation is as follows:

Forest = f (*AVEAGE*, *AVEEDU*, *YRFARM*, *DISPROAD*, *DISUROAD*, *ADULTM*, *ADULTF*, *CHILD*, *INCTOT*, *ROADCON*, *CHAIN*, C*ATTLE*, *WORKER*, *LOANS* and *BANKAC*)

Distance of paved road is the only significant variable and it is positive (Table 5). This can be explained by examining settlement patterns of the farmers. The first settlers will claim the area closest to the paved road. As mentioned before, the first colonists will have the greatest impact on the land, or deforest the most because of their access to markets and paved roads. The land will continue to be colonized in concentric circles around the previous settlers. The farther away the lot is from the paved road, the later the lot was settled and less deforestation has occurred which leaves more forest land. The corresponding F statistic is 1.183 with a p-value of 0.039, which means that the model is significant at the 0.05 level. The adjusted R squared is 0.075, which indicates a poor model, or perhaps an underspecified model. This may suggest that farm families do not consider decisions of how much standing forest should remain on a lot in the same way they make other land use choices.

Table 5
Forest Results

Variable	AVEAGE	AVEEDU	YRFARM	DISPROAD	DISUROAD	ADULTM	ADULTF	INCTOT
Coefficient	0.116096	0.611644	0.201585	0.599174	-0.03453	0.737858	-0.37476	6.13E-05
P-value	0.2736598	0.4042499	0.2572168	0.0036129	0.5590844	0.3602256	0.6383052	0.4543127

Variable	ROADCON	CHAIN	CATTLE	WORKER	LOANS	BANKAC	CHILD	Intercept
Coefficient	-0.15163	-1.0859	0.014761	-1.04638	-0.54246	-3.81012	0.75256	-2.91891
P-value	0.9024546	0.6033688	0.3425927	0.6696099	0.793672	0.1609507	0.1483696	0.6957022

		P-value
R Squared	0.166669	
Adj R Sq	0.074758	
F-stat	1.813367	0.0385358

(g) Estimation of Agroforestry Land

In the estimation of agroforestry the regression equation was:

Agroforestry = f (*AVEAGE*, *AVEEDU*, *YRFARM*, *DISPROAD*, *DISUROAD*, *ADULTM*, *ADULTF*, *CHILD*, *INCTOT*, *ROADCON*, *CHAIN*, C*ATTLE*, *WORKER*, *LOANS* and *BANKAC*)

It is beneficial to determine significant variables of area used in agroforestry as the dependent variable since adoption of this practice may reduce the amount of deforestation. However, there is some difficulty measuring this dependent variable since only 4.6 percent of the farmers surveyed practice agroforestry. The F statistic is 2.941 with a p-value of 0.000 and the adjusted R squared is 0.162, weakness in this model is most likely a direct result of the small sample size. Significant positive variables include education level, total income, number of workers and number of loans (Table 6). It is probable that income is significant because wealthier farmers have the ability to purchase the tools and supplies needed for agroforestry. In addition, wealthier farmers may be more willing to take higher risks since they will not have as much to lose as a subsistence family. The empirical results also suggest that available financial assistance and additional laborers can increase the use of agroforestry. Unexpectedly, the number of bank accounts is significant and negative.

Smith et al. (1996) established that there are several constraints on farmers that prevent them from implementing sustainable, or intensified land usage; these include inadequate development of agro-industries, the absence of credit available for farmers, the lack of irrigation systems that are required for these methods, the absence of a title to the farmer's land and insufficient planting materials. Despite these possible constraints, the farmers that practice agroforestry are considered resource poor and do not necessarily need an abundance of capital since agroforestry is a relatively low input method of agriculture. It requires little to no fertilizers or pesticides and is not extremely labor intensive (Smith et al., 1996). This implies that perhaps there are other barriers discouraging agroforestry methods, such as lack of education or availability of supplies.

Table 6
Agroforestry Results

Variable	AVEAGE	AVEEDU	YRFARM	DISPROAD	DISUROAD	ADULTM	ADULTF	INCTOT
Coefficient	0.0085984	0.1874994	0.0076073	0.0190549	0.0063552	-0.048787	0.0854447	1.43E-05
P-value	0.399664	0.008705	0.656572	0.330043	0.265238	0.529749	0.266881	0.07164

Variable	ROADCON	CHAIN	CATTLE	WORKER	LOANS	BANKAC	CHILD	Intercept
Coefficient	0.1350765	-0.12625	-0.000867	0.6779294	0.6696091	-0.891532	-0.000772	-1.740655
P-value	0.258238	0.530788	0.562328	0.004686	0.001021	0.000818	0.987669	0.016579

		P-value
R Squared	0.2449151	
Adj R Sq	0.1616337	
F-stat	2.9408133	0.000458

4. IMPLICATIONS

The results of this empirical study can be applied to environmental policy. If the factors that drive farmers to make land use decisions are considered when designing policy, it may effectively reduce the rate of deforestation in this area. It is important to note that deforestation is not necessarily a negative occurrence. People migrate to forestland to seek better financial and social opportunities. Cities can be overcrowded and cause increased unemployment and scarce living accommodations. Deforestation may be just a part of the country's developmental process. Perhaps studies that investigate the optimal amount of deforestation for the society could therefore be useful in guiding policy.

However, deforestation due to current agricultural methods in areas like Rondonia, Brazil may result in substantial negative effects such as prohibiting productivity increases in agriculture. This implies that the social cost of deforestation may be greater than the personal benefits gained. Furthermore, if farmers are well informed, they can learn to successfully grow annual crops that they would produce in the absence of agroforestry as part of an intercropping system. Agroforestry, when used effectively for the needs of the community, could result in increases in yield for personal consumption and a diversity of products to sell in the market. Assuming that degradation of the land will continue at such a high rate, these factors make planning and policy decisions vital to the future of tropical forests.

Variables such as education level, number of loans and number of bank accounts that are found to be significant in the empirical models can all be affected by policy. An interesting finding of this study was that number of loans was significant and negative when total deforestation and pasture is measured and significant and positive for agroforestry estimation. Contrary to Almeida's (1992) expectation of loans to be a positive coefficient for total deforestation, the number of loans seemed to reduce deforestation and increase agroforestry. This could possibly play a major role in the reduction of deforestation. If programs are developed to aid farmers who are willing to use agroforestry methods with increased access to loans or credit, farmers may be more susceptible to the idea of agroforestry.

However, this policy could be hindered because the government subsidizes cattle ranching in

Rondonia. As a result, ranching can become an increasingly attractive option for small producers. Walker et al. (2000) explain that currently, large producers may specialize in cattle production in large areas but, small producers are adopting ranching at an increasing rate. Consequently, the only way to reduce deforestation is for the government to implement policies that target specific groups. This and the removal of ranching subsidies would be essential to a policy designed to increase agroforestry for small produces.

Increased education can also be a major policy objective in this area. The average person receives between one and six years of schooling. This might be a result of the high unavailability of schools to children and the high opportunity cost of children attending school. These farm families rely heavily on labor-intensive agricultural activities; this is evident in the estimation of agriculture where number of children and number of males and females on the farm is significant and positive. An additional advantage is that education is also beneficial to the society. Education is an investment in human capital and results in future benefits such as a more productive worker who earns a higher income and has a wider range of employment opportunities. One possible solution is to structure schooling seasonally so that children attend school less during the harvest time. Families will not experience such a great loss in production thus lowering the opportunity cost of education.

It is worthy to mention that households respond to incentives that increase their total utility from farming activities. A farmer will choose to raise cattle if the government provides financial incentives and he possesses the financial and technological means to do so. Similarly, a farmer will increase crop size if he has enough labor for the intensive land use and the financial means and access to markets or agroforestry techniques may be used if he has the capital and the education level required to do so. The important aspect of policies designed to reduce deforestation is that farmers must be given reasonable options and means to reduce deforestation of the land and they must feel that they will be better off with these alternatives. Otherwise, the policy objectives will not be obtained.

5. CONCLUSIONS

This paper attempts to identify factors that result in deforestation by dividing land use into the five different categories to suggest policy guidelines that will be successful in reducing the deforestation rate in the Amazon. As a result of this division, the regression results suggest which factors are influential to farm families when making land use decisions. Policy makers can use such results to form feasible plans for small producers to reduce deforestation levels with the least possible production loss.

The agricultural methods that are currently being used by farmers in this area may not be choices that are socially optimal. The government must take a more active role in preventing unnecessary deforestation by targeting specific groups of people. In the case of Ouro Preto do Oeste, Rondonia, specific actions by the government can include providing agroforestry materials such as seedlings, the building of nurseries, financial assistance and incentives to those farmers who use agroforestry, the removal of subsidies for ranching and increased educational opportunities for children. Policies such as these could prevent irreversible damage to our valuable tropical forests.

TABLE 1
Variable Definitions

Variable	Definition
PASTURE -	The area of land that is used for pasture, in hectares
AGRI -	The area of land that is used for agriculture, in hectares
TOTDEF -	The total area of land deforested or pasture plus agriculture
SUSTAGR -	The area of land that is used for sustainable agriculture, in hectares
FOREST -	The area of land that remains forest, in hectares
AVEAGE -	The average age of male and female household heads
AVEEDU -	The average years of education for the male and female household heads
YRFARM -	The number of years the family lived on the lot
DISPROAD -	The distance of paved road to the city center
DISUROAD -	The distance of unpaved road to the city center
ADULTM -	The number of males living on the farm, 10 years and older
ADULTF -	The number of females living on the farm, 10 years and older
CHILD -	The number of children living on the farm younger than 10 years old
INCTOT -	The estimated total family income
ROADCON -	The conditions of the road during rainy season 1- good, 2 - passable, 3- impassable
CHAIN -	The number of chainsaws that a household owns
CATTLE -	The number of cattle that a household owns
WORKER -	The number of workers a household hires for agricultural purposes
LOANS -	The number of loans the household has
BANKAC -	The number of bank accounts the household has

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Notes

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[1] The 2000 data collection was supported by the National Science Foundation Grant: SES-0076549 and provided by my faculty advisor, Dr. Jill L. Caviglia-Harris.

[2] For data such as this from a developing country, it is not unusual to observe adjusted R squared measures as low as 0.20.