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Market Participation in the Age of Big Dams: The Belo Monte Hydroelectric Dam and Its Impact on Rural Agrarian Households

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Abstract: With rapid population growth comes the ever-important task of meeting the energy demand that this growth requires, and many of the world's tropical regions have turned to hydropower to address the challenges associated with increasing energy consumption. Hydropower is an important energy policy issue in Brazil, and it is promoted as the preferred electricity option, because it is the least expensive in terms of long-term returns on investment; the Belo Monte dam in Northern Brazil provides an opportunity to study the effects of large investments in hydroelectric infrastructure on the surrounding local population. Using a matched panel data spanning 10 years (2005 to 2015), we study the impacts of Brazil's Belo Monte dam on cocoa and other food crop producers in the region. We find that households have seen a decline in rural employment opportunities, and despite improvements in cocoa productivity households have experienced declining food production. With the construction of the dam largely completed, farmers must now face the challenges of decreased food access and shifts in employment opportunities, and while there are many advantages and opportunities associated with this new development, special policy considerations are necessary to ensure that there are safety nets in place to assist those who will see a decline in access to economic opportunities.

Keywords: hydroelectric dam; Brazil; agricultural productivity; markets

1. Introduction

With rapid population growth comes the ever-important task of meeting the energy demand that this growth requires. For many regions, this demand has been met with thermoelectric facilities and fossil fuels, but many of the world's tropical regions have turned to hydropower to generate and supply the energy they need [1]. Hydroelectric dams represent major investments that do not come without controversial public opinion about their social and environmental impacts [2]. Hydropower offers a reliable source of domestically-produced electricity, yet comprehensive assessments that help minimise the environmental and social impacts that these dams cause are rare, often constrained by the limited availability of information and conflicts of interest, despite efforts from the World Commission on Dams to promote better strategic assessments [1]. Most studies that measure the impacts of hydroelectric dams focus on their environmental impacts and on their effects on the livelihoods of riverine communities and displaced population—while largely ignoring how these dams affect the livelihoods of rural agricultural households. This paper will focus on these impacts to contribute to how hydropower dams affect a variety of stakeholder populations.

The complex environmental impacts caused by the construction and operation of large dams cannot be overstated. In order to build a large dam, an extensive area needs to be flooded in order to create the reservoir, resulting in deforestation at the site, which in turn stimulates the deforestation of surrounding areas [3–5]. Deforestation depletes soils of important minerals, and exposes them to rapid degradation, while the ecosystem services that rainforests provide are many, such as the continuous recycling of carbon dioxide into oxygen, the retention and sequestration of carbon, and the preservation of biodiversity. The effects of deforestation are particularly relevant in the Amazon region, which is the largest extant rainforest. Additional impacts include the manipulation of river flows, and while upstream from the dam land will be vulnerable to waterlogging, downstream land will see a drastic decrease in the flow and quantity of water. Fisheries will suffer as the migration trajectories of fish are blocked by the dam, and the water level of the river decreases downstream [6].

When likely losers from the construction of a dam are identified, efforts to compensate them may not always successful. After the creation of the Tucuruí dam in Brazil in 1984, for example, over 23,000 people were displaced from the reservoir and resettled in areas that were deemed of lower utility; this population experienced problems related to health outcomes, lower productivity due to poor fertility of allocated lands, and a lack of infrastructure to facilitate the reconstruction of their livelihoods [7]. For families living along the body of water serving the dam, health outcomes have often been negative, as stagnant water in some areas has become the breeding ground of infectious diseases (malaria, dengue, etc.) and low-flowing rivers that serve households' needs carry bacteria that should have been flushed out with higher flow levels [8,9].

Despite past failures to properly compensate those affected by large infrastructure projects, recent studies have found that displaced communities have been able to succeed, and policy makers no longer put financial gain above environmental and social costs [10]. In a qualitative study of compensation strategies for communities affected by the Belo Monte dam, Randell [11] finds that most migrant communities displaced due to the construction of the dam were able to attain their financial aspirations. Klein [12] also identified opportunities for collaboration and participatory mobilization among groups resisting the construction of the Belo Monte dam, and highlights the importance of emerging political voices among often marginalized communities.

Hydropower development will impact the agricultural sector of the region. On the one hand, productivity may decrease due to flooding of some of these prime lands, so farmers have to move to less fertile lands where their productivity is lowered, while deforestation may accentuate flood and drought events and destabilise soils [13]. On the other hand, there may be new opportunities to market goods due to new access to markets, both national and international. Despite some research on the effects of dam construction on agricultural productivity, how these developments impact the livelihoods of agricultural households remain largely unaddressed. The purpose of this research article, therefore, is to measure how rural agricultural households have been affected by the development of a large dam, in terms of productivity, market access, and employment opportunities. To do this analysis, we focus on the Amazonian region of Brazil, home to the third largest hydroelectric dam in the world: the Belo Monte Dam.

The following sections are organised as follows. We begin with a review of hydroelectric dams and their impacts on agriculture and other sectors, followed by a section discussing the development of the Belo Monte Dam in Brazil. We then present a description of the methods and data utilised in this study, and follow with a section discussing the results. We end with some concluding remarks and a discussion of the implications of the results on future research and policy.

2. Background

Dams have been built on most of the major rivers in industrialised countries, and many countries in the global south with access to large rivers have been following suit. Dams need to be placed on significant altitudinal gradients, and turbulent river sections need to be replaced with still water pools, affecting the flow and temperature regimes and the transportation of sediments [14]. Dams retain water, and how the water is used depends on the purpose of the dam. Some dams are used as reservoirs to store and supply water for large cities, while others are used to store water for the irrigation of agricultural lands. Finally, other dams store water to generate electricity.

2.1. Dams and Agricultural Impacts

The literature on how dams have affected agriculture and rural livelihoods has primarily focused on irrigation dams, in order to measure the impact on rural households [15,16]. From studies such as these, we learn that dams are generally beneficial for agricultural productivity, as farms gain access to irrigation water on a consistent and regular basis. This is particularly beneficial in arid and semi-arid regions, where moisture is a major constraint on agricultural production.

In a study of the impacts of large irrigation dams on agricultural productivity in India, for example, Duflo and Pande [16] find that agricultural production in the district where these dams are located decreases, but increases in areas downstream from the dam. The authors suggest that the decrease in productivity at the site of the dam is a result of land degradation, and downstream communities compensate for this decline by increasing their own production, since they do not bear the environmental costs of the dam construction. They also find that poverty increases significantly in districts where dams are built, but is reduced in areas downstream from the dam, a likely result of the lower productivity of farms near the dam. They conclude that large irrigation dam construction in India is a cost-ineffective public policy, as the poverty reduction in downstream communities is too small to compensate for the poverty increase in the dam's own district. Little is known, however, about how dams that serve other purposes affect agriculture. Most of the literature on the impacts of hydroelectric dams focuses on impacts that do not include non-irrigated agriculture and rural livelihoods.

In a study of the long-term impacts of large water storage facilities (for irrigation) on agricultural productivity in the western United States, Hansel et al. [17] find that farmers in the region use more water for irrigation and see an increase in productivity and land dedicated to crop production. Taghi and Hamid [18] find that embankment dams in Iran have been successful in promoting economic prosperity and improving productivity. Severnini [19] studies the spillover effects of dams in the United States, and propose that even if the main purpose of the dam is to generate electricity, the agricultural sector will benefit, as water from the reservoir could also be used for irrigation, and often is. Even water-rich areas such as Michigan have seen an increase in irrigated lands because of the growing uncertainties and fluctuations in precipitation in recent years.

2.2. Dams and Other Impacts

Hydroelectric dams are hailed as a clean form of renewable energy, because of the claim that they do not emit greenhouse gases; proponents of these dams often highlight the economic benefits that the construction of the dam generates, through job creation at the site and due to the economic activity that is associated with the dam and the reservoir. In China, for example, hydropower dams are promoted as a pathway for poverty alleviation and environmental protection [20]. Additionally, many highlight the benefits of having energy sovereignty, and not depending on fossil or imported fuel sources [21]. Other indirect benefits from building a dam include improved infrastructure in the form of roads, power grids, and waterways that serve the inhabitants of the region [22]. In the case of Brazil, public policy makers talk about how other public policies like health facilities, educational facilities, and economic compensation are implemented that benefit the population. However, this discourse has been found wanting on most dams built to date, as these benefits come too late and rarely offset the huge costs incurred by the local populations.

Opponents of these dams argue that most of the gains from dam construction occur far from the site, and that the losers are mostly local and are not properly compensated [23]. These opponents argue that people living upstream suffer significant losses of agricultural and forest land, and that they are also exposed to diseases, such as malaria, resulting from the large-scale impounding of water [9]. Furthermore, some research has shown that dams are not as clean a form of energy as many suggest [6]. There are notable emissions of methane and CO_2 from the decomposition of organic materials, since most biomass in the areas flooded by the dam is not removed from the reservoir before it is filled, and that biomass decomposes over many years. In a study of the effects of the Owen Falls hydroelectric dam in Uganda, Elkan and Wilson [24] find that the economic growth expectations were not met, and development around the dam did not increase as expected.

Dams, in many ways, represent a central problem that many public investments and policies have—namely, that the economic gains often come at the cost of making some groups worse off [16].

Perhaps the most studied impacts from dam construction are the changes in the fisheries where dams are built. Dams affect the levels of water depth and temperature, the discharge and flow of the water, and the sediment and nutrient composition of rivers. The physical infrastructure of the dam also obstructs the migration of fish to spawning or feeding grounds, while decreasing the quality of the fish habitat [22]. As the riverine ecosystem declines in quality, so does the livelihood of communities that depend on these fisheries for income generation and food. These effects are likely to be intensified with climate change, as water resources become more uncertain [25].

In tropical regions, dam construction results in the rapid deforestation at the dam site and surrounding areas [26,27]. In addition, with these dams comes the need for roads to connect the site with cities outside of the region. As mature forests are cleared to open roads, settlements are created, and previously isolated communities see new opportunities to market their goods and services to cities and towns that can now be accessed through these roads [28]. These roads and new opportunities often result in outmigration and a depopulation of the area, opening it up to land concentration and growing income inequality.

2.3. The Belo Monte Dam

Hydropower is an important energy policy issue in Brazil, and it is promoted as the preferred electricity option, because it is the least expensive in terms of long-term return on investment; this, however, is an assumption that many have challenged [6,29]. The Belo Monte Dam, the third largest in the world in installed capacity, represents the struggle of balancing the needs of a rapidly growing economy with the growing concern for the protection and conservation of forests and natural resources. The original plans for this dam were drawn in the 1970s, and from its inception, this project had been marred by controversies; attempts to move the project forward were cut short decade after decade. It was not until 2011 that work began in the Altamira region of the Amazon, on the Xingu River, despite repeated attempts to halt the process on economic, environmental, and social grounds [30].

Due to the construction of this dam, some 20,000 people were displaced and large areas upstream of the dam were flooded [11]. Despite findings that infrastructure investments are often associated with growth in the agricultural sector [31], the impact of the Belo Monte, through the displacement of rural households, paints a different picture. Displaced rural households saw their livelihoods disrupted in several unexpected ways, and by the failure of the responsible agencies to provide alternative farmland [30]. Some farmers were compensated handsomely at first, but the compensation formula was soon changed, and the great majority received much less than the first ones. It is unclear whether this was intentional, in order to encourage farmers to choose financial compensation over new land areas as compensation, or simply a way for the construction company not to have to bother with finding new land areas for farmers. Abers et al. [32] suggest that the Brazilian government has failed to implement social and environmental programs to help affected communities in Brazil while largely forging ahead with large infrastructure projects, using the Belo Monte dam as their case study.

Early research on the impacts of the Belo Monte dam and its surrounding areas has found disturbing results. Fishing communities downstream from the dam have experienced a dramatic decrease in the quality and quantity of the fish, as well as lower water levels in areas that have been used for generations as a feeding and reproduction ground for fish [33]. Additionally, as the city of Altamira boomed with the surge of migrant labour, residents saw an increase in vector-borne diseases, such as Dengue, as well as an increase in crime rates, prostitution, drug use, and sexually transmitted diseases [8].

One of the clear and immediate impacts from the Belo Monte project has been the creation of many employment opportunities, either directly through the construction and maintenance of the dam, or indirectly through the services and infrastructure creation needed to serve the high migrant population. Rural households now had an opportunity to diversify their income potential by moving away from agricultural employment (in their own farms or elsewhere) and seeking employment at the construction site. This was a brief opportunity that by 2015 had already begun to close, as the major construction part was completed and workers were let go. The only ones remaining are those working on the turbines and other final stage details, only a fraction of the peak of 30,000 workers employed in 2012 and 2013. The controversy around the construction of Belo Monte lies on the tension of diverging priorities: exploiting natural resources that will benefit the nation versus the environmental and social costs to the population living in the region where the dam is constructed.

3. Research Question and Hypotheses

In this paper, we turn our attention to how rural livelihoods and agricultural production have been impacted by the construction of Belo Monte. We explore how rural households' allocation of labour has changed, and focus on changes to the productivity of annual and perennial crops. The main crop of interest in this study is cocoa. Cocoa is an important commodity produced in Brazil, a perennial tree crop that is produced year-round, and which possesses many important agro-ecological benefits. Brazil ranks as one of the largest cocoa producers in the world [34,35]. Until very recently, cocoa produced in the Amazonian region had very low comparative advantage, as high transportation costs made Amazonian cocoa uncompetitive on the national or international market. Cleary [36] found that the only cocoa farmers in the Amazonian region who were profitable were the ones living near urban markets in highway corridors, due to easier access to transportation infrastructure. How, then, is cocoa production affected by infrastructure changes associated with the Belo Monte dam construction in the region?

Smith [37] states that in the Brazilian Amazon, there are three main constraints to the adoption of commercial agroforestry (such as cocoa): socioeconomic infrastructure (such as market access), credit capacity, and technology delivery. He states that the challenge is not whether cocoa will grow well in the Amazon, but rather, whether producers will be able to sell their product in large enough quantities, and at a price that makes it a win-win proposition for all stakeholders. These challenges are often compounded with other barriers that farmers face, such as the unequal distribution of resources under rapid population growth, high transportation costs, and limited access to inputs [37,38]. For cocoa production in the Amazon, for example, farmers must have access to arable land, skilled and unskilled rural labour, and agricultural capital [38].

How has the development of a large hydroelectric dam affected rural households in the region? In this paper, we explore changes in labour and crop productivity due to the construction of the dam; in addition, we hypothesise that the construction of the dam has resulted in the movement of labour away from rural agriculture and towards opportunities surrounding the Belo Monte construction. We further hypothesise that despite more limited labour, the additional infrastructure will enable cocoa farmers to better market their products, in part due to lower transportation costs that result from the activities surrounding the construction. Finally, with an influx of migrant labour to the region and a resulting higher demand for food, we hypothesise that rural households will increase production of their food crops to supply the migrant population.

4. Data and Methods

The study area is the region up to 140 km west of the city of Altamira along the Transamazon Highway, in the lower Xingu Basin of the Brazilian Amazon (see Figure 1 below). Remote sensing tools were used to define the study area and sample, using 10 aerial photographs and Landsat Thematic Mapper satellite images, with three- to six-year intervals covering the period 1970 to 1996 [39]. As this region was colonised from 1970, Moran et al. [39] found that in the early years, migrant families developed an average deforestation pattern of three hectares per year in the front of the properties. Forest openings greater than five hectares were therefore indicative that agricultural activities had been initiated. Sampling of the population on farm properties was done by selecting a property once five hectares had been cleared [40,41]. This area is equivalent to 404.7 thousand hectares, where 3916 properties were demarcated by the National Institute of Colonization and Agrarian Reform (INCRA). In 1997, a sample of 402 properties was selected to conduct in-depth interviews with the households therein, and data on socio-economic and demographic characteristics, their agricultural strategies, and their land-use history were collected. These households were initially selected as part of a study of land use change in the region and the role of the age/gender structure of households on deforestation. Follow-up surveys of this panel study of 402 households were carried out in 2005 and 2015, where the same properties were revisited. For this study, we rely on data from the 2005 and 2015 waves of data collection.

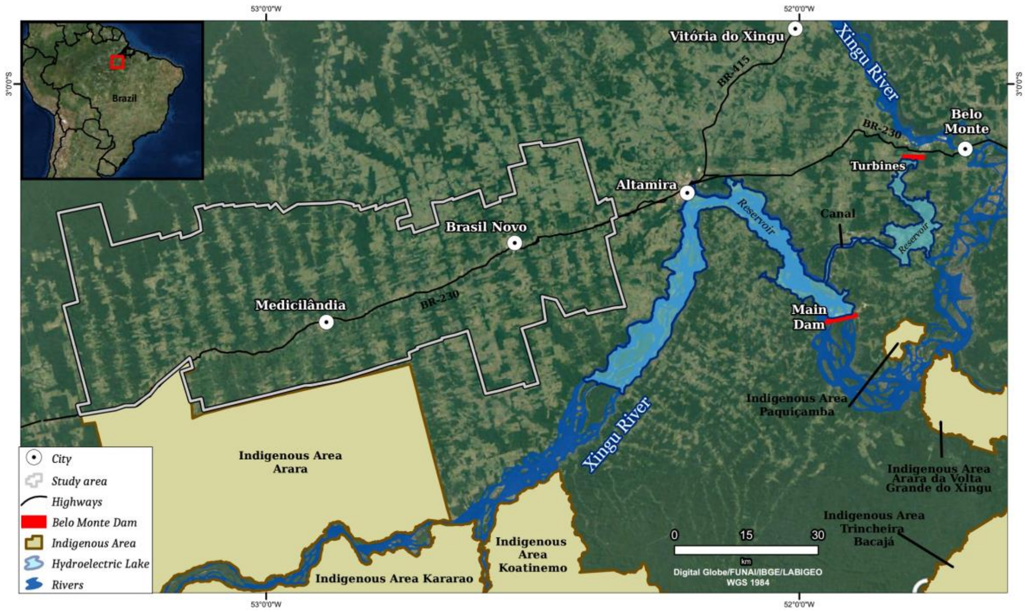

Figure 1. Map of the Belo Monte Dam and Study Area.

During field research in 2015, two questionnaires were used. The first was applied to all the located owners (those managing the property), addressing mainly productive strategies and economic aspects of land use and land cover. The second questionnaire was applied to the family member in charge of the household activities (usually through the female head of household) to understand their demographic characteristics. This instrument dealt with family composition, the characteristics of the household, and their perceptions about the recent changes in the political and economic conjuncture. To achieve the goals of the panel study, we used questionnaires similar to those applied in 2005, adding new elements to understand the possible role of the Belo Monte hydroelectric dam in the socioeconomic dynamics of the region.

The analysis performed in this paper has three main components: (1) we begin by doing a descriptive analysis of perceived impacts of the Belo Monte dam on rural households; (2) we then perform an econometric analysis to study the determinants of cocoa productivity in 2015; and (3) we end with an analysis of the panel data, in order to measure changes in cocoa productivity from 2005 to 2015.

The focus of this study is to measure changes in cocoa productivity, by identifying the effect of different covariates on productivity. The econometric specification of our model follows:

$$y_i = \beta X_i + \mu_i \tag{1}$$

where y_i represents our dependent variable (household cocoa productivity in 2015), X_i is a vector of explanatory variables or covariates (including highway characteristics), and μ_i is the error term. The explanatory variables included in this model are the following: sex of household head, a categorical variable indicating level of education of the household head, age of the household head, household size, distance from the farm to the Transamazon highway, an indicator variable for whether the highways is paved or not, an indicator variable for whether a member of the household works at the Belo Monte dam, area under cocoa production, and two indicator variables for the perceived impact of the dam on the household.

To assess how productivity has changed through time, we use data collected from 2005, which allows us to measure the same household at different points in time (2005 and 2015). With this panel data, we can control for stable characteristics, which are characteristics that do not change over time, such as sex and ethnicity, together with time-varying characteristics, such as the amount of land owned. We used a random effect model via generalised least squares, where we measure the effect of covariates and explanatory variables on a continuous dependent variable: cocoa production.

$$y_{it} = \mu_t + \beta X_{it} + \gamma z_i + \alpha_i + \varepsilon_{it} \quad (2)$$

where y_{it} represents the dependent variable (cocoa productivity) for a given household in the two time periods, μ_t is the intercept term that can be different for each time period, X stands for all time variant independent variables (education, age, household size, area of cocoa production), z is a vector of time-invariant independent variables (sex, distance to highway), and α_i *and* ε_{it} are the error terms in this model, where α varies for each individual and ε varies across time and individuals. A Hausman test was conducted to test the assumptions of the random effects model, and we do not find any evidence against the random effects model in favor of the fixed effects model (p = 0.882).

5. Results

Table 1 shows the characteristics of the surveyed households. Of the surveyed households, 86% of them are male-headed, the average age of heads of households is 54 years, and the average size of these households is three members. The majority of surveyed household heads (65.7%) has completed some portion of elementary school, without finishing it. Additionally, 67% of these households produce cocoa on farms that average 18 hectares of cocoa area planted, and produce an average of 5055 kg of cocoa per year; furthermore, the average distance of these households to the Transamazon highway is 25 km, and for 63.4% of these households the section of the highway closest to their fields is paved. Finally, almost 88% of these households have worked in the agricultural sector for all of their lives.

How has labour been reallocated with the construction of the dam? We find that 14.4% of households have had one or more of its members leave to work directly on the construction of the Belo Monte dam. This does not include those who work on related service jobs. These are household members who have been employed by the construction activities surrounding the dam work, yet this estimate does not account for labour that has been reallocated due to indirect impacts from the dam construction, such as through the higher demand for services and goods in the cities or employment in the service sector serving the dam workers and activities.

Perceived impacts from the construction of the Belo Monte dam at different scales (from the household to the country) are presented in Table 2. We find that sample respondents tend to see the impacts from the dam as positive at larger scales (i.e., at the regional and national level), yet perceive more negative impacts as the scale becomes smaller (i.e., at the community and household level). These results are not surprising, since the purpose of the dam, as was widely promoted, was to provide a source of hydroelectric energy to a large proportion of urban areas of the country, helping ease the burden of imported energy. Those opposing the dam, however, often spoke of the dam's impact on local communities, through the displacement of large numbers of people and through its impact on the ecosystem (fisheries and forests). The perceived impact, therefore, may be associated as positive for the larger cities further away, but negative at the local level. These results support similar findings from other studies, which have seen that tensions from the dam construction rest on how the construction benefits those who are far away to the detriment of those who are close [6,16].

Table 1. Sample characteristics.

Variable	Average (Percent Where Noted)	*n*
Male	86.5%	340
Age (years)	54	340
HH Size (members)	3.3	340
Education		340
No Formal Education	6.2%	
Some Elementary	65.7%	
Elementary	1.5%	
Some Secondary	3.8%	
Secondary	9.7%	
Above Secondary	12.6%	
Produce Cocoa	67%	340
Total Area Cocoa (ha)	17.9	228
Cocoa Production (kg)	5055	228
Always Worked in Ag	86.2%	340
Works at BM	14.4%	320
Distance to HW (km)	24.8	336
Paved HW	63.4%	336

Table 2. Perceptions of the Belo Monte impacts.

	Good	Neutral	Bad	Do Not Know	*n*
Impacts to the Household	35%	31%	15%	18%	223
Impacts to the Community	42%	25%	21%	12%	222
Impacts to Altamira	50%	14%	23%	13%	222
Impacts to the Region	61%	17%	11%	11%	221
Impacts to Brazil	67%	11%	7%	14%	221

What are the impacts of the dam on rural households? We begin by exploring how farmers have perceived changes to their livelihoods (Figure 2). Most households have reported improved access to higher quality foods and higher quantities of foods for consumption, together with higher marketability for agricultural output (crops and livestock). They have also reported increases in cocoa production and improved livestock production. Farmers, however, also reported a decrease in opportunities to produce annual crops, and have reported lower productivity of these same crops. Furthermore, households have experienced decreases in rural employment opportunities.

There are many ways in which large infrastructure investments can create opportunities for the commercialization of goods: (1) the influx of migrant labour drives the demand for more products, and farmers are able to diversify where and to whom they sell their products to; (2) new roads and access to better transportation services helps with the commercialization of their products; and (3) with population growth and the demand for more food products, often imported to the region, households are able to access higher quantities of food that are more diverse [19]. As households see an improvement in the opportunities to market their goods, they also invest in those sectors (livestock and cocoa). This pattern is not reflected in the production of annual crops; despite a rise in opportunities to market these goods, the households' productivity seems to have declined. This could be partially explained by the presence of new imports of food from other regions of Brazil (making local food supply less relevant), as well as by the relocation of labor from farming to urban employment opportunities. As households choose to leave food crop production, and potentially dedicate that land to growing more cocoa or using it as pasture land for their livestock, the opportunities for rural employment will likely fall, as the labour associated with annual crops is higher at very concentrated moments in the calendar year (clearing, planting and harvesting) than the labour associated with cocoa and livestock production, which is more spread out throughout the year.

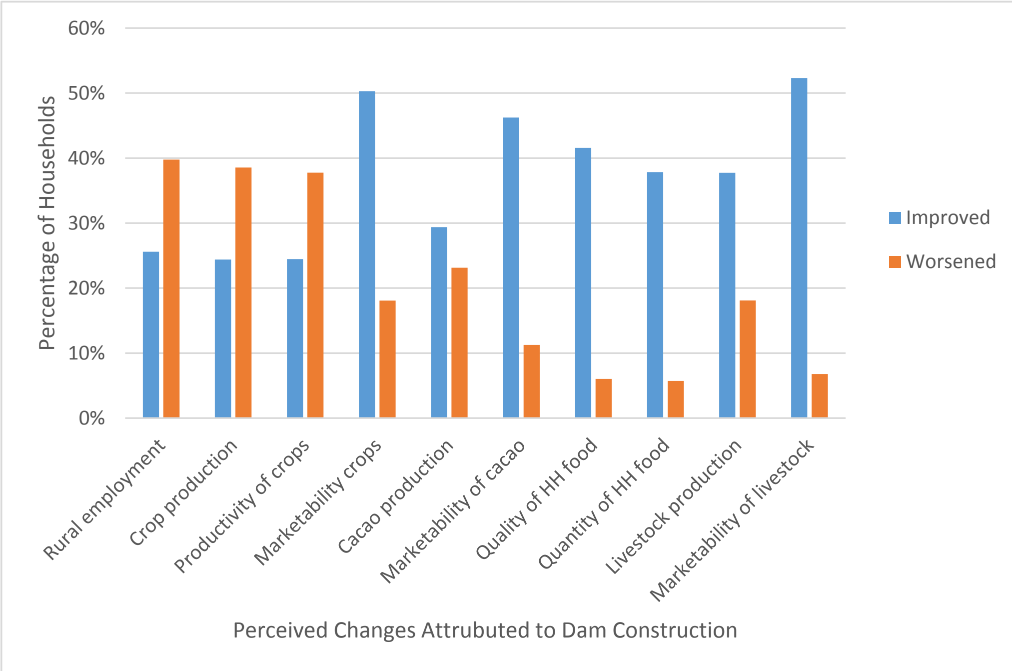

Figure 2. Perceived changes caused by dam construction.

Production data for these households for 2005 and 2015 are consistent with the perceptions of farmers in changes in productivity (Table 3). From paired *t*-tests, we see that households increased the production of cocoa significantly from 2005 to 2015, from a household average of 426 kg of cocoa in 2005 to 5055 kg in 2015. Food production, however, has gone significantly down between 2005 and 2015, with significant decreases in the production of rice, beans, and maize. Cassava production, however, significantly increased from 2005 to 2015; this is likely due to local food preferences that value locally produced farinha, or cassava flour, which is distinctly different in texture and flavor from farinha from other regions of Brazil. Because many farms no longer routinely produce farinha, it brings in a very good price in the local market. These results run counter to our hypothesis that food production would increase in the region in response to the higher food demand from the migrant population. From the field, we received reports that most of the food for the dam workers is imported to Altamira from the southern, southeastern and midwestern states of Brazil, so households do not have an incentive to produce more; in fact, with a combination of better conditions to produce other crops and more available food coming into Altamira, farmers may be less likely to invest in the production of staple food crops.

Table 3. Changes in the production of staple foods and cocoa.

	2005 Production (kg)	2015 Production (kg)	*p*-Value
Cocoa	426.25	5054.62	
Rice	31.11	1.02	0.0000 ***
Beans	5.2	0.52	0.0003 ***
Maize	3.27	23.22	0.0006 ***
Cassava	39.29	138.8	0.0626 *

Note: *, **, *** represent significance at the 0.1, 0.05, and 0.01 level.

Farmers have stated that there has been a decrease in rural employment opportunities as a direct result from the Belo Monte construction. We explore further how these households may have experienced these changes in Table 4.

Table 4. Perceptions of employment opportunities.

	Yes	No
HH Labour is Enough	46.8%	53.2%
Hard to Find Workers	85.8%	14.2%
HH Labour has been reduced	33.0%	67.0%

It is clear that rural households in the Altamira region are facing labour constraints, with 53.2% of households stating that the household labour is not enough to meet their needs. Compounded upon this challenge, 85.8% of households have stated that it is hard to find labour to hire to work in their farms. One third of households have found a reduction in the availability of household labour; of these households facing reduced household labour, 48% stated that the reduction of labour was due to family members seeking employment in other communities (Table 5).

Table 5. Reasons why household labour has been reduced.

	Percentage
Moved Away to Work	48%
Moved Away to Study	17%
Works at Dam or Related Sector	17%
Other	18%

These results are in line with our hypothesis that labour allocation has changed in response to the dam construction, and that a large proportion of households are struggling to hire workers. This is especially problematic when we combine this challenge with households that are not able to meet their labour demand with household labour. A look at the small number of people in households interviewed quickly confirms that household labour is largely insufficient to support a family farm by itself.

Table 6 shows the results from the ordinary least squares (OLS) regression, a model which looks at the determinants of cocoa production in 2015. We find that after controlling for amount of land dedicated to cocoa production, the most significant variable that affects cocoa production is how much households have perceived direct and indirect impacts from the Belo Monte dam. We find that households that have expressed that the dam has affected their households directly produce on average 3522 kg more than households that reported no impacts from the dam construction; in addition, households who reported indirect impacts from the dam produce an average of 3038 kg more than households that reported no impacts from the dam. In other words, farmers who reported no impacts from the dam had lower production than farmers who reported impacts from the dam. These are households that own significantly less land than the households that reported having been impacted (25.3 ha versus 15.1 ha), suggesting that they do not have as much access to productive resources as the larger farms. Another possible explanation for the difference is that households that have perceived impacts from the dam construction might have taken steps to counteract the perceived negative effects, while those households that have not perceived any changes, would be less likely to change their production practices.

Farmers in the rural Altamira region in past decades expressed that poor access to highways was a major challenge, as their transportation costs were high, the time to get their product to markets were too long, and during the rainy season transport was particularly difficult [42]. Farms that are closer to highways do produce more than those farther away from highways, although not significantly more.

We find that farms that have direct access to a paved highway produce significantly less cocoa than farms that do not have direct access to a paved highway. Of the 125 km of highway in the study area, 50 km are still unpaved. Most of the cocoa production in the area is in this segment of the highway, where soils are richer and more fertile. Farmers in this region tend to dedicate their fertile land to cocoa production, while poor soils are often converted to support pasture land, in order to support livestock production [39,43].

We also find that households that are larger, more educated, with male and older heads produce more, although not significantly. In addition, households who reported having a member working at the dam also produce more, but again not significantly.

Table 6. OLS results for 2015 cocoa production.

2015 Cocoa Production	Coef.	Std. Err.	*p*-Value
Male	2114.4	1810.0	0.244
Education	90.6	371.6	0.808
Age	11.8	43.1	0.786
HH Size	145.0	396.5	0.715
Distance to Highway	−1.9	2.8	0.485
Paved Highway	−2362.3	1361.2	0.084 *
Works at BM	882.4	1796.2	0.624
Cocoa Area	272.5	34.5	0.000 ***
Perceived Direct Impact	3522.1	1917.3	0.068 *
Perceived Indirect Impact	3038.2	1477.2	0.041 **
_cons	−3273.1	3549.7	0.358
n	209		
Prob > F	0.000		
r-squared	0.3		

Note: *, **, *** represent significance at the 0.1, 0.05, and 0.01 level.

We took advantage of data from these same households collected in 2005 to see how cocoa productivity has changed in ten years, a period of time that encompasses the construction of the dam (2011 to 2016) (Table 7). We found that productivity has increased significantly from 2005 to 2015, with farmers producing on average of 3162 kg more cocoa in 2015 than in 2005. Additionally, distance was a bigger factor for productivity in 2015 than in 2005; farms that were located further away from the main highways produced less in 2015 than in 2005. As expected, larger farms also produced more in 2015 than in 2005.

Table 7. Random effects model for 2005-2015 cocoa production.

Cocoa Production	Coef.	Std. Err.	*p*-Value
Year: 2015	3162.9	587.6	0.000 ***
Male	784.5	894.1	0.380
Education	−86.6	175.9	0.622
Age	17.4	23.1	0.450
HH Size	−10.3	179.5	0.954
Distance to Highway	−44.1	15.6	0.005 ***
Cocoa Area	74.1	30.7	0.016 **
_cons	−1466.4	1814.4	0.419
Number of Obs.	322		
Number of Groups	172		
x^2	33.1		
Prob > x^2	0.000		

Note: *, **, *** represent significance at the 0.1, 0.05, and 0.01 level.

Why are farms with better access to roads producing less in 2015 than in 2005? In 2005 there was a much smaller proportion of cocoa farmers, and those who farmed cocoa were viewed as pioneers of a crop that only later became an important regional commodity. As more land was occupied, those properties would be further from the main highway, and those farmers would be adopting the new favored cocoa crop as an economic strategy. These are newer farms with younger cocoa trees (and therefore with lower yields). Another explanation resides in the mechanisms for the provision of financial services to agricultural households. In the past, financial institutions only provided services to farmers who had access to fertile land for cocoa production, but as prices improved with time, farmers turned to less fertile soils to plant cocoa, despite the lack of financial credit from banks [44]. It should be said that farmers tend to have a balanced land use portfolio of cocoa and pasture, which they believe protects them from the fluctuating price of these commodities. Cattle pastures can be located further from the highway, since cattle can walk their way out to the highway, whereas cocoa has to be transported by truck.

As hypothesised, cocoa production has increased considerably from 2005 to 2015. Farmers overwhelmingly attributed higher production and improved marketability of cocoa to the construction of the dam, yet international market prices for cocoa have also seen a similarly positive trend (Figure 3). We expect, however, that in addition to the improved marketability induced by the activities surrounding the dam construction, farmers responded to the higher prices by increasing their cocoa production. This link is made by Godar el al. [43], who see that despite strong governmental incentives for cattle ranching in the region, farmers have shifted their production strategies to meet the demand for cocoa.

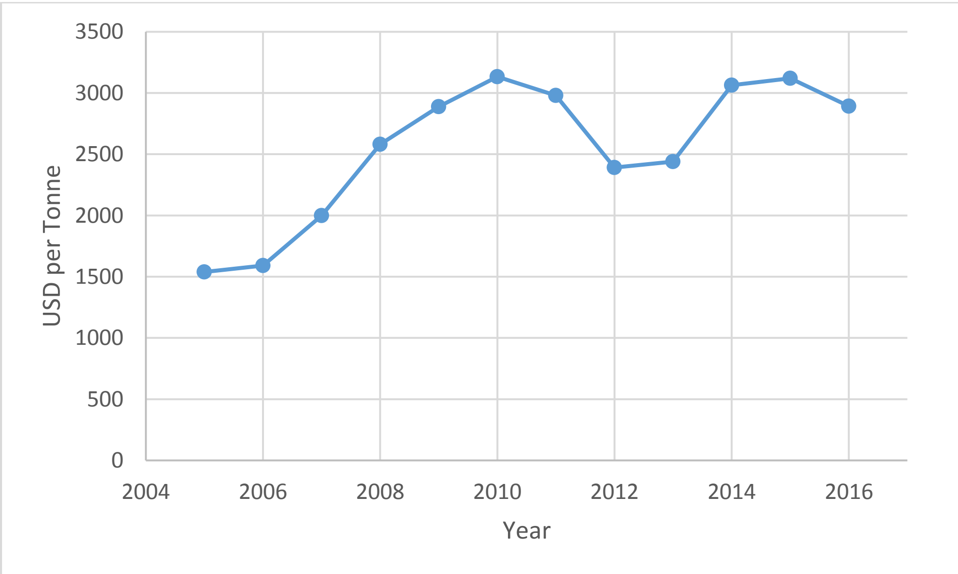

Figure 3. International cocoa prices from 2005 to 2016. Source: International Cocoa Organization.

6. Conclusions

The Brazilian Amazon has undergone a large transformation in the past 50 years, starting with the opening of the Amazon through the construction of the Transamazon Highway in the 1970s, followed by the construction of multiple dams throughout the region. The indigenous and local communities have experienced the economic booms that population growth and capital that come with these developments, together with the challenges that come hand in hand, as the institutions are not in place to meet the swelling population [42]. Early evidence suggests that the cycle of economic growth and collapse of the institutions is likely to be repeated as the Belo Monte undergoes its final stages of construction.

In this paper, we have looked at how agricultural households in Altamira have been affected by the construction of one of the largest hydroelectric dams in the world. Farmers in the Altamira region are experiencing many changes with the development of the Belo Monte dam; while some of them are positive, some challenges still remain. Overall, the Belo Monte project has been beneficial for farmers' ability to market their products—in particular, farmers feel that the project has improved their conditions to produce cocoa and livestock, as the production of both has increased and so has their marketability. Despite these changes, farmers have found it harder to produce annual food crops. As the population in Altamira began to swell, the demand for food was met by increasing food imports into the region, and not by boosting production by local farmers. We saw that food production has decreased from 2005 to 2015, and that the opportunities for local rural employment have decreased.

Lower food production could be a problem with the now shrinking population in Altamira. As the largest proportion of the migrant labour from the dam construction returns to their home states, will the demand for food continue to be met through imports, or will rural households fill this demand by boosting their own production? For local production to increase, agricultural policies will need to reevaluate how to best support the agricultural sector, and how to incentivise farmers to return to staple food production, through financial services and other technical support, for example.

In the past 10 years, cocoa farmers have seen important improvements as better conditions to market their cocoa emerged due to better transportation and commercialization opportunities, farmers in the region significantly increased their production. Farmers have sought some of the most fertile land in the region to use for cocoa production, and have seen major production boosts. World market prices for cocoa have followed a similar trend; after 2005, cocoa prices have been steadily increasing, with the exception of a two year drop (from 2012 to 2014), a further incentive for farmers to increase their cocoa production. In addition, as employment opportunities decrease as a result of the Belo Monte project (construction, services, etc.), this newly available workforce will need to find new and alternative employment, which could mean returning to work in farms or leaving the region altogether in search of new opportunities.

The Belo Monte dam has already been constructed, for better or for worse, and as Brazil continues to expand and invest in hydroelectricity, it behooves proponents and those implementing these projects to take anticipatory actions to face the inevitable and sometimes negative changes that will occur as a consequence of the construction. From looking for opportunities to use the local agricultural sector, to supplying food for construction workers, to ensuring that all of those affected are properly compensated.

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