Agricultural Change and Urban Growth in Mato Grosso

Using Satellites and GIS to Measure Urban Population Growth and its Relationship to Rural Economic Change

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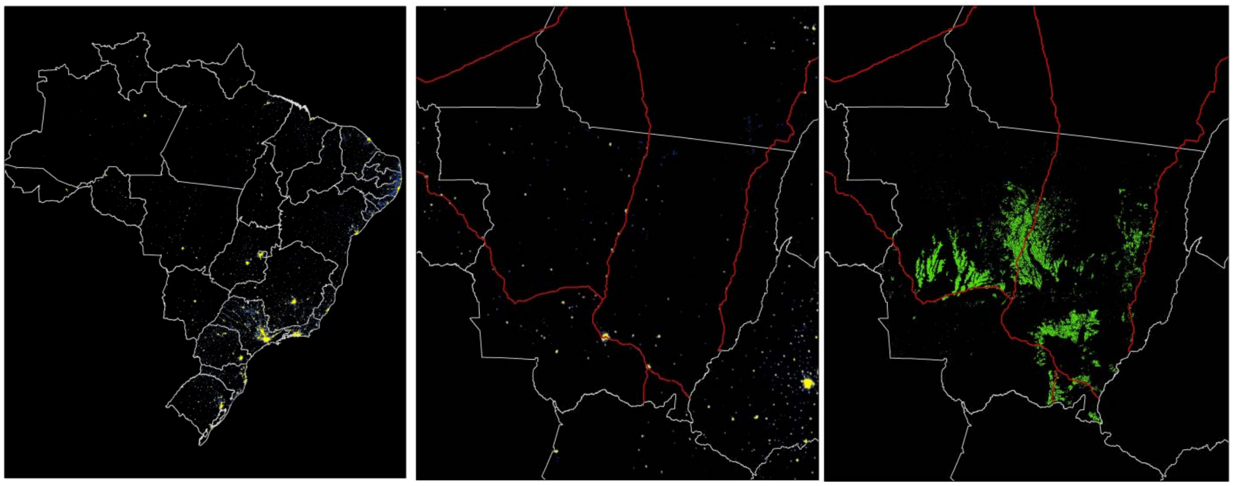
The past decade has brought swift and significant social and environmental change to Brazil's Amazon and cerrado regions. Changes in trade policy, a growing demand for natural resources, particularly from new middle class consumers in Asia, and currency fluctuations, have combined with 1970s era highway and colonization projects to reshape the once inaccessible regions of northern and central Brazil into a source region for globally traded commodities. Today the fields, timber strands and mines of Brazil interior are now furnishing the materials that house, clothe, and feed a wealthier, and increasingly urban, base of global consumers. Iron from Parauapebas is melted in the steelyards in East Asia, leather from Brazil's cattle herds are tanned and molded over car seats in Italian and Chinese factories, and soybeans, corn, and poultry are rendered into the processed edibles demanded by the world's emerging and expanding middle classes.

The production of raw commodities in the Amazon and cerrado has certainly come at a cost, and to date, an extensive and still growing body of research has recognized the environmental impacts of sourcing globally traded food commodities from these regions (Pfaff and Walker 2010, Walker et al. 2008, DeFries et al. 2010, Rudel et al. 2009). In this research, however, we take the environmental costs of agricultural expansion as given, and turn our discussion to the social impacts of landscape change in central Brazil. We thus turn our focus to economic and environmental changes in the Brazilian State of Mato Grosso, where we argue that the production of grain and oilseed crops is a key driver of urban growth. Specifically, we argue that in Mato Growth urban growth is propelled and supported by support services to the agricultural sector, and that cities surrounded by more farms are growing comparatively faster than their counterparts. Our research thus breaks from the extensive body of work that has examined environmental change as an artifact of urbanization or urban growth, and instead turns to consider how rural economic development is driving socioeconomic change in urban centers.

We organize our argument as follows. First, we offer both theoretical and contextual background to our work. To this end, we begin by considering (a) past frameworks considering urban growth in the Amazon; (b) the recent evolution of the agricultural sector, and its impact on urban areas; and (c) drawing out a framework for considering the role of rural resources in driving economic change. We then proceed to a discussion of the spatially explicit database built from remotely sensed data products: (1) a land use data product derived from MODIS remote sensing imagery; (2) NOAA's DMSP dataset on nighttime light emissions. Next, we present our empirical strategy, namely a two stage least squares approach, where we instrument for changes in agricultural area using past agricultural areas, slope, property size, and soil attributes. We then present a discussion of our results, and seek to situate our work within ongoing discussions over the relationship between rural economic changes and urban growth, and of the potential sustainability of urban booms tied to globally traded export commodities.

Background



From Left to Right: 1a: Nighttime light emissions in Brazil, 2010; 1b: Nighttime light emissions in Mato Grosso State, 2010; 1c: Cropland in Mato Grosso State, 2010 (Data from Spera, et al.). Principal roadways are shown in red in figures 1b. and 1c. Cropland shown in green.

2.1 The Amazon's Cities

Research on urbanization in the Amazon has long connected urban change and development to external demand for the region's most valuable assets: for raw commodities of the forest or which lay beneath; for land, or the soil, sunlight and precipitation, which can be harnessed for agriculture; or for its strategic geopolitical location as an interior border frontier in South America. Each successive wave of interest led to the creation of new cities. The rubber boom of the early 20th century, for example, led to the creation of a constellation of urban areas along the principal ports and tributaries of the inner basin, as well as the so-called scramble for the Amazon, when Brazil struggled against its neighbors for control of the continent's interior (Hecht 2013). In the late 1960s another wave of interest shook the basin, this time occurring as the newly established military government set into motion a series of mega-plans for the colonization and occupation of the Amazon. New roads were built and cities were founded, partly as a means to concentrate regional services in education, health, and government administration. As a colonization objective, the planning and erection of cities served as a vehicle for the advancement of not only regional occupation, but for the solidification of Brazil's political claims on the Amazon (Becker 2005). Much of Mato Grosso's present day urban structure is directly traceable to this era of geopolitical maneuvers by Brazil's military government of the 1960s and 1970s.

In the late 1980s and early 1990s social science research on urbanization in the Amazon then sought to frame the urbanizing process as a function of government interest and subsidies. Urban growth, per this perspective, was contingent on government subsidies, or on services to a transient and mobile labor resources bent on the rapid extraction of commodities such as gold or timber (Godfrey 1990). The cities that served as transportation and bureaucratic hubs to the region's vast reserves of newly accessible natural resources, they argued, would first swell with in-migrants in search of gold, timber, or land, but inevitably decline as the most accessible resources were exhausted. Urban growth after the initial expansion was thereafter contingent on government investments, or on public services (Roberts 1995).

Urban growth, per the prevailing conceptualizations of urban change in the Amazon in the 1980s and 1990s, was thus regarded as unrelated to agricultural change or development. It was also unrelated to local migration patterns, as low rural population densities neither constituted a source of rural migrants, nor provided significant demand for locally produced urban based services or manufactured goods (Browder and Godfrey 1997). Instead, cities were conceptualized as government-subsidized outposts of society, as vehicles for converting public financing into private fortunes, or as economically irrational, environmentally destructive investments in colonization. The resulting conceptualization framework, *disarticulated urbanization*, has since been widely used as a means of understating urban growth where political interests appear to supplant economic rationality as a driver of urbanization and social change.

In our conceptualization of urban growth in Mato Grosso we build on and revise Browder and Godfrey's disarticulated urbanization thesis by re-conceptualizing urban growth in Mato Grosso as a direct function of local rural economic change. We argue that not only is present day urban growth in the Amazon directly linked to rural economic change, but rather, it is directly and positively correlated with agricultural development. Conceptualizations of urban growth as fundamentally reliant on government subsidies and economically irrational, we suggest, are lost in the present economic climate of the Amazon, and particularly in the State of Mato Grosso, which has transformed itself into a global heavyweight in the production and international trading of key agricultural commodities. This process has not only reshaped the state's economy, but growth in its interior cities. In the following sections we turn our attention to the development of Mato Grosso's agricultural sector, and thereafter, to the linkages between agricultural growth and urban change.

2.2 Mato Grosso's agricultural sector

Soybeans, which are widely consumed across the world, generally in processed foods or through meat consumption, are presently one of Brazil's most valuable export commodities. The development of the soybean into an export crop in Brazil, and in Mato Grosso specifically, however, is a relatively recent phenomenon and can only be traced back to less than fifty years. In Mato Grosso, soybeans became a viable crop choice in the late 1980s and 1990s, when farmers and technicians adapted seed varieties to the shorter daylight hours of the lower tropical latitudes, and to the acidic soils of the cerrado and Amazon region. Physical adaptations alone, however, were not sufficient to transform Mato Grosso into a global trader and exporter of soybeans. For it was only when a series of key institutional reforms were enacted in Brazil, including the reduction of ICMS taxes, new regional trade agreements, and the removal of price supports for domestically consumed crops, that Brazil's export sector began to expand (Warnken 2002, Goldsmith and Hirsch 2006, Helfand and Rezende 2004). This process was accelerated in 1999, when the Brazilian real was devaluated, which effectively tripled returns to soybean production in Brazil even as, globally, soybean prices in US dollars were declining and in the US farmers were actively retracting their production areas (Richards et al. 2012). After Brazil's currency devaluation, or the period from 2000-2005, Brazil more than doubled its production areas for soybeans. In Mato Grosso alone the soybean crop grew from an area of less than three million hectares to more than six.

The environmental impacts of the soybean boom have been widely documented, and have brought concerns over linkages between deforestation and agricultural expansion to the forefront of discussions over the tradeoffs between food production and environmental sustainability. Many of these concerns have since been allayed, however. For since 2006, returns to production have declined or stabilized, and new policies have been instituted to limit the creation of new agricultural lands or new forest clearings (Assunção, Gandour and Rocha 2012). Production areas have likewise remained stable. Today, Mato Grosso presently produces soybeans on 6.9 million hectares, only slightly more than in 2005. However, total grain output has increased dramatically, largely due to an expansion of double cropping (Brown et al. 2013, VanWey et al. 2013).

Double cropping, or the production of a second crop after the initial soybean harvest, has swept across Mato Grosso in the later part of the last decade. In Mato Grosso, double cropping first emerged around the city of Lucas do Rio Verde, Mato Grosso, where farmers could sell their corn harvest to local poultry factories. Rather than leaving land to lie fallow for much of the year, farmers developed a plant method where the initial crop of soybeans, planted with the onset of the rainy season in September or October and harvested in January or February, could be followed immediately with the planting of a second crop of corn, cotton, or millet. The second crop is relatively risky, particularly if there is uncertainty in regard to the duration of the rainy season or the possibility of a drought in April or May. Nevertheless, double cropping is now widely practiced across Mato Grosso, and has had a dramatic impact on total productivity across the region.

Today, Mato Grosso's agricultural sector is concentrated in four principal regions: (1) the Araguaia region, in the east; (2) the BR-163 region in north-central Mato Grosso; (3) in the southeast, between Primavera do Leste and Rondonopolis; and (4) in the western cerrado, north of Tangará da Serra (see FIGURE 1, to be created). Six of Mato Grosso's fastest growing cities are located centrally to these agricultural regions, with each of these cities serving as a service center to the local farming sector. Lucas do Rio Verde, an agricultural village a decade ago, is now the fastest growing city in Mato Grosso, and now boasts both crushing facilities for soybeans and poultry and swine factories. Farther north, Sinop and Sorriso have each grown by more than thirty thousand over the past decade. Elsewhere, cities such as Tangará, Primavera, and Rondonopolis have expanded behind the production, light processing and transportation of soybeans, corn or cotton. None of these products are primarily consumed locally. Rather, much of the food produced in Mato Grosso is destined for dinner plates outside of the region.

Today, soybeans from Mato Grosso are largely shipped to international ports, by road, either north to ports on the Tapajós River, or south, towards Brazil's Atlantic ports, where trucks are emptied and soybeans are sent overseas to the growing metropolises of Asia, or to markets in Europe. The returns come in the form of processed foods, fresh vegetables and dairy, and consumption goods produced in Minas Gerais, São Paulo, or abroad. Much like their counterparts in the oil rich, urban nations of the Middle East, in Mato Grosso, cities have grown on the strength of agriculture, and have been created under conditions of global trade and rising demand for meat and processed foods. To draw on historical analogy, as the Midwest cities supplied basic food and meat commodities to the industrialist northeast corridor (Peet 1969, Cronon 1991), today Mato Grosso's agricultural heartlands provision food commodities to the industrializing metropolises of East Asia.

2.3 Agriculture as a driver of urban change

A key component of this research rests on the argument that agricultural production and agricultural expansion drive urban economic growth. In this regard, our work builds on recent research linking socioeconomic and urban change to soybean production. To date, this work has shown that many of the soybean producing counties of Mato Grosso rank among the highest in the Amazon in terms of the UN's human development indices (PNUD 2001). Additionally, county level statistics suggest that agricultural intensification in Mato Grosso, particularly in relation to single or double cropping, is correlated with higher education attainment and incomes

(VanWey et al. 2013). Research has also broadly drawn correlations between soybean production and increased incomes and decreased poverty, but also increased income inequality (Weinhold, Killick and Reis 2011).

In this research we theorize that agricultural change drives urban growth through two key avenues, or through the development of (a) a service support sector, and (b) through the consumption of resource rents. For the former, we recognize that farming requires a steady stream of costly inputs, from financing, to machinery, to seeds and fertilizer, to technological expertise, and to silage and transport. For each input, labor and sales are required to move, sell, and negotiate each transaction. Many of these services will be located centrally in urban areas, where they contribute directly to the development of an urban sector through demand for labor and the circulation of capital. Thus the presence of a strong rural agriculture sector ensures sustained demand for inputs and agricultural services, and as a consequence, an urban based employment sector.

Agricultural production, assuming that farming is profitable, also generates capital returns, and demand for consumption goods. In profitable years, farmers have more capital to spend on consumption goods. Much of this capital passes through, or remains in, urban areas. In Mato Grosso, many farmers will live in nearby cities (rather than on farm) where, in addition to having better access to urban based agricultural services, they can take advantage of access to better schools and educational opportunities, government and public infrastructure, as well as quality of life amenities. The concentration of services, and the urban residences of both farmers and those who work at the periphery of the agricultural sector, ensures that a percentage of production returns are spent locally, whether on construction, on property, or on consumption goods, from weddings, to restaurants, to home goods or vacations. And when returns to agriculture are high, presumably, the demand for these goods, as well as investments in the agricultural sector, is also heightened. Consequently, we argue that agricultural production is not only positively tied to urban growth, but that the effect of rural agricultural production on urban growth will be higher during those years when returns are highest. To test this hypothesis, we turn to two remotely sensed data products, and to a series of geospatial control variables.

3 Data

3.1 Nighttime Lights. To measure urban growth and economic activity we draw on the Defense Meteorological Satellite Program (DMSP) satellite data on nighttime light emissions (NOAA 2013). Each DMSP data set consists of pixels at 30 arc second resolution (approximately 1km²). Each pixel is valued at between zero and sixty three. Sixty-three signifies maximum light output, while zero is no stable lights. We use the raw, unprocessed DMSP dataset, then execute several steps of light processing to extract nightlight data. First, we omitted any light emissions below a level of eight, which effectively omitted non-urban lights, including lunar reflectance. This step did not, however, omit nighttime lights from deforestation, a light source that we observed was often included in the stable lights database). To remove lights derived from deforestation we created clusters of lights, and cross-checked each cluster against urban census tracts from Brazil's 2010 census. We then discarded any nightlight emission that occurred outside of the set of light clusters over urban areas.

The DMSP dataset extends from 1992 to 2010, in theory providing a continuous time series of nightlights that extends over an eighteen year period. However, the time series is compiled from a total of six different satellites, with satellites capturing a total of 1-7 years of nighttime light data. Within this series measurements are influenced by satellites and by passing times. To minimize error we limit our analysis to a series of intervals. Specifically, we focus on three time periods: (1) 2001-2005, (2) 2005-2009, and (3) 2001-2009. This allows us to focus on differences within satellite (thus avoiding satellite inter-calibration) and limits our analysis to two satellites: satellites F15 (active 2000-2007) and F16 (2004-2009). We use satellite F15 for the interval 2001-2005, and for the 2001 baseline in the 2001-2009 interval. We then use F16 for 2005-2009, and for the later benchmark for the 2001-2009 time period.

The DMSP data on nightlight emissions have been widely used as a proxy measure for population, particularly in less developed regions, where paucity of data poses an obstacle to statistical analyses of growth (Sutton and Costanza 2002, Doll, Muller and Elvidge 2000). The data have been widely used across Africa (Henderson, Storeygard and Weil 2009), but also in studies in the Brazilian Amazon, where research indicates high correlations between nighttime lights and population and power consumption in the State of Pará (Amaral et al. 2005, Amaral et al. 2006). From our data, we estimate correlations of 0.96 between urban population, estimated in 2000 and 2010 censuses, and our measures of total nighttime light emissions.

For our analysis we focus on a measure of total urban lights per city. We calculate this value as the sum of light emitted from with each county (based on 2010 county tracts in Mato Grosso) per year. We exclude the cities of Cuiabá and Varzea Grande, which jointly comprise Mato Grosso's metropolitan capital region, from our analysis. This leaves a set of 139 cities.

3.2 Spatial Neighborhoods and Agricultural Data. We paired the nighttime light data with remotely sensed land use data. Specifically, we use land use data developed by Spera, et al, indicating the location of soybean areas in Mato Grosso. This land use data is based on MODIS based land use classifications, which identify land use according to one of three categories: non-soybean production, soybean production (single cropping agriculture), and soybean production followed by a second crop (double cropping) (Spera, *forthcoming*). The data consist of yearly classifications between 2001 and 2011 (we thus limit our time of analysis to 2001).

We focus on two measures of agricultural activity: (1) total agricultural area and total harvests. Our general hypothesis is that total agricultural area and total harvested area will both be positively related to urban growth, and that the relationship between area of agriculture will carry a larger impact than number of harvests. Because agriculture generally does not overlap with nightlight emissions, it is necessary to provide a spatial measure connecting rural land use to urban growth. To accomplish this we develop a measure of neighborhood agricultural area and total harvests for each city in Mato Grosso.

We define a city's neighborhood as the total area reachable in 120 minutes' driving. We then calculated each city's neighborhood by laying a grid of 5km x 5km squares over Mato Grosso State, and estimating driving times between each grid centroid and each city using ArcGIS's network analyst tool. Any centroid estimated to be reachable in less than the two hour limit was included in the neighborhood. We then compiled a sum figure for each city of total agricultural areas and harvests in each city's neighborhood.

3.3 Controls and Location Data. We include several locational control variables in our models. We thus calculate each city's (a) distance to the nearest principal river, (b) to the nearest 1970s era federal highways, and (c) minutes of driving time to Cuiabá, the state capital.

3.4 Instruments. We pursue our analytical models through an instrumental variable approach. We instrument for agricultural area and total harvests using three variables that are exogenous to urban growth: (1) soil type and texture; (2) slope; and (3) property size. We acquired a soil type shapefile from Embrapa and estimate the most common soil type for each city's neighborhood. We then derived slope from topographic data produced as part of NASA's SRTM missions. We used the 3arc second scale (roughly $90m^2$) elevation data to estimate slope, then calculated the average slope for each neighborhood. Finally, we estimated average property size for each city's neighborhood from GIS shapefiles acquired from Mato Grosso's Department of the Environment (SEMA).

4. Empirical Strategy

We estimate urban growth as a function of urban size (*U*) in a previous time period, the change in total agricultural area and total harvest area in a city's neighborhood (A^N), a vector of local and locational attributes, shown as *D*, namely distance to nearest highway or river, or minutes to Cuiabá, and a set of dummy variables, shown here as *M*, which control for each *micro*-region, an official sub-state level political unit (n= 22).

We express our basic model (1) as:

$$\Delta U_{t,i} = f(\, U_{t-1,i} + \ {U^2}_{t-1,i} + \Delta A^N_{i,t-1} + \ D_i + \ M_i + \ \varepsilon) \quad (1)$$

We include U_i as both a squared and unsquared term, as we expect that larger cities will grow faster than their smaller counterparts. The script ε represents unobserved error. The subscript *i* and *t* represent city, our spatial unit of analysis, and year interval, respectively. All of our models include robust standard errors, clustered by *meso*-region (n=5 in Mato Grosso).

We include time lagged variables for all of our temporal variables, including agricultural areas and harvest areas. We recognize, however, the possibility of endogeneity between the change in urban aea and changes in agricultural area. For example, if urban growth is resulting in an increased demand for agricultural land, or if urban generated profits are increasing the supply of investment capital, leading to investments in the surrounding rural areas, then our estimations may be biased. Additionally, the built urban sector, which consists of agricultural services and is invested in agriculture, urban areas may in fact act to sustain agricultural production in the surrounding rural areas. We seek to control for potential bias by instrumenting for changes in agricultural area and change in total harvest area.

We focus on four key instruments: harvests or agricultural area in the previous time period, slope, property size, and soil texture and type. We define our instruments based on statistics and attributed from each city's surrounding two hour neighborhood. For example, we calculated total agricultural areas, most common soil type and soil texture, average slope, and property size surrounding each city. We expected to find strong correlations between the change neighborhood agricultural areas and our instruments, given that these factors are critical elements in agricultural suitability. For example, slope (*SP*) is essential for mechanized farming, where high slopes can impede the utilization of the large harvesting and planting machines used in the production process. Discussions with farmers in Mato Grosso suggest that slopes of more than ten percent grade are generally not used for agriculture. Slopes of less than five percent are preferred. Soil type (*SO*) and texture (*TX*) are also of key importance. Farmers prefer dark red latosols, the iron rich soils often found in the tropics. The euthrophic alfisols of the Pantanal and Araguaia regions, in contrast, are less conducive to agriculture. In our sample, mean production areas and total harvests in latosol regions are above the sample mean, while those areas dominated by eutrophic alfisols are far less.

We include property size (*SZ*), a key indicator of landowner access to both the capital and the areas needed to take advantage of returns to scale essential to soybean production. We argue that it is essential to include each of these variables, given that all three conditions are often key factors underlying agriculture suitability, and it is impossible to estimate agriculture from a single physical attribute. For example, perfectly flat land comprised of small properties or eutrophic alfisols (which is the case in the flat, seasonally flooded regions of the Argauaia valley and the Pantanal) may be unusable for agriculture. Finally, we also include agricultural area and total harvests as a means to control for room for expansion in areas already dominated by agricultural production.

We thus reframe equation one as:

$$\Delta U_{t,i} = f(\, U_{t-1,i} + \, U^2{}_{t-1,i} + \widehat{\Delta A^N}_i + \, D_i + \, M_i + \, \varepsilon)$$

Where $\widehat{\Delta A^N}_i = \, A_{i,t-1}{}^N + (A_{i,t-1}{}^N)^2 + \, SP_i^N + SZ_i{}^N + (SZ_i{}^N)^2 + \, SO_i{}^N + (SO_i{}^N)^2 + \, TX_i^N$

We test our model over two time intervals. We first test the period 2001-2005, or during the height of Brazil's soybean boom. Second, we test the interval 2005-2009, or post soybean expansion years. Our principal hypothesis is that both agriculture areas and harvested areas will be associated with positive and significant urban growth. However, because we assume that the impact of agriculture on urban growth is closely tied to production returns, we hypothesize that the coefficients associated with agricultural for the first time period (2001-2005) will be greater than the later period (2005-2009). Finally, we assume that the estimated effect of each unit of agricultural area will be larger than for a unit of harvested area. This hypothesis follows from the realization that the marginal production cost and returns for a single crop will be larger than for the second crop (e.g., machinery used in the initial soybean harvest is re-used in the planting and harvesting of the second harvest).

5. Results

We begin by presenting first stage results from three model specifications, applied to both total agricultural area and total harvests. Each specification includes the principal explanatory variables, namely slope, property size, and soils attributes, as well as urban nightlights. In specification 2 we include controls for location, namely distance to the state's principal highways and rivers, and minutes of travel time needed to reach the state capital. In the third specification we include an additional set of controls, namely micro-region controls. All standard errors are robust and are, clustered by *meso-region* (n=5), a political unit that encompasses the principal regions of the state (north, central, northeast, southeast, and southwest).

5.1 First Stage Results

We estimated our first stage models using a linear regression model. The first set of specifications estimates changes in agricultural area; the second, changes in total harvest area. Our resulting first stage estimations indicate a positive but declining impact of agricultural area or harvest area on changes, and negative changes with respect to slope, as expected, as well as declining returns to scale for property size (see table 2, only results from 2001-2005 models are shown). The specifications also indicate positive and significant relationships between latsols and agriculture, and negative relationships with euthrophic soils, also as expected. The coefficients are stable across the first two specifications, but are absorbed when we include the micro-region effects.

We find similar results for specifications for both agricultural area and total harvests. The impacts of key factors such as soil type and slope on total harvests, however, are larger than their impact on agricultural area. This suggests that high intensity agricultural is relatively more sensitive to physical conditions.

5.2 Second Stage Results

We next present our second stage results, estimated using our instruments for agricultural area and harvest intensity. Here we include results from 2001-2005, or during the soybean boom years and 2005-2009, or post boom. We aggregate the results into two tables. We model change in nighttime light emissions as the dependent variable in both tables. We again test two sets of models, testing first for agricultural area and second, for the effect of total harvests. We include the results for agriculture area in Table 3. Results for total harvests are included separately as Table 4.

Our estimations indicate that both agricultural area and total harvested area have positive and significant impacts on nighttime light emissions. The estimated coefficients for agricultural area and harvest area (shown in bold) increased as additional controls were included in the specifications. The third model specification, which includes the micro-region and location controls, and the instrumented variables, suggest an estimated impact of agricultural area of as much as 0.148. The OLS estimations and the 2SLS estimations are similar, but suggest that ols may actually underestimate the impact of agricultural change on urban growth.

We hesitate to directly compare the results of the two regression periods, given that the two time periods use data collected by different satellites (the magnitude of sum nightlight and nightlight increase was far higher under satellite F16 (2005-2009) than F15 (2001-2005). To standardize the changes across the two periods, we calculated elasticities of urban change with respect to agricultural area (see Table 5. These estimates suggested that the elasticity of nighttime light emissions with respect to a one percent change in agricultural area ranged from between seven and sixteen percent, which is expected, given the high returns to agriculture, investments, and growth in agricultural areas during this period. For total harvest area, this figure was only slightly lower, ranging from between seven and thirteen percent for the instrumented models; however, much of the increase in harvested area during this period was tied directly to expanding cropland areas. As we expected, the impact of agricultural change on urban growth during the years of the soybean boom, or during the initial period of analysis, was far higher when examined in comparison to changes in the later period.

From 2005 to 2009, increases in harvested area had a larger impact on urban growth than changes in area of production. We interpret these statistical results as a partial artifact of the relative stagnation of agricultural areas during the latter half of the decade. However, the rapid expansion in double cropping, assumed a larger role in spurring urban growth. During this period we estimate a one percent increase in total harvest area as having as much as 2-5 times an impact on nighttime light emissions as area expansion.

6. Interpretation of Results and Discussion

In this paper we estimate the relationship of rural economic changes on urban nighttime light emissions in the Brazilian State of Mato Grosso. Our estimations, which utilize a two stage least squares approach, and an ordinary least squares linear regression, suggest that rural agricultural growth and intensification can have significant localized impact on local urban nighttime light emissions, and by proxy, urban based population or economic growth. We estimate that the impact of agriculture was largest from 2001-2005, or during the height of the soybean boom, when urban areas not only absorbed increases in rural production returns and local consumption, but when new investments in infrastructure and land clearing were rapidly increasing future regional capacity for resources production and extraction.

In this article we focused on urban growth and on rural drivers of urban change. The work calls attention specifically to the effects and impacts of Mato Grosso's soybean boom on nighttime light emissions. In our approach we call explicitly on a recent and growing body of work that has broadly tied the state's soybean sector to changes in the social fabric of cities and counties in Mato Grosso, and more broadly across the Amazon (Weinhold, Killick and Reis 2013, VanWey et al. 2013). We build on these recent efforts by extending this past work on several key channels. First, we focus explicitly on urban growth, rather than on county level indictors of well-being or socioeconomic status. Second, we utilize spatially explicit, remotely sensed data to analyze urban growth. We step outside the bounds of county level census data, and instead draw our own conceptualization of neighborhoods; one that we argue provides a more realistic interpretation of spatial influence and access, and one which is exogenous to the drawing of political borders. Third, take the innovative approach of modelling urban changes as a function, in part, of the context of rural surrounding areas. While research has long assumed this relationship, particularly as it respects population dynamics and relationships, here we seek to quantify the relationship through the regional production of capital.

We situate our findings within two sets of ongoing discussions, first, the relationship between rural economic and environmental changes and localized urban growth; and second, the role of rural commodity producing regions within a globalized network of food production and consumption. With respect to the former, we fully acknowledge the host of literature that has examined the environmental impacts of urban change, but question the extent to which social science has recognized the means or extent to which regional environmental changes are also reshaping our urban environments.

Discussions over the environmental relationships between urban and rural have long been anchored by research on the how urban behavior reshapes and redefines rural environments and land use. Research in urban areas across the globe, and in particular in the US, for example, has broadly suggested that urbanization adversely impacts local temperature and rainfall levels (Grimm et al. 2008), biodiversity (McKinney 2002), and leads to increased stress on water systems, and on local construction resources (Fry 2011). Still other research has connected urban changes to systemized reductions in local forest cover. Even in the Brazilian Amazon, concerns continue to percolate with regard to the local environmental implications of urbanization on regional forest cover (DeFries et al. 2010). In this literature, and specifically with respect to the Amazon region, significant question remain, including whether urbanization in the Amazon, and in Mato Grosso specifically, is also driving regional changes in land use or land cover. Here we suggested that rural land use changes occurring in the context of Mato Grosso are in fact not artifacts of the past decades of urban growth. Instead, we argue, urban growth is a symptom, rather than a driver, of agricultural growth and, by extension, regional forest losses.

We hope that future work will increasingly recognize the importance of rural economic changes on urban growth and dynamics, and the extent to which population and economic growth is a direct residual to regional, rural context. Urban population and economic growth, particularly in regions traditionally comprised of crop or ranch lands, has often been conceptualized as a function of urban centers' ability to capture marginal labor from surrounding rural areas (Lewis 1954). Implicit in much of this work is the juxtaposition of diminishing marginal returns to rural labor, whether due to high fertility or technical innovations, or labor mobility, or to increasing returns to urban labor. As the differential between urban and rural wages increases, rural workers shift from rural to urban locations (Todaro 1980, Taylor 1980). The rural-urban relationship, however, extends beyond the displacement or distribution of people, and to the generation and absorption of profits and capital in the urban areas that service the extraction and transportation of the production and extraction of rural resources.

We also take the position that trade relationships are redefining the role of the urban center, not only in the Amazon, but in resource rich regions in developing nations across the globe. Recent research has increasingly come to recognize that the urbanization process in many developing regions is shifting from a process intertwined with manufacturing, and with the movement and relocation of populations bases from rural to urban locations, to one that hinges on the availability and consumption of resources rents (Gollin, Jedwab and Vollrath 2013).

Here, rural regions supply capital in the form of globally traded resources or commodities, while urban areas service production and provide access to consumptive goods, and facilitate the transportation of these goods to other urban areas, where they are traded for manufactured and food items. Urban growth, thus framed, is contingent on the generation of rural capital, rather than on the endogenous production of industrial or processed goods. Manufactured goods and even food items need not be produced or extracted locally, but rather can be imported from external regions. Given that urban growth, in this conceptualization, is contigent on trade relationships, it follows that globalization and the development of trade linkages can accelerate the process.

In Mato Grosso, and in Brazil's Amazon region more generally, macroeconomic shifts and new trade policies have transformed the region into a provider of beef and soybeans to consumers in Europe and Asia (Walker et al. 2009, Nepstad, Stickler and Almeida 2006, Garrett, Rueda and Lambin 2013). The process has facilitated the rendering of large portions of Mato Grosso into seemingly endless expanses of cropland and pasture, with much of this new crop and pastureland has come at the expense of native vegetation types, including the endangered cerrado biome and the carbon rich tropical forests of the Amazon (Morton et al. 2006). Deforestation and environmental degradation, however, have not come without positive economic tradeoffs. In fact, we argue that an often overlooked symptom of environmental change in Mato Grosso is the emergence of a new constellation of cities across the state, in in-migration to the cities of the interior, and to economic growth. Profits accrued from the lands that were once forest now furnish capital to local economies and urban areas, which, in turn, have further developed their service sectors and in some cases, invested in public and private infrastructure development.

We close with the acknowledgment that urbanization in Mato Grosso, which we have tied directly to changes in the state's agricultural sector, is by proxy closely connected to international trade networks. Recent interest in land use relationships, and in the telecoupling of distal changes, has shed new light on the need to understand how trade and networks are reshaping the location and geography of environmental and social change, as well as our understanding of the location and full extent of any social changes residual to local changes in behavior or consumption. Urban change growth in Mato Grosso is one such change, and one that has been widely overlooked in discussions over how to balance environmental impact with economic growth.

Table 1 Summary Statistics

	Note	Year	Mean	Std. Dev
Nightlights	Sat F15	2001	411	700
	Sat F15	2005	417	817
	Sat F16	2005	454	842
	Sat F16	2009	672	1208
Cropland				
	Area	2001	1692	2253
	Area	2005	2422	2972
	Area	2009	2502	3127
	Harvested Area	2001	1978	2687
	Harvested Area	2005	3119	3956
	Harvested Area	2009	3910	5114
Location				
	Km to Rivers		26	24
	Km to Principal Roads		73	74
	Minutes to Cuiaba		367	264

Table 2	**Change in Agricultural Area**	2001		**Change in Total Harvests**		
Specification:	One	Two	Three	One	Two	Three
Agricultural Area /Total Harvests	0.418**	0.364**	0.381*	0.580**	0.518**	0.45*
Agricultural Area /Total Harvests²	-0.00*	-0.00*	-0.00*	-0.00**	-0.00*	0.0
Slope	-504	-486	--1,939	490	514	-2,676
Slope²	-187	-196	570	-1,195	-1,215	800
Property Size	0.00	-0.00	0.00	0.001	0.000	0.00
Property Size²	-0.00	-0.00	-0.00	-0.00	-0.00	-0.00
Soils	Included	Included	Included	Included	Included	Included
Textures	Included	Included	Included	Included	Included	Included
Nightlights	Included	Included	Included	Included	Included	Included
Nightlights²	Included	Included	Included	Included	Included	Included
Location		Included	Included		Included	Included
Region Controls			Included			Included
R^2	0.89	0.90	0.94	0.91	0.92	0.96
N	139	139	139	139	139	139

* p<0.05; ** p<0.01

Table 3	2001-2005 **Change in Night lights**				2005-2009 **Agricultural Area**			
	IV1	IV2	IV3	OLS	IV1	IV2	IV3	OLS
Nightlights	-0.126*	-0.129**	-0.185**	-0.174*	0.338**	0.336**	0.281**	0.319
Nightlights²	0.000**	0.000**	0.000**	0.000**	0.000	0.000	0.000	0.000
Δ.Agricultural Area	**0.066****	**0.076****	**0.148****	**0.122**	**0.115****	**0.139***	**0.465**	**0.163***
Location Controls		Included	Included	Included		Included	Included	Included
Microregion Controls			Included	Included			Included	Included
R^2	0.39	0.39	0.51	0.51	0.61	0.63	0.69	0.71
N	139	139	139	139	139	139	139	139

* $p<0.05$; ** $p<0.01$

Table 4	2001-2005 **Change in Night lights**				2005-2009 **Agricultural Area**			
	IV1	IV2	IV3	OLS	IV1	IV2	IV3	OLS
Nightlights	-0.130*	-0.133**	-0.185**	-0.179**	0.297**	0.304**	0.268**	0.296
Nightlights²	0.000**	0.000**	0.000**	0.000**	0.000	0.000	0.000	0.000
Δ.Total Harvest Area	**0.041****	**0.046****	**0.088****	**0.079**	**0.067****	**0.066***	**0.115**	**0.070***
Location Controls		Included	Included	Included		Included	Included	Included
Microregion Controls			Included	Included			Included	Included
R^2	0.40	0.40	0.52	0.52	0.63	0.64	0.71	0.72
N	139	139	139	139	139	139	139	139

* $p<0.05$; ** $p<0.01$

Table 5
Elasticity of nightlight growth w.r.t. 1% increase in agriculture or harvest area

	S1	S2	S3	Iv
Area 01-05	7%	8%	16%	13%
Harvest 01-05	7%	7%	12%	13%
Area 05-09	0.04%	0.05%	0.17%	0.06%
Harvest 05-09	0.24%	0.24%	0.42%	0.25%

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