An alternative method to measure non-registered economic activity in Mexico using satellite nightlights

Erick Rangel-Gonzalez and Irving Llamosas-Rosas

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Introduction and Motivation

- There are many economic activities that are not registered in the Gross Domestic Product (GDP).
  - For example, small business or shops that are founded in the streets that produce or sell goods and services to the population. A large number of these economic agents are not likely to be registered formally with the government.
  - It is also possible that some registered establishments report a lower level of production and sales, and therefore there is part of the economic activity that are not measured by the official estimates.

- The non-registered economic activities, also known as shadow economy, are by nature difficult to measure, because the agents in this sector try to remain undetected for monetary, regulatory or institutional issues.

- The estimation of the total economic activity, including official and non-registered production of goods and services, is important :
  - To determine the welfare level of the population in one country.
  - for designing economic policies to encourage development, or policies that respond to changes in the economic cycle.
  - As a fundamental input to estimate tax evasion and for design policies aimed for combating this problem.

Introduction and Motivation

- Previous works for Mexico have used different methods in order to obtain a measure of this unobserved economy, the MIMIC method has larger estimates compared against National Accounts Methods (Medina and Scheider, 2017). According to the last one, INEGI reports for México in 2017 an amount of informal economy of 22.7 percent of the economy, while MIMIC has an estimate of 31.7%. Monetary demand methods has estimations that goes from 24.46% for the period 1996-2000 (Chapa et al. 2008), and 22.95 % for 2012 (Santos-Pérez, 2016).

- Other studies like Gyomai and van de Ven (2014) estimates that the size of underground economy in Mexico is 5.5%, and 10.4% for the Informal sector, for a total of non-observed economy of 15.9% (this calculation does not includes illegal activities). Using the predictive mean matching method between 1991 and 2015, they also found that in México the shadow economy is 24.8 percent (more in line with INEGI national accounts approach).

Introduction and Motivation

- In this research we use an alternative recently developed approach that employs nightlight data observed from space to measure non-registered economic activity, or shadow economy, in Mexico.

- Nightlight data represent an attractive path to analyze the shadow economy because luminosity detected from the space captures all kind of economic activity: formal and informal.

- Donaldson and Storeygard (2016) group the main advantages of such remote sensing data into three categories: 1) access to information difficult to obtain by other means; 2) unusually high spatial resolution; and 3) wide geographic coverage.

- The idea is to use satellite images of nightlights, through which economic activity can be captured, to measure economic activities not recorded in GDP by the differential between the estimated output by brightness and the official data. This idea had already been exploited Ghosh et al. (2002), who used the U.S. economy as a reference, as it has very low levels of informality.

Introduction and Motivation

This research has several differences with respect to Ghosh et al. (2002):

- i) we use GDP instead of Gross National Income as a measure of economic activity, which we believe is more appropriate for the analysis since we are using luminosity inside the country ;

- ii) we use a different econometric specification to estimate the correlation between luminosity and economic activity, our model accounts for the fact that the relationship between nightlights and economic activity differs by sector;

- iii) we also present estimations using a different reference economy (not only the US): the state of Nuevo Leon that it is recognized as the federal entity with the lowest levels of informality in Mexico;

- iv) we use more recent data from the NASA VIIRS satellites, which have higher resolution on luminosity and has similar or even better results for estimating economic statistics than DMSP lights used in previous works (Chen and Nordhaus, 2019).

Literature Review

- The first paper to analyze the relationship between nighttime lights and economic activity was done by Elvidge et al. (1997). They study the connection of luminosity with population, GDP, and electric power consumption for twenty-one countries, during the period 1994-1995, at different levels of economic development.

- Ebener et al. (2005) analyzed correlation between nighttime lights and per capita GDP at the national and sub-national level. They used different parameters to test the relationship and found that the total and mean frequency of lights to be better correlated with per-capita GDP than lit area.

- Henderson et al. (2012) used a panel data of GDP and the night light intensity between 1992-93 and 2002-03 to estimate income growth, and GDP at the national and subnational level.

- The nighttime lights data in addition to population data have also been used to produce a poverty map (Elvidge et al. 2009).

Literature Review

- Chen and Nordhaus (2019) compare both databases for the United Sates and conclude, among other things, that VIIRS nightlight data is more useful to provide cross-sectional GDP estimations than DMSP-OLS.

- Work using nightlights and informality:

  - Ghosh et al. (2009) use regression models using nightlights and adjusted official gross state product for the USA, and use the calculated parameters to obtain Estimated Gross Domestic Income (EGDI) at the national level and at the state level.

  - The same exercise is also applied for the Indian economy by Gosh et al (2010).

  - Harati and Hardy (2013) argue that since economic activity predicted by nighttime lights must capture both formal and informal activities the difference between light predicted and official GDP might be used to estimate informal activity.

  - Brock et al. (2014) analyze the change in luminosity and gross country product between 2000 and 2006 for the state of Veracruz (Mexico) to identify the evolution of the formal and informal activity.

  - Tanaka and Keola (2015) analyze the shadow economy in Cambodia by estimating the relationship between nightlights and sales across regions separately for both formal and informal firms using a question of the economic census that allows them to identify registration with administrative agencies.

What is nightlight satellite data?

## Figure 1. Nightlight data for United States and Mexico, 2016
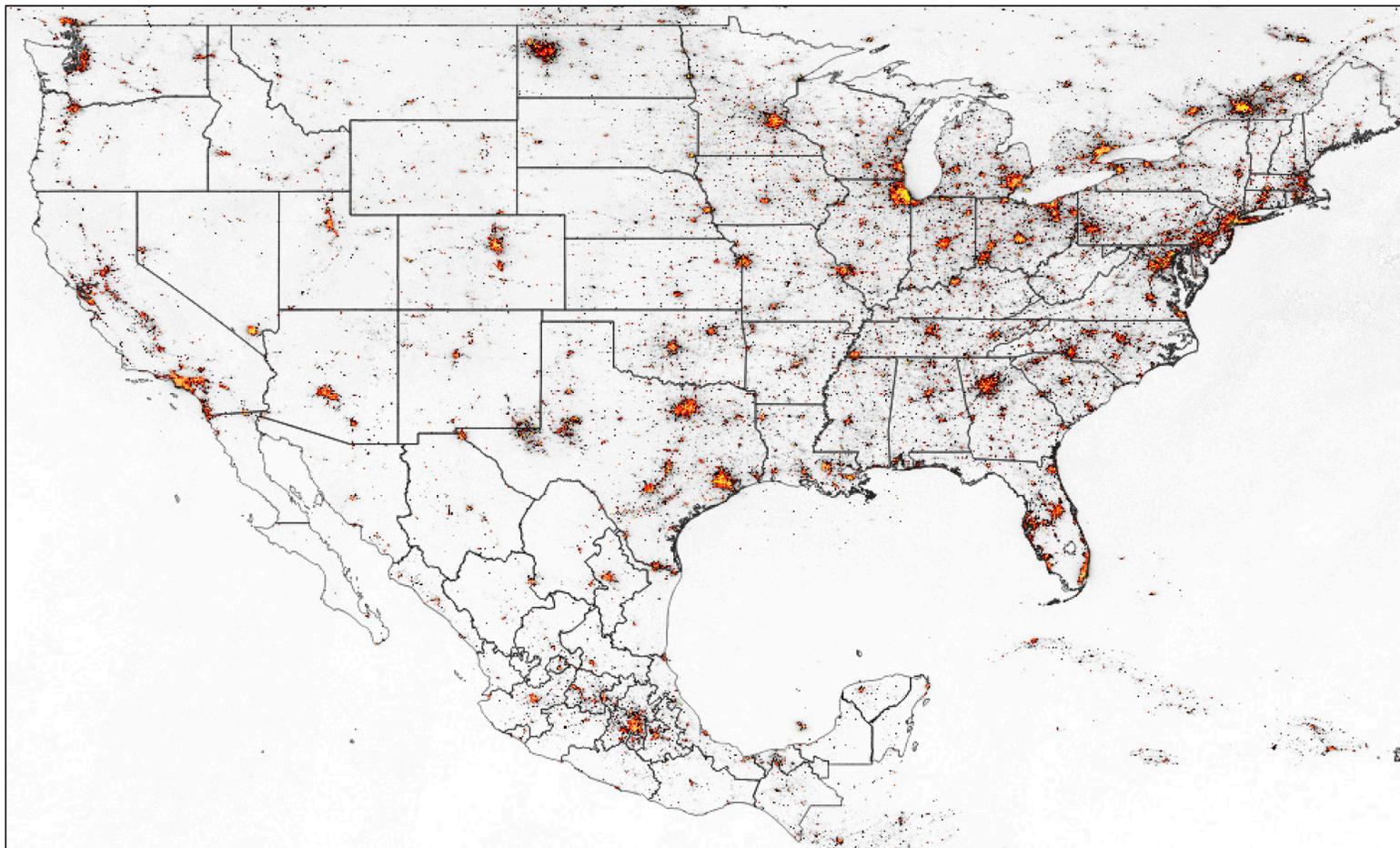
Source: NASA/NOAA , VIIRS-Night Light Satellite Data

What is nightlight satellite data?

- Since 1992, satellites' images (DMSP-OLS) have been systematically digitized at the NOAA National Geophysical Data Center (NGDC). After 1992, the NASA and the NOAA via the Suomi National Polar Partnership (SNPP) with the VIIRSS released data nightlight.

- The data observation unit is the pixel that corresponds to a geographic area equivalent to 0.44 square kilometers (15 arc-seconds grids). Within each pixel the brightness is measured on a scale from 0 to 4536.23 for the 2015 raster. Subsequently, the data are reported according to a system of angular geographical coordinates (latitude and longitude) and paired with USA and Mexico States' administrative boundaries through GIS software.

- The satellite data was processed following the methodology proposed by Henderson, Storeygard and Weil (2012) to adjust the change in pixel size due to the curvature of the Planet, as well as take into account the reflections of the lights in water fields and Coastal.

- Figure 2 summarizes the processing of the data.

What is nightlight satellite data?

Figure 2. Graphical Description of Data Processing

3. Geo-referencing administrative boundaries.

2. Firm Land and area/pixel size correction

1. Satellite captures the images (NASA)

4. Extract map data into administrative datasets, in order to use them in statistical models.

64	42	20	15
36	40	10	0
25	33	5	1
0	2	0	0
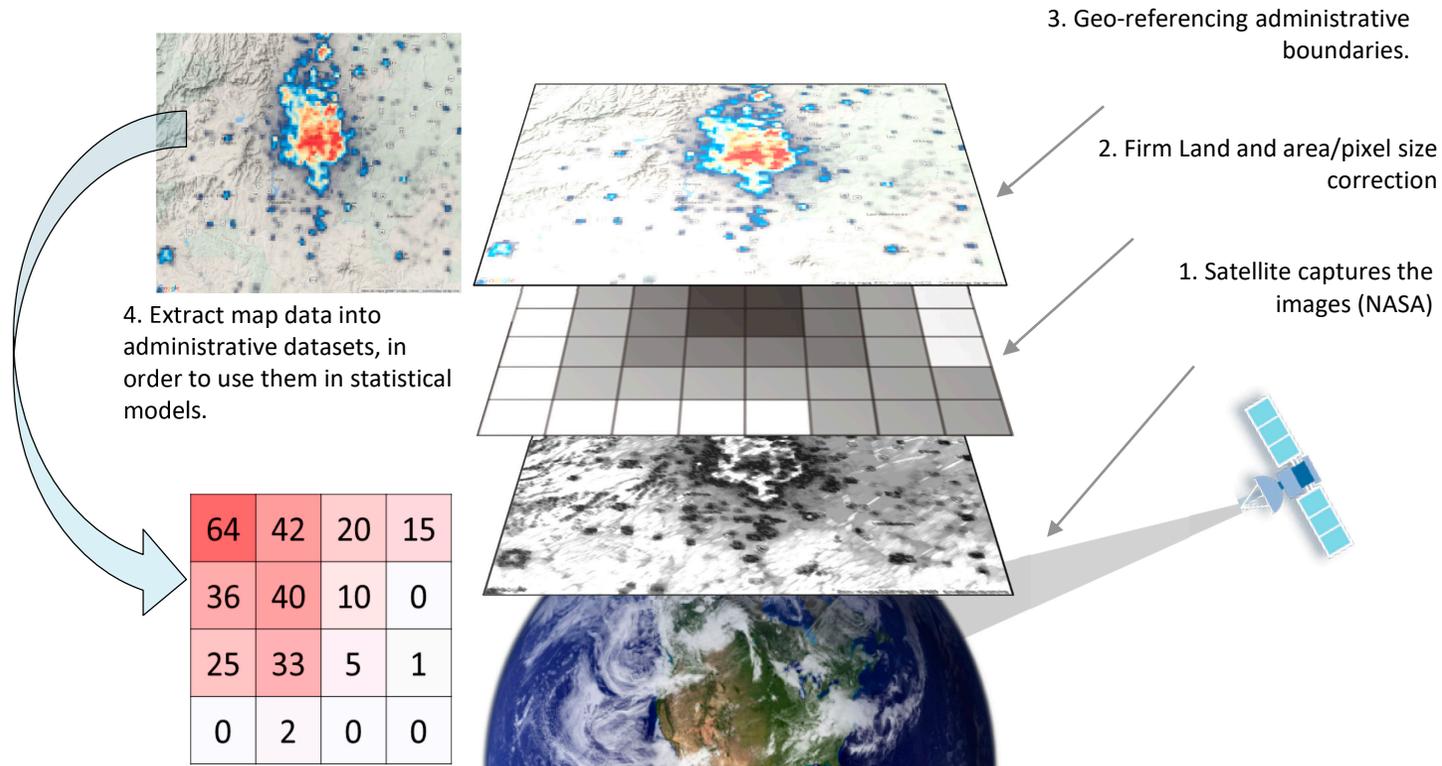
Source: Own elaboration

Economic Data

- For the economic activity in the USA, we took the real GDP by state, in millions of chained 2012 dollars from the Bureau of Economic Activity, seasonally adjusted.

- Since different types of activities may have different impact in lights, we divided the economic activity in primary (agriculture, forestry, fishing and hunting), secondary (mining, quarrying, and oil and gas extraction, utilities, construction, manufacturing) and tertiary (rest) based on the North American Industry Classification System.

- In the case of Mexico, we have the real GDP by state from the National Institute of Statistics, Geography and Informatics (INEGI) divided by sector.

Economic Data

Table 1. Economic and Satellite Data for USA. 2015-2016 averages.

State	Sum of Night Time Lights (average 2015-2016)	GDP (in millions 2012 chained dollars, average 2015-2016)	Primary Sector participation	Secondary Sector participation	Tertiary Sector participation	Population (millions)
California	211,909,232	2,462,491	2%	16%	82%	39.081
Texas	349,771,392	1,591,553	1%	32%	67%	27.712

Source: NASA/NOAA , VIIRS-Night Light Satellite Data and Bureau of Economic Analysis.

Empirical Model

Step 1

$$\ln\left(GDP_i^{US}\right)$$

$$= \alpha + \beta_1^{US} \ln\left(SL_i^{US}\right) * P_i^{US} + \beta_2^{US} \ln\left(SL_i^{US}\right) * S_i^{US} + \beta_3^{US} \ln\left(SL_i^{US}\right) * T_i^{US} + \gamma_1^{US} Pop_i^{US} + \gamma_2^{US} Pop^{US}{}_i^2 + \varepsilon_i$$

- Here, $\ln(GDP_i)$ is the natural logarithm of real Gross Domestic Product for state i, $\ln(SL_i)$ is the natural logarithm of the sum of night time lights for each state; P_i, S_i, and T_i are the participation rate of primary, secondary and tertiary sector, respectively; and Pop_i is the population in millions for each state.

Step 2

$$\ln\left(\widehat{GDP_i^{MX}}\right)$$

$$= \alpha + \beta_1^{US} \ln\left(SL_i^{MX}\right) * P_i^{MX} + \beta_2^{US} \ln\left(SL_i^{MX}\right) * S_i^{MX} + \beta_3^{US} \ln\left(SL_i^{MX}\right) * T_i^{MX} + \gamma_1^{US} Pop_i^{MX} + \gamma_2^{US} Pop^{MX}{}_i^2$$

Empirical Model

Step 3

$$d_i = \widehat{GDP_i^{MX}} - \left[GDP_i^{INEGI} * PPP \left(\frac{US}{MX} \right) \right]$$

So, $d_i / \left[GDP_i^{INEGI} * PPP \left(\frac{US}{MX} \right) \right]$ is the percentage of the economic activity un-registered in the official estimates.

Step 4

In order to estimate the nonregistered economy at the national level, we have to add d_i for all states and divide it by the sum of all official GDPs per state.

Empirical Model

Figure 3. Process of estimating non-registered economy using US data.
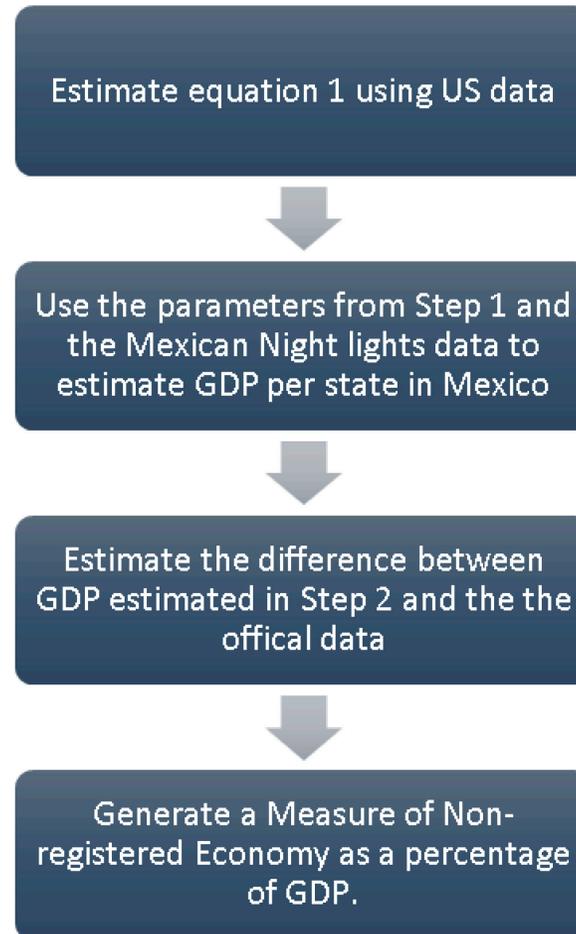
Empirical Model

When using Nuevo Leon as benchmark

Step 1

$$\ln\left(GDP_i^{MX}\right) = \alpha + \beta_1^{MX}\ln\left(SL_i^{MX}\right)*P_i^{MX} + \beta_2^{MX}\ln\left(SL_i^{MX}\right)*S_i^{MX} + \beta_3^{MX}\ln\left(SL_i^{MX}\right)*T_i^{MX} + \delta\ln\left(SL_i^{MX}\right)*NL_i + \gamma_1^{MX}Pop_i^{MX} + \gamma_2^{MX}Pop^{MX^2}_i + \varepsilon_i$$

Step 2

Predict GDP for every state considering the additional elasticity not obtained by the average state in México.

Step 3

Estimate the difference between GDP estimated in Step 2 and the the offical data

Step 4

$$d_i^{NL=1} = composed\ \widehat{GDP_i^{MX}} - GDP_i^{MX}$$

So, $d_i^{NL=1}/GDP_i^{MX}$ is the percentage of the economic activity un-registered

Empirical Model

**Figure 4. Process of estimating non-registered economy using Mexico's data.**
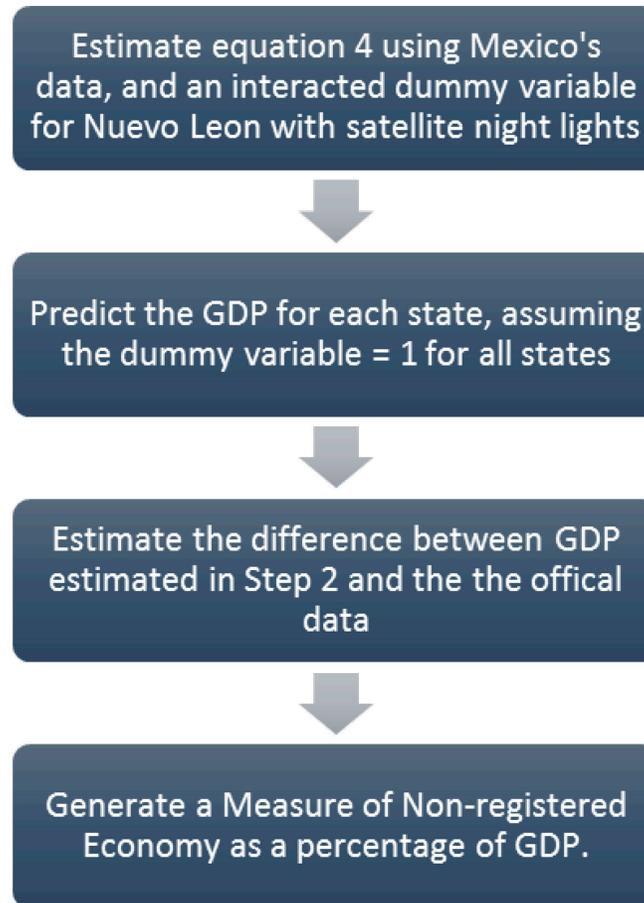
Results Using US as Benchmark

Table 2. Estimation Results of Equation 2, US Data, 2015 and 2016

| Variables	2015		2016	
Ln(Light)*Primary Sector	0.228		0.165	
Ln(Light)*Secondary Sector	0.355	***	0.327	***
Ln(Light)*Tertiary Sector	0.465	***	0.453	***
Population	0.130	***	0.132	***
Population^2	-0.002	**	-0.002	**
Constant	3.866	*	4.189	**
Observations	49		49	
R^2	0.956		0.955	

Source: Own calculations using NASA/NOAA , and BEA

Graph 1. Actual vs Estimated GDP for the U.S. states
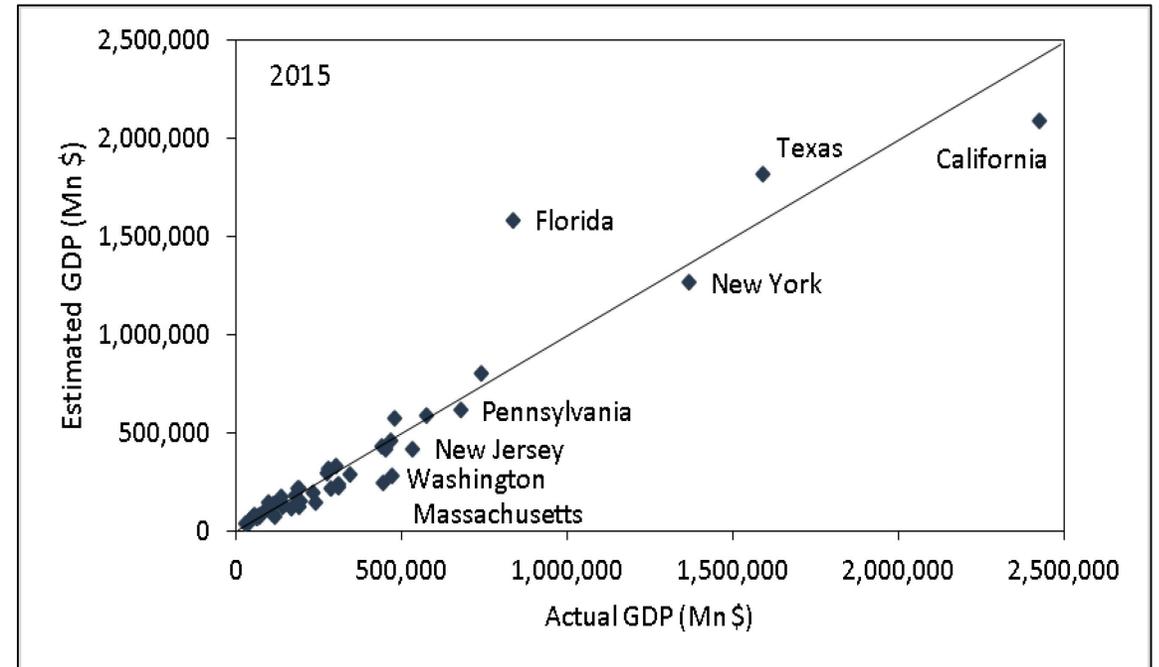
Source: Own calculations using NASA/NOAA , and BEA

Results Using US as Benchmark

Graph 2. Actual vs Estimated GDP using Mexican nightlights and US parameters
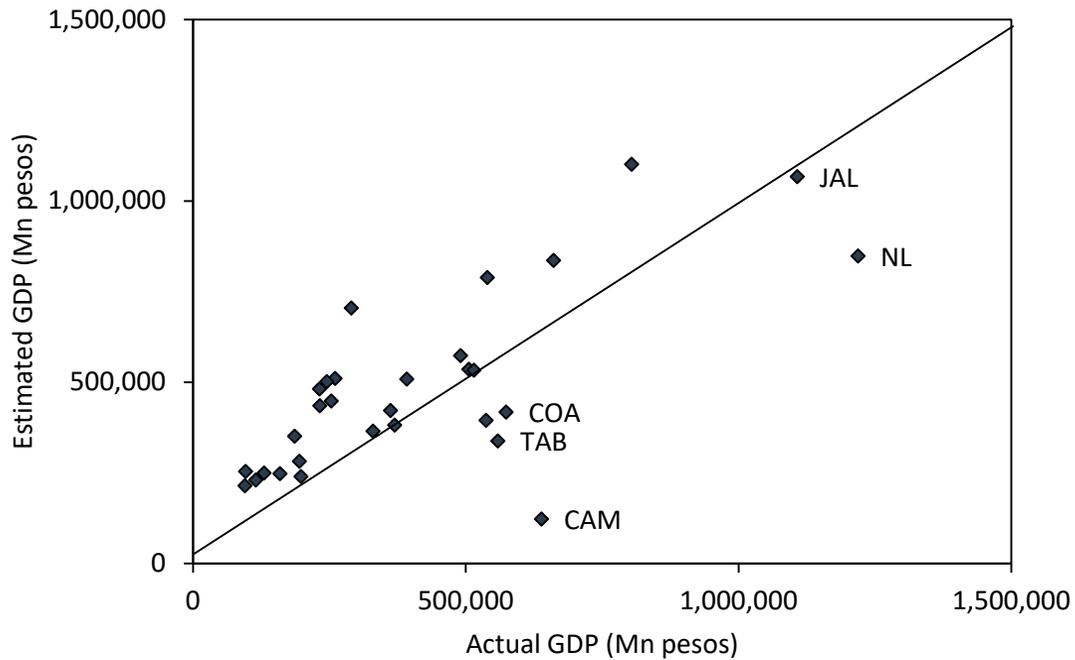

Source: Source: Own calculations using NASA/NOAA , VIIRS-Night Light Satellite Data and INEGI.

Figure 5. GDP Differentials using Mexican nightlights and US parameters (in percentage points)
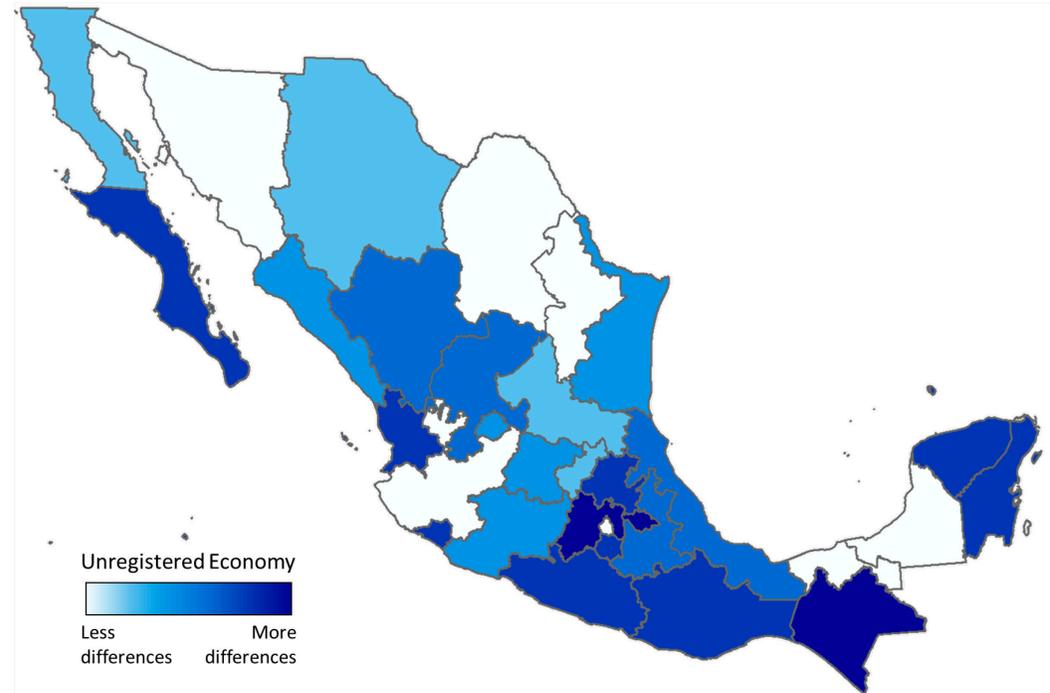
Source: Source: Own calculations using NASA/NOAA , VIIRS-Night Light Satellite Data and INEGI.

Results Using US as Benchmark

Graph 3. Labor Informality vs Non-Registered Economy
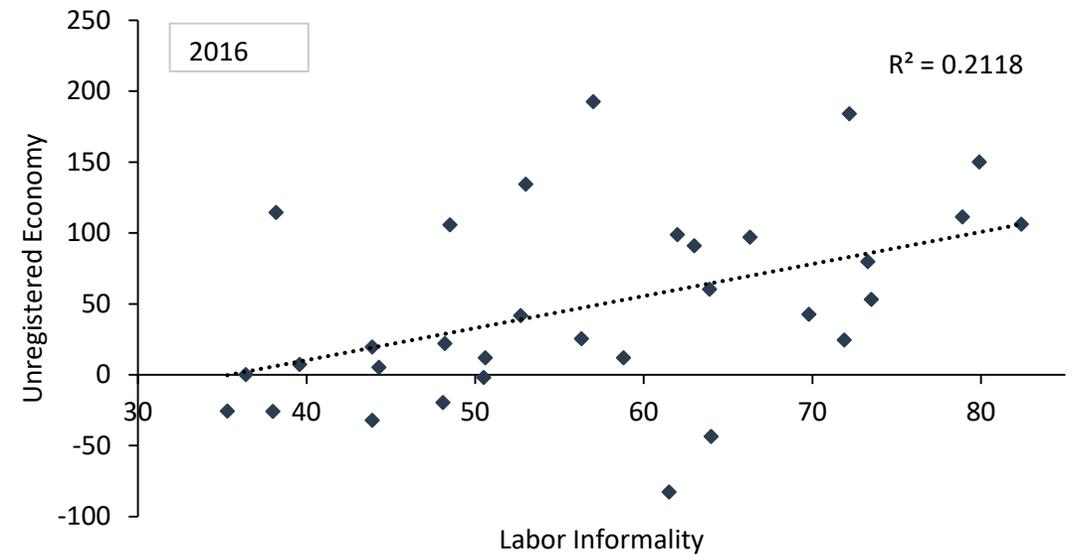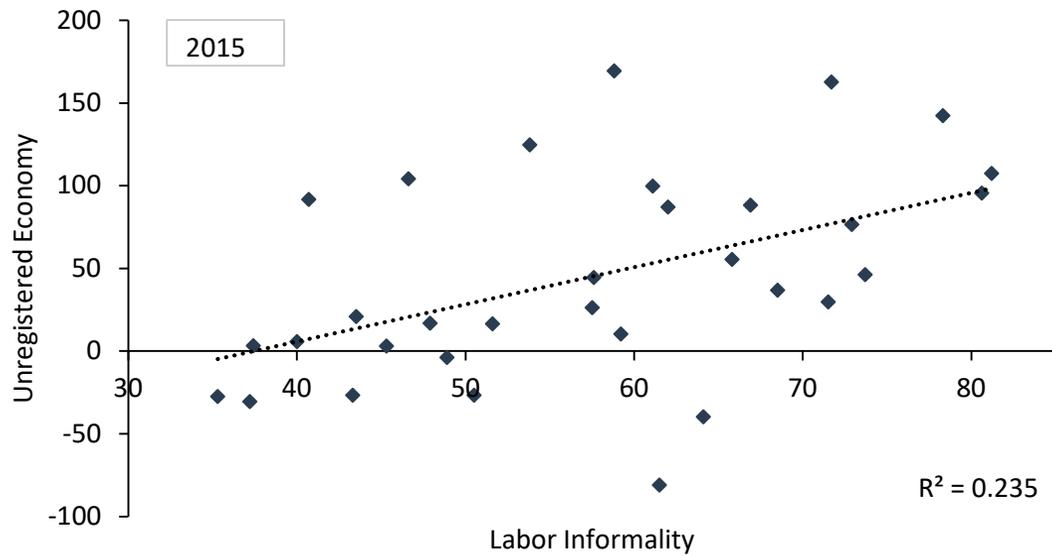
Source: Own calculations using NASA/NOAA , VIIRS-Night Light Satellite Data and INEGI.

Results Using US as Benchmark

- The result indicates that the size of the non-registered economy is 22.72% and 27.78% of GDP for the years 2015 and 2016 respectively. That is, our results indicates that an average of 25.25% of the economic activity in Mexico is not registered by the official numbers. When performing the same exercise for the US economy the estimations are 1.89% for 2015 y 2.39% for 2016.

Results Using NL as Benchmark

Table 2. Estimation Results of Equation 2, Mexico Data, 2015 and 2016

Variables	(1) 2015		(2) 2016	
Ln(Light)*Primary Sector	0.029		0.002	
Ln(Light)*Secondary Sector	0.407	***	0.339	***
Ln(Light)*Tertiary Sector	0.336	***	0.255	***
Population	0.288	***	0.303	***
Population2	-0.011	***	-0.011	***
NL*Light	0.023	***	0.027	***
Constant	6.433	***	7.591	***
Observations	1835		1828	
R^2	0.817		0.805	

Source: Own calculations using NASA/NOAA , and INEGI

## Graph 4. Actual vs Estimated GDP using Mexican nightlights and MX parameters
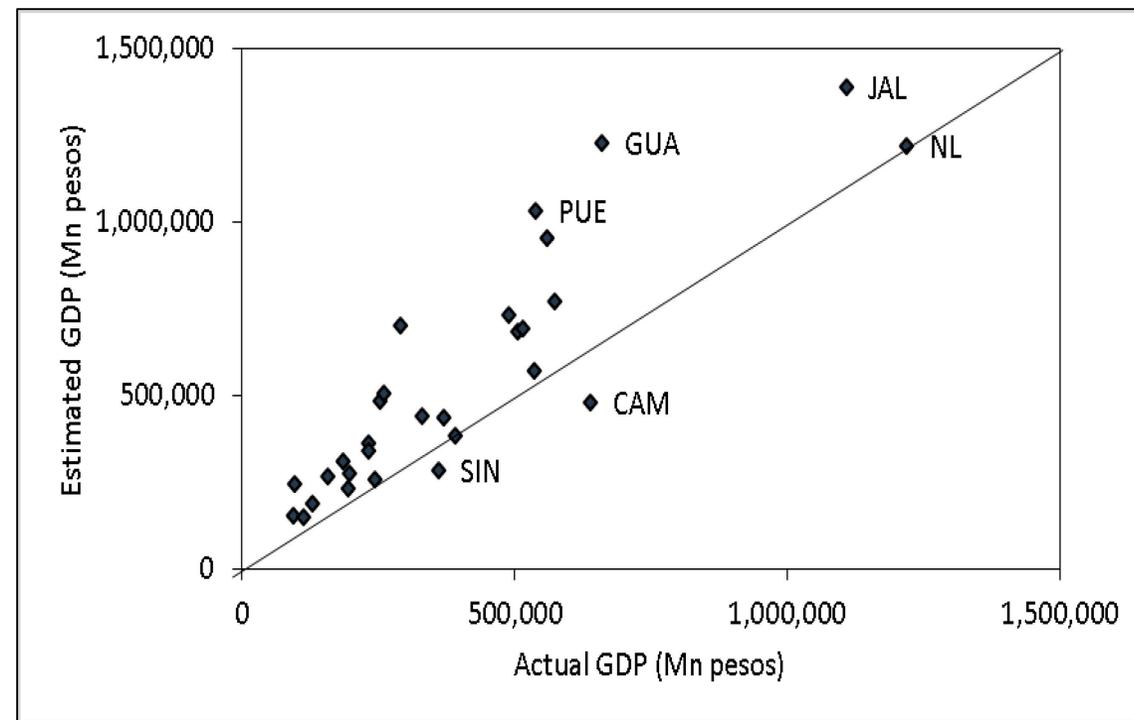
Source: Own calculations using NASA/NOAA , and INEGI

Results Using NL as Benchmark

Figure 6. GDP Differentials using nightlights and NL as the Reference Economy
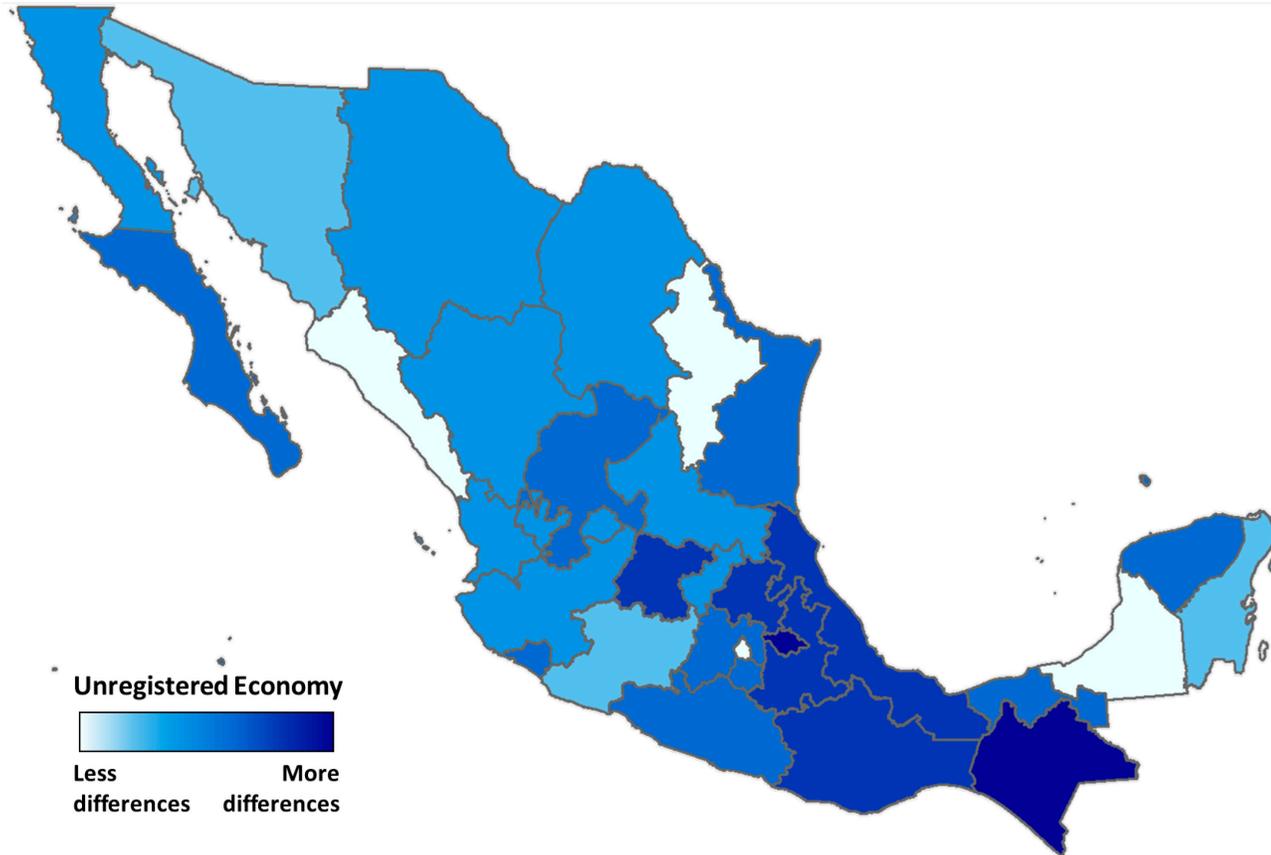
Source: Own calculations using NASA/NOAA , VIIRS-Night Light Satellite Data and INEGI.

Results Using NL as Benchmark

Graph 5. Labor Informality vs Non-Registered Economy
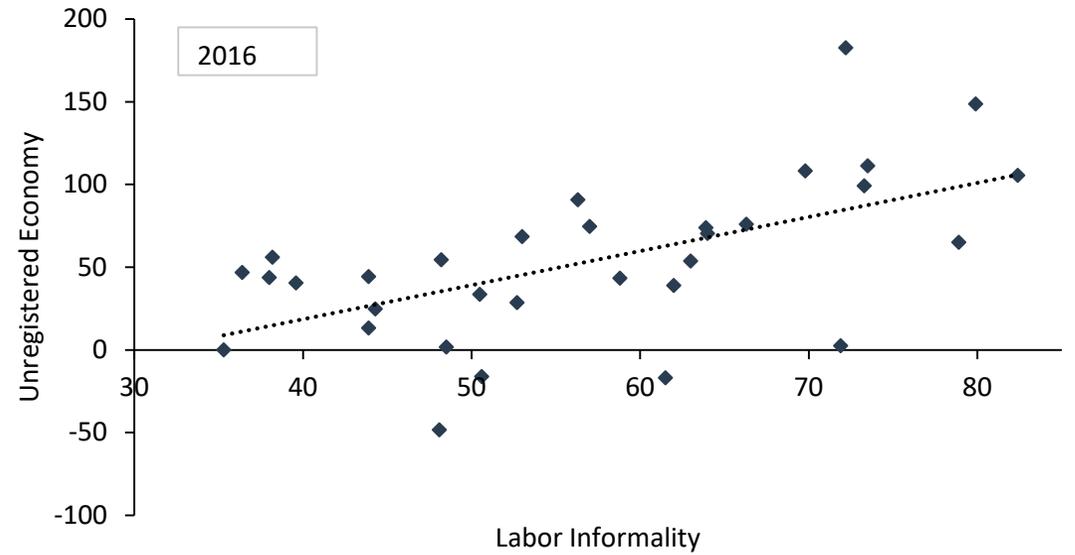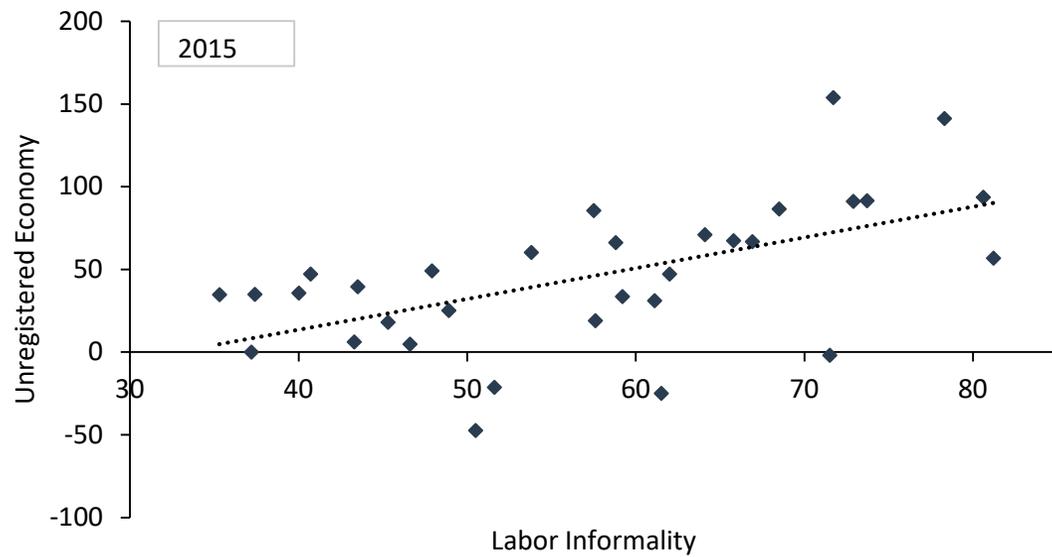
Source: Own calculations using NASA/NOAA , VIIRS-Night Light Satellite Data and INEGI.

Results Using NL as Benchmark

- The result indicates that the size of the non-registered economy is 27.80% and 34.54% of GDP for the years 2015 and 2016 respectively. That is, our results indicates that an average of 31.17% of the economic activity in Mexico is not registered by the official numbers.

Conclusions

- The shadow economy in developing economies, such as México, represents a non-negligible size of the economic activity.

- In this research we use satellite images of nightlights, through which economic activity can be captured, to measure economic activities not recorded in GDP by the differential between the estimated output by brightness and the official data.

- Our estimates indicates that the size of the non-registered economy in Mexico is about 25.25 % of the GDP when using the US economy as a reference, and 31.17% when using the state of Nuevo Leon as a benchmark economy.

Conclusions

- Our estimates are similar to previous measures of the non registered economy in Mexico using traditional methods of estimation.

- State level estimates should be taken with caution since the econometric model does not allow to considerate to many specific characteristics, other than mixture of primary, secondary and tertiary sector within every federal entity. However, they can be used as a starting point for ranking the size of the shadow economy.

- One limitation of the study is that we are assuming that the relationship between nightlight data an economic activity is the same for the United States and Mexico (in the first estimation) and for Nuevo Leon and the rest of the estates (in the second estimation), which might be not true. The use of the mixture of economic sectors (primary, secondary and tertiary) helps to attenuate the problem but not to eliminate it, since there might be differences in technology within every sector.

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