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Analysis of Panamanian DMSP/OLS nightlights corroborates suspicions of inaccurate fiscal data: A natural experiment examining the accuracy of GDP data

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ABSTRACT

Governments have incentives to misreport their economic productivity to advance their political goals. These incentives have long been understood, but the validity of government data has been difficult to estimate in the absence of viable external estimates. Using historic Defense Meteorological Satellite Program's Operational Linescan System nightlights imagery we corroborate reports that Panama's government data has been increasingly politicised since the handover of the Panama Canal on 31 December 1999. The Canal Handover represents a "natural experiment" in which the production of government data changed in Panama for reasons separate from the desire to manipulate that data. The amount of light a country produces at night, known as nightlight production, has been shown to strongly correlate with GDP. Using subnational Panamanian nightlight production from 1996 to 2012, we detect a significant divergence between the relationship of subnational reported GDP and nightlights before the Canal handover (when the U.S.A. was very involved in their statistical agencies) and the correlation after the handover (with no U.S. involvement). Our results indicate that between 2000 and 2012, Panama reported approximately 19% more GDP than what was expected by their nightlight production from 2000 to 2012, or a total of around 40 billion U.S. dollars. Our results suggest governments may engage in political manipulation of government statistics to improve the appearance of government performance. While indirect data can never definitely confirm economic phenomena, this analysis presents a unique research design and application of historic satellite imagery to corroborate reports of GDP misreporting.

1. Introduction

Governments have incentives to manipulate their economic data to demonstrate good management of their economies. Nearly all economic data is produced by the governments themselves, making it difficult for scholars, investors, and policymakers to independently verify the accuracy of reported numbers. In this article, we demonstrate a possible technique, using satellite-based measures, to estimate changes in economic productivity and politicization of government statistics with external data.

Building upon a growing literature in economics and political science showing that reporting of gross domestic product (GDP) is at times under- or over-reported, we leverage a dataset of satellite-based historic nightlight production to detect this suspected underreporting of Panamanian subnational GDP (Chen and Xu, 2015; Alt et al., 2014, Wallace, 2016). Panama's government statistics and economic measurement were subject to considerable oversight by the United States during the period prior to the handover of the Panama Canal to Panama on 31 December 1999. The strong interest of the United States in managing information related to its territory, military interests, and fiscal extraction from the Canal Zone was largely removed with the handover in 2000. We argue that the Canal handover to represent a natural experiment in which the reporting of GDP will be different in the pre- and post-handover periods, as Panama has the increased ability to bias its government data for political purposes. Reports of GDP are anticipated to be substantially overreported after 2000 due to the increased ability of politicians to use government data for political purposes.

Research in the social sciences has increasingly used nightlight data to measure economic productivity where GDP is assumed to be misleading or biased (Hodler and Paul, 2014; Harbers, 2015). Standard GDP data accumulated by agencies such as the World Bank and the International Monetary Fund (IMF) are produced by national governments that may have political incentives to misreport (Alt et al., 2014).

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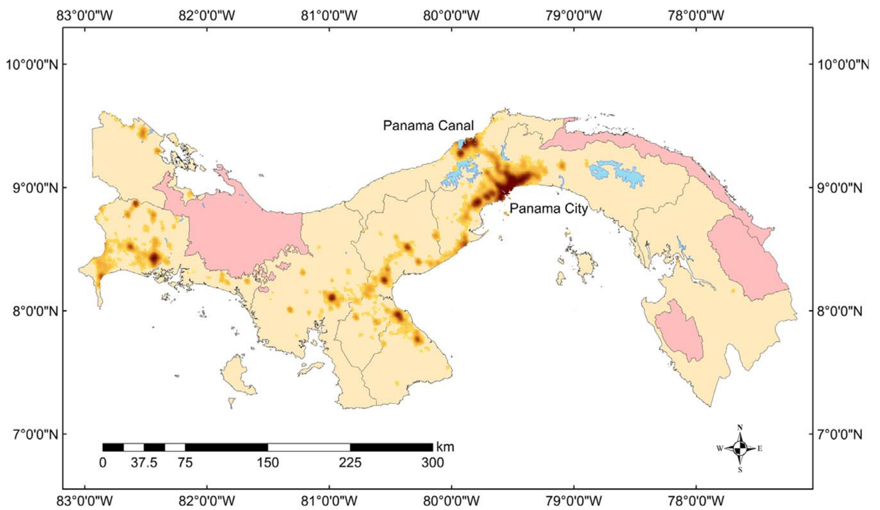

Fig. 1. The study area (beige) consisted of the nine Panamanian provinces. Inland lakes (blue) and indigenous regions and sub-provinces (rose) were not included. Panamanian nightlight production in 1996 is shown from yellow (lowest = 1) to red (highest = 63) was concentrated in Panama City and the adjacent Panama Canal and Colón Free Trade Zone.

For example, both China's national and sub-national GDP estimates have been shown to be systematically over-reported (Wallace, 2016). Moreover, many developing nations have large informal economies that make the accurate estimation of GDP challenging even where statistical agencies are not politicised (Wu et al., 2013). Nightlight data thus offer a reasonably objective measure to capture GDP levels and growth in data-poor environments.

Existing research has typically taken for granted that nightlight data will accurately capture economic productivity without strong research designs to estimate the accuracy of that relationship. The most common approaches are correlational, cross-sectional, and based on national-level GDP values. These approaches cannot account for systematic variance between GDP and nightlight values over time and within nations that may have very important economic or political significance. We know, for example, that nightlight values would substantially underestimate GDP in natural resource-based economies because agriculture and resource extraction are not electricity intensive. On the other side, GDP values would fail to capture informal economies and illicit activities that nightlight data may observe more easily. Overall, scholars will have a difficult time evaluating when, where, and why GDP and nightlight data might diverge based on correlational studies of national-level GDP. We focus on Panama to implement a research design that highlights why nightlight and GDP data might systematically diverge, using more fine-grained sub-national data and a specific time period in which we have theoretical reasons to expect these values to deviate.

2. Research approach

The Defense Meteorological Satellite Program's Operational Linescan System (DMSP/OLS) detects and records the brightness of the Earth's surface at 1 km pixels, or squares. This imagery was produced by the United States Air Force Weather Service to operationally monitor weather patterns for flight operations (Kramer, 2012). Today this data is aggregated into an annual product that controls for fires, clouds, and satellite differences, producing a stable time-series dataset of nighttime brightness from 1992 to 2013 (National Geophysical Data Center, 2013). This dataset has been demonstrated to be useful in a variety of applications including the detection of urban extents and population density (Sutton, 1997), greenhouse gas emissions (Elvidge et al., 1997), and rural electrification (Min et al., 2013). Increasingly, nightlights are used to evaluate and track specific phenomena such as humanitarian disasters (Henderson et al., 2009) or the impact and spread of conflict (Li et al., 2015; Witmer and O'Loughlin, 2011).

Nighttime light production has also been shown to strongly correlate with economic activity (Henderson et al., 2009), has been shown to be an effective proxy to measure GDP for economies in transition (Feige and Urban, 2008), and to document regional favouritism in autocratic countries (Hodler and Paul, 2014).

These applications rely on using a signal detected in nightlight production as a proxy for detecting a phenomenon. For example, a sudden decline in brightness over a city may be linked to the presence of military conflict in that city. While the accuracy of using nightlight production as a proxy in these applications can be assessed with ancillary data, such as eye-witness accounts, remotely-sensed data are best used in applications where direct observation or data are not available, or used as an independent variable to evaluate existing data. In this research, we employ a time-series analysis of nightlight data and reported subnational GDP as independent means to evaluate claims that Panama's GDP estimates have become less reliable after the Canal handover at the end of 1999. This analysis is not meant to definitively prove politicization of government statistics, but to help inform and corroborate claims of Panamanian governmental corruption and data manipulation.

3. Study area

The Republic of Panama (Fig. 1) is the southernmost country of Central America and North America. Panama comprises 30,193 square miles and is divided into nine provinces, three indigenous regions, and two sub-provinces. The study area consists of the nine Panamanian provinces: Bocas Del Toro, Chiriquí, Coclé, Colón, Darién, Herrera, Los Santos, Panamá, and Veraguas. The three indigenous regions and two sub-provinces were not included because subnational GDP data are not available. Because these regions have significantly lower population and economic production than the nine provinces, their omission does not significantly affect the ability of this analysis to describe all of Panama.

4. Methodology

The input data for the study includes subnational GDP reporting from the Panamanian government, annual worldwide night time light production coverage from 1996 to 2012, and the land area of Panama's nine provinces.

4.1. GDP data

Subnational GDP data from 1996 to 2012 were obtained for Panama's nine provinces (Panamanian National Institute of Statistics and Census 2016) (Table 1.) Beginning in 1996, the Panamanian national statistical agency collects and compiles these data on a yearly

Table 1
Panamanian-reported provincial GDP in millions of US dollars (Panamanian National Institute of Statistics and Census 2016).

	Provincial GDP × 10^6 1996 US$									GDP × 10^6 1996 US$
Year	Bocas del Toro	Chiriquí	Coclé	Colón	Darién	Herrera	Los Santos	Panamá	Veraguas	Annual Total
1996	193	721	346	1241	52	157	132	6218	263	9322
1997	197	745	351	1421	54	161	142	6575	279	9924
1998	193	738	366	1534	61	176	154	7138	293	10,653
1999	193	795	337	1489	56	191	159	7548	303	11,070
2000	195	834	311	1544	59	190	166	7764	308	11,371
2001	203	912	351	1608	68	195	179	7601	319	11,436
2002	206	939	362	1557	67	203	180	7857	320	11,691
2003	174	918	390	1613	75	212	193	8275	334	12,183
2004	204	970	427	1715	76	223	200	8921	364	13,099
2005	198	1024	450	1967	60	247	225	9494	376	14,041
2006	212	1095	451	2130	60	260	229	10,387	415	15,239
2007	244	1182	512	2330	68	286	258	11,725	481	17,084
2008	315	1275	522	2471	76	312	281	13,079	482	18,813
2009	324	1311	545	2547	72	362	244	13,695	439	19,538
2010	258	1422	637	2693	59	362	271	14,813	478	20,994
2011	437	1425	705	3000	67	390	311	16,401	539	23,275
2012	521	1596	745	3092	115	420	372	18,353	573	25,787
Province Total	4267	17,902	7806	33,953	1145	4345	3697	175,843	6564	255,522

basis for all non-indigenous provinces using reported data of economic activity. The subnational figures give a much better specified geographic locus than do national GDP with which to match territorially-specific nightlight data.

4.2. Remotely-sensed data

The Defense Meteorological Satellite Program (DMSP) is a series of six satellites that provided continuous coverage of the Earth's surface from 1992 to 2013. The satellites are equipped with the Operational Linescan System sensor, which measures brightness from values 1–63. Data is acquired at a spatial resolution of about 2.7 km and distributed at 0.01 degrees. The 'Average Visible, Stable Lights, & Cloud Free Coverages' product is an annual aggregation by satellite of this data controlling for fires, clouds, and satellite differences (National Geophysical Data Center 2013). In cases where an annual product was offered by more than one satellite, such as F142003 and F142003, composites from the newer satellite were used.

4.3. Remotely-sensed data processing

DMSP nightlight 'Average, Visible, Stable Lights, & Cloud Free Coverages' were processed in ArcGIS 10.4 to select pixels that were contained within the nine Panamanian provinces and not touching inland lakes (DIVA-GIS, 2016). Because the satellites in the DMSP constellation do not have on-board calibration, an inter-calibration coefficient was applied to each pixel's value (digital number) to improve the data's use in a time-series analysis (Weng, 2014). Because five different satellites from the constellation were used in the analysis, this was a critical step to producing meaningful results. Post-calibration pixel values greater than 63 or less than 6 were removed per Weng (2014). Each province's pixel values were summed by year to compute the annual provincial nightlight. Processing was first tested within ArcGIS Model Builder and once the steps were validated, Python code was developed to automate the process and output the data (Fig. 2) (Table 2).

5. Analysis

Our data analysis has two stages. The first stage uses an ordinary least squares regression to predict and analyze the relationship between provincial nightlight production and reported GDP for both pre- and post-Canal handover time periods. The second analysis creates a dependent variable that standardises provinces by GDP and nightlight production. This permits the authors to estimate the impact of the Canal handover while adding control variables which account for satellite differences, differences in provinces, differences in years, and the role of financial services in the provincial economy.

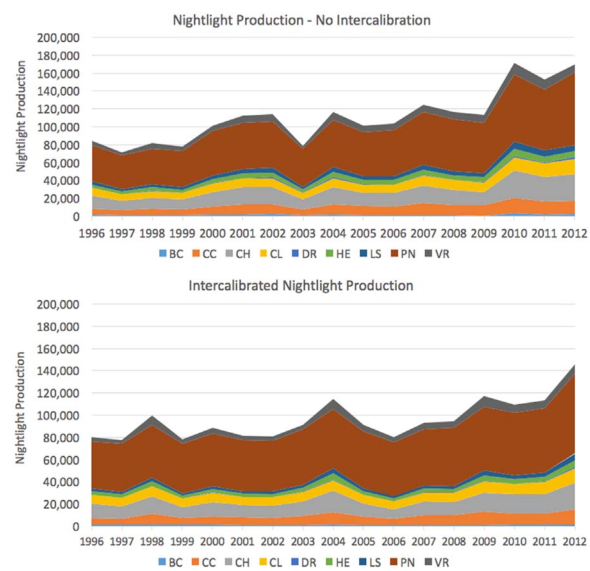

Fig. 2. The importance of satellite inter-calibration for DMSP data is shown through the discrepancy of nightlight production summed by province without inter-calibration (top) and with inter-calibration (bottom). The significant increase in nightlight production from 2009 to 2010 without inter-calibration (top) is due to the first year of the F18 satellite data with its more sensitive detection of lower light levels (DNs less than 6).

5.1. Pre- and post-canal handover GDP and nightlight production relationship

Our approach first analyses the correlation between provincial GDP and provincial nightlight production before the Canal handover 1996–1999). Due to heavy involvement of the U.S. government (Schneider and Enste, 2000; Lindsay-Poland, 2003), this period is used as a baseline representing full reporting of economic activity. Of course, there were incentives to misrepresent government economic data prior to the handover of the Panama Canal by the Panamanian government. U.S. involvement, however, should have minimized this potential manipulation. During the leadup to the Canal handover, the U.S. had strong incentives to accurately estimate economic activity to ensure a

Table 2
Annual Panamanian provincial nightlight production. Units are in arbitrary digital numbers.

Nightlight Production (Sum of digital numbers)										
Year	Bocas del Toro	Chiriqui	Cocle	Colon	Darien	Herrera	Los Santos	Panama	Veraguas	Annual Total
1996	1388	6052	12,598	8236	67	3051	2429	42,471	3682	79,973
1997	1158	5723	10,833	7950	31	2964	2345	43,132	3466	77,602
1998	1557	9650	15,425	9029	400	4351	3219	47,540	8718	99,889
1999	1144	5898	10,172	7562	7	2823	1848	44,638	4013	78,105
2000	1466	7245	13,083	8544	185	3078	2621	47,302	4820	88,344
2001	844	7187	10,717	7553	120	2727	2239	46,060	3818	81,264
2002	934	6067	11,265	7800	135	2792	2516	45,660	3775	80,944
2003	1132	7973	12,999	8616	591	3206	2850	49,866	4068	91,303
2004	1512	11,158	19,079	9677	672	5433	4743	53,166	9276	114,714
2005	854	7868	11,750	7807	7	3052	2679	51,378	6002	91,398
2006	630	5937	8752	7108	21	2558	2148	48,238	4587	79,978
2007	796	9253	12,165	8140	93	3334	2651	50,754	5690	92,876
2008	852	8763	11,839	8937	78	3151	2537	52,456	5955	94,568
2009	994	12,045	16,761	10,614	410	5137	4467	57,177	9420	117,025
2010	1470	9936	17,094	9270	340	4041	3284	56,756	7259	109,450
2011	1326	9706	17,678	11,354	440	4019	4017	57,640	7107	113,287
2012	1773	13,295	24,027	13,284	1163	6022	5943	71,965	8608	146,080
Province Total	19,828	143,756	143,756	151,482	4759	61,737	52,535	866,202	100,264	1636,799

smooth transfer, and to be sure US business affairs would be managed appropriately after 1999. The U.S. government provided technical assistance during this period to the Panamanian statistics agency to strengthen measurement capacity.

Although nightlight data are available starting in 1992, provincial GDP data are only available starting in 1996. The correlation between annual provincial nightlight totals and reported GDP for the baseline period showed a strong relationship ($R^2 = 0.98$) using a second-order polynomial regression (Fig. 3). While exponential regressions are often used to model the increase in per capita GDP, it has been shown that polynomial regressions correlate well with modelling GDP growth in transition economies (Amirkhalkhali and Rao, 1985; Draper and Smith, 2014; Weede, 1980). This relationship can be used to calculate the 'Expected GDP' of a province based on that province's annual nightlight production (Eq. (1)).

$$G_{\text{Expected}} = 1.948\,(N)^2 + 67,\,280\,(N) + 13,\,361,\,176 \tag{1}$$

5.2. Multivariate regression models controlling for province and satellite specific effects

An alternative way to evaluate the pre- and post-Canal transfer difference in GDP reporting is to use multivariate ordinary least squares regression with fixed effects. In Table 4, below, we verify the results of the estimation in Section 6 and provide evidence consistent with our hypothesis that GDP and nightlights should significantly diverge after the Canal handover.

To provide additional evidence of a pre- and post-canal handover divergence between reported GDP and nightlight production, we created several models that control for different attributes including by province and by satellite. In this analysis, our dependent variable is the ratio of the provincial share of national nightlights to the province share of national GDP (Eq. (2)). This allows us to look for differences in provinces because we can analyze, for instance, if a small province contributes a larger amount of nightlight production than we would expect from its reported GDP. Using a ratio also helps to manage concerns due to provinces with very different economic productivity levels (heteroskedasticity). We also account for serial autocorrelation in the discrepancy between predicted and reported GDP. Some provinces have economic features that make them particularly likely to have discrepancies between nightlight values and reported GDP, and these different are expected to persist over time (Durbin and Watson, 1951). This can cause inaccurate estimates due to correlation of the province errors across time. We control for this using an autocorrelation (AR1) process. We also use an estimator, time series panel corrected standard errors (pcse), particularly suited to cases of heteroscedasticity and serial autocorrelation (Beck and Katz, 1995). Overall, the fixed effect model helps to control for unobserved economic attributes of provinces that may otherwise influence our statistical results. The primary independent variable, or dummy variable, is years following the Canal handover (after the year 1999).

$$\frac{(N_{\text{Provincial}}/N_{\text{National}} - G_{\text{Provincial}}/G_{\text{National}})}{(N_{\text{Provincial}}/N_{\text{National}})} \tag{2}$$

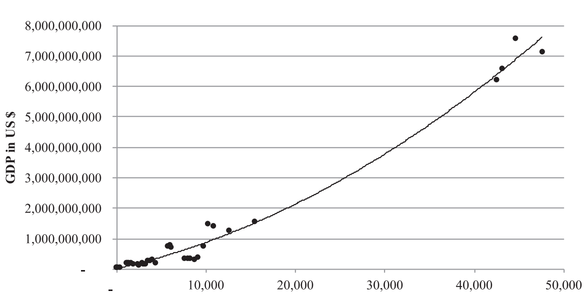

Fig. 3. Each point represents the annual GDP and nightlight production for each province before the handover of the canal. Second-order polynomial regressions provide an accurate method to model this relationship.

6. Results

We estimated each province's expected GDP as a function of its annual nightlight production score using a basic second-order polynomial regression of baseline years (Section 5.1) and a multivariate ordinary least squares regression with fixed effects (Section 5.2). Our results indicate a 19% (Section 5.1) overage in reported GDP versus expected GDP as estimated from nightlight production. Additionally, while Fig. 3 shows somewhat erratic expected GDP based on nightlight production, this divergence is corroborated in the fixed effects regression analysis developed in Section 5.2 that includes additional controls and stringent econometric modelling, and standardises the dependent variable to pinpoint variation between provinces.

Table 3
Expected GDP in millions of U.S. dollars as a function of provincial nightlight production.

	Expected GDP × 10^6 1996 US$									GDP × 10^6 1996 US$
Year	Bocas del Toro	Chiriquí	Coclé	Colón	Darién	Herrera	Los Santos	Panamá	Veraguas	Annual Total
1996	111	478	1157	686	4	223	175	6371	274	9480
1997	80	449	957	658	2	217	168	6525	257	9314
1998	109	831	1501	766	27	330	237	7600	735	12,136
1999	80	465	886	620	0	205	131	6884	301	9573
2000	103	590	1214	717	13	226	190	7541	370	10,961
2001	58	584	945	619	8	198	160	7231	285	10,089
2002	1268	2472	1005	643	9	203	182	7133	282	13,197
2003	79	660	1204	724	40	236	208	8198	306	11,655
2004	106	993	1993	833	46	423	363	9082	792	14,631
2005	59	650	1059	644	0	223	194	8598	474	11,903
2006	43	468	738	577	1	185	153	7777	350	10,293
2007	55	789	1107	677	6	246	192	8432	446	11,950
2008	59	739	1070	757	5	231	183	8889	470	12,402
2009	69	1093	1675	934	28	397	339	10,214	807	15,555
2010	103	861	1719	791	23	304	242	10,093	591	14,727
2011	93	836	1798	1015	30	302	302	10,349	577	15,301
2012	125	1239	2741	1237	81	476	469	14,929	723	22,020
Province Total	2599	14,198	22,768	12,899	326	4624	3888	145,847	8038	215,186

6.1. *Results of pre- and post-canal handover GDP and nightlight production relationship*

We estimated each province's expected GDP as a function of its annual nightlight production (Eq. (1)). These variables showed a strong relationship ($R^2 = 0.98$) with a second-order polynomial regression (Fig. 3) of each province's GDP and nightlight production as a data point for the baseline years of 1996–1999 (n = 36).

This relation was then extrapolated for post-canal years 2000–2012), using Eq. (1) with nightlight production for each province from 2000 to 2012 creating expected GDP (Table 3). When compared with the annual reported GDP (Table 1), our results indicate that Panama's reported GDP from 2000 to 2012 was 19% more than what was expected given their nightlight production (Fig. 4). Importantly, our main expectation is that Panama's GDP should significantly diverge from nightlight estimates following the Canal handover. Fig. 3 shows a major divergence in the nightlights in particular after 2004. What we can also observe is that the expected GDP values become, overall, more erratic beginning in 2000, with an even bigger divergence in 2004. We can estimate the particular year of divergence more accurately in the fixed effects regression below.

6.2. *Results of multivariate regression models*

The results in Table 4 show that provinces diverged significantly in reported GDP values from expected GDP values after the Canal

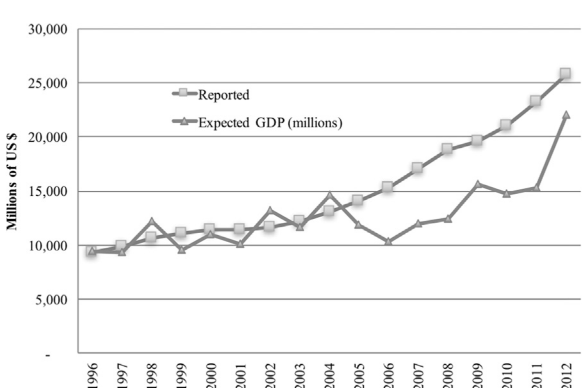

Fig. 4. While expected Panamanian GDP correlated with reported GDP, large differences from 2000 to 2012 equate to 19% more reported GDP than was expected for the study period.

Table 4
Fixed Effects Models.

Outcome is divergence between predicted and reported GDP values	(1)	(2)	(3)	(4)
Post-Handover	4.696**	3.722*	3.380*	3.569*
	(2.219)	(2.002)	(1.968)	(1.916)
GDP per Capita (logged)			6.678	
			(7.808)	
Agricultural Productivity (% GDP)				−0.140
				(0.352)
Satellite 12			2.136	1.93
			(2.243)	(2.160)
Satellite 16			−2.307	−1.503
			(2.459)	(2.068)
Satellite 17			−2.810	−1.254
			(4.105)	(3.038)
Constant	−3.867	−3.110**	−53.301	0.991
	−2.553	−1.576	−58.694	−10.034
Province Fixed Effects	No	Yes	Yes	Yes
Observations	153	153	153	153
R-squared	0.22	0.22	0.23	0.23
Number of Provinces	9	9	9	9

Standard Errors in Parenthesis.
***p < 0.01.
** p < 0.05.
* p < 0.1.

handover period. These multivariate regression estimates do not reveal the direction of the divergence between the predicted and reported GDP estimates, they simply capture the deviation. This is statistically significant for all four Models (1 − 4). In Models (1) and (2) we simply estimate the difference in the post-handover period without added control variables. We do so without controls (Model 1), and with no controls but including province fixed effects (Model 2). In Model 3 we include controls for the existing level of development, measured with GDP per capita (logged) and controls for specific satellites (F12, F16, F17) used in the analysis. We find that there is no significant difference across satellites in our results. This suggests that our inter-satellite calibration within our nightlight estimates have effectively controlled for differences across the satellites. Finally, in Model (4) we also control for agricultural productivity (% of province GDP) to be sure our results are not driven by provinces with types of economic activity that are not light-intensive (Wu et al., 2013). We find no significant effect of agricultural economies. This is expected because agricultural provinces tend to remain agricultural-based overtime. Our province fixed effects would capture nearly all of the variance explained by province economic structure. We also tested the timing of the divergence across different years. We found that the post 1999 period is the clear "cut-point" in the data when estimates begin to diverge. This helps to corroborate our assertion in Section 5 that the divergence began prior to the clear drop in values in 2004. We demonstrate across all of the models that the actual and predicted GDP diverged significantly after the Canal handover, and these results are robust to very stringent statistical specifications.

7. Discussion

Our analysis identifies divergence between Panama's reported GDP and its expected GDP based on nightlight production. This divergence widened significantly in 2000, when Panama gained control of the Canal and the United States significantly reduced its oversight of the country's activities. We suggest that this divergence is consistent with political incentives to over-report GDP to give the appearance of successful government management of the economy (Wallace, 2016).

Because there is no 'ground-reference' dataset (outside of government reports) to verify sub-national GDP, and because the use of remote sensing in this application indirectly measures expected GDP based on nightlight production, it is not possible to prove that the divergence is due to over-reporting or other factors. However, it documents very similar findings in other nations using 'ground-reference' datasets and statistical anomalies in government datasets (Alt et al., 2014; Wallace, 2016). Therefore, this analysis serves to corroborate other reporting and explore the application of nightlight data in GDP inaccuracies, and leaves to future research the task of verifying data manipulation in the specific Panamanian case. This analysis could be further strengthened by

8. Conclusion

Panama provides a unique case study to explore the ability of historic nightlight data to detect sub-national GDP misreporting. With the assumption that there was no GDP bias in reporting until the end of 1999 due to heavy U.S. government involvement in the country, we were able to evaluate whether nightlight data could detect possible misreporting after the Canal handover. Our analysis showed a statistically significant deviation in reported and predicted GDP values after 2000. Specifically, we find an increase in reported GDP compared with nightlight production after the Canal handover of up to 19% from 2000 to 2012, or a total of 40 billion U.S. dollars. While we are not able to evaluate definitively whether this relative decrease in sub-national GDP was due to misreporting, it corroborates a significant body of reporting and allegations that corruption has increased in Panama since 1999 (International Consortium of Investigative Journalists, 2016).

Our approach also showed that suspected GDP misreporting (over-reporting for much of the period) was significantly higher when the government had greater leeway to manipulate their data. The value of this study is to stretch the applications on which remotely sensed data could potentially inform policy-makers. While measuring phenomena like corruption or politicization with remote sensing is by definition indirect, it can provide researchers a unique, independent dataset to consider along with other reporting. It is best used in data-poor areas, where a natural experiment, such as the 1999 Canal handover, provides an opportunity to look for a change that can be sensed with these datasets and corroborated with other reporting. In the future, with more effective satellite inter-calibration, these techniques could help provide a way to capture economic activity in data-poor countries around the world.

The utility of historic remotely-sensed data continues to increase as researchers learn how to leverage these data on topics not traditionally informed by remote sensing, such as economics and politics. The utility of these data also increases as organisations such as the United States Geological Survey and the National Oceanic and Atmospheric Agency continue to make these data available, and inter-calibration work continues to make freely available products such as the 'Average Visible, Stable Lights, & Cloud Free Coverages' more valuable.

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