Shedding (Nighttime) Light on the Local Resource Curse

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Abstract We explore the existence of a local "resource curse" related to Brazil's oil reserves. To this end, we examine the effect of changes in international oil prices interacted with measures of oil access on nighttime light – a measure of economic activity – across the country's localities. We detect no evidence of a resource curse: in fact, better access to oil enhances the positive effect of oil prices on economic activity. Our estimates indicate that a doubling of oil prices causes an average increase in luminosity of some 50 percent more in oil rich than in oil poor states; and 30 percent more, on average, in localities within 100 km distance to the nearest oil field relative to more remote localities. We also present evidence that, beyond the direct effect of oil revenues, the luminosity response is also due to a linkage effect.

Keywords Local resource curse, nighttime light, oil price shocks.

JEL classification O11, O13, Q33, R11.

Acknowledgements to be added

1 Introduction

There is controversy about the growth effects of natural resource abundance. On one hand, many of the currently richest countries in the world, in terms of income per capita, are large oil and gas producers.[1] Before the era of mass oil exploitations, quite a few of these same countries used to be poor. On the other hand, an influential body of scholarship has emerged arguing that natural resources are a curse (e.g., Sachs and Warner, 1999, 2001). Often cited examples in this regard are those of Nigeria, Angola, and Venezuela, which have had long periods of economic slump, despite being well endowed with oil and gas. A substantial early amount of work has been done on this issue in the context of cross country analyses – with mixed results (van der Ploeg, 2011, is a good summary of this effort). Some papers have found that natural resources constitute a curse for economic growth; whereas others have argued otherwise.[2] More recently, the research focus, reviewed more in detail below, has switched to within-country analyses that automatically account for the unobserved between-country heterogeneity that may drive cross-country correlations between natural resources and economic performance.

In this paper, our objective is to contribute to this new literature by exploring the local effect of international oil price changes on the intensity of economic activity, focusing on Brazil in the years 1992–2013. We analyze the case of Brazil for several reasons. One is that it is a significant player in the world oil market, yet not a price maker.[3] Another is that almost the entire source of Brazilian oil is concentrated offshore and is affiliated with just three states in south-east, which enables a distinction between oil rich and oil poor states.[4] The third reason is that most of oil revenues have been kept by these affiliated states, and there has been relatively little redistribution of oil revenues across the states. Finally, the effects of Brazil's oil resources on other outcomes has been analyzed in other papers as reviewed below, making it possible to compare the effects of oil prices on multiple outcomes.[5]

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[1]Among top ten richest economies, in terms of per capita GDP in 2014, five (Qatar, Brunei, Kuwait, Norway, and UAE) were largest resource economies.
[2]See Alexeev and Conrad, 2009, Brückner and Gradstein, 2014, Lederman and Maloney, 2008, Sachs and Warner, 1999, 2001, for some examples. Furthermore, Smith and Wills, 2016, use, as we do here, nighttime light as an outcome variable and find that it is positively affected by oil price increases in a cross country setting. An important consensus has emerged from this literature acknowledging the importance of political factors and institutions.
[3]As of 2014, Brazil is the ninth largest oil producer in the world, producing less than four percent of the world output according to the World Factbook, CIA, available at https://www.cia.gov/library/-publications/the-world-factbook/.
[4]Whereas some oil fields are also located in north-east, offshore south-east fields and, in particular, oil reserves, are much more significant in terms of oil output.
[5] In principle, while the approach could also be used in the context of additional countries, our identification hinges upon a country being a net exporter of oil and a price taker in the international oil market, as well as on oil revenues being mainly retained based on proximity to oil fields. This also implies, inter alia, that our analysis could not be replicated for, say, natural gas in Brazil, because the country is a net importer of that resource. It, therefore, appears that Brazil's oil is an ideal setting for our analysis.

The outcome in our analysis, the level of economic activity, is captured by nighttime light across Brazil. More specifically, we consider its annual changes, for reasons elaborated upon below. One important advantage of this measure for our purposes is that it enables analysis of local effects at almost any geographical resolution. Having in mind potential spillovers and geographical linkages across locations, this provides a valuable contribution to existing work, which has focused primarily on administratively defined localities. Additionally, because of the prevalence of the informal sector in Brazil, nighttime light may well be a superior measure of true economic activity relative to official statistics.[6] Further, provided that the bias of official reporting differs by locality, nighttime luminosity may well provide more accurate estimates across localities.

We relate our outcome measure to annual changes in world oil prices, weighted by spatial measures of oil access, such as the distance from the nearest oil field. The presumption is that the potential effect of spillovers from any potential oil benefits fades with distance. Partly this presumption is rationalized by the administrative incidence of oil revenues: most of them accrue to the nearest state. But additionally, it is justified by considering that the magnitudes of the potential spillovers themselves are likely to be distance related.

Our analysis first establishes a strong correlation between nighttime light and local (municipality level) income in Brazil, based both on cross-sectional and fixed-effect panel regressions. It then establishes a strong correlation between local (municipality level) oil revenues and oil prices that depends positively on the access to oil. More to the core of the paper's objective, we then investigate local nighttime light effect of oil prices. Contrary to a hypothesized local resource curse, we find that better access to oil enhances the positive effect of oil prices on luminosity. This finding is shown to hold for a variety of regression specifications that account for the potential effects of, for example, alternative commodity prices; or important spatial characteristics, such as the distance to the industrialized coastal areas as well as the initial level of economic activity. Moreover, the effect is economically significant. For example, our estimates indicate that a doubling of oil prices cause on average an increase in luminosity of some 50 percent more in oil rich than in oil poor states; and 30 percent more in localities within 100 km distance to the nearest oil field relative to more remote localities. Further, when confining attention to cells in narrow bands around the borders between oil rich and oil poor states, we find that increases in oil prices enhance luminosity significantly more in cells located on the oil rich, relative to oil poor side of the band. Our results can be interpreted as lending support to two channels of the effect of natural resources. One is the revenue effect, whereby receiving localities (say, cells in oil rich states) benefit more from an increase in oil revenues than non-receiving ones. Further, since we find that the importance of distance to the nearest oil field in mediating the effect of oil prices on nighttime light is greater in oil rich relative to oil poor states, this indicates that economic linkages are important, even beyond the effect of oil revenues. Going beyond that, we find indications that distance to the nearest oil field matters even after controlling

[6]Schneider et al., 2010, report that the size of the informal sector in Brazil accounts for about 40 percent of the economy in the recent years.

for oil revenues, which reinforces our interpretation that linkages have an independent role in mediating the effect of oil prices on economic activity.

This paper belongs to the recent literature that focuses on local effects of resource abundance, say, within a country. For one, this has the potential of a superior causal identification relative to cross country studies. Additionally, it may shed light on general equilibrium effects of localized natural resources. Indeed, in a recent paper, Allcott and Keniston, 2015, adjust existing models of Corden and Neary, 1982, and Matsuama, 1992, to exhibit a potentially ambiguous local effect of natural resources.[7] Depending on the magnitude of spillovers and on the intensity of learning-by-doing, they can be either a curse or a blessing. From a different perspective, Brollo et al., 2013, argue that political competition among jurisdictions over resource windfalls may result in emergence of corruption, also undermining the quality of politicians.

Emerging empirical work has begun addressing the local effect of natural resource abundance. Some of this work has been done in the US context; see for example, Allcott and Keniston, 2014, Black et al., 2005, and Michaels, 2011. These papers generally do not discover the presence of a resource curse in the US context, and they tend to report overall positive – or, at least, non-negative – local growth effects of resource abundance.[8]

In contrast, the picture that emerges from the studies of developing countries is more ambiguous. For example, Brollo et al., 2013, find that resource abundance causes corruption in Brazilian municipalities; whereas Monteiro and Ferraz, 2014, do not detect this. Caselli and Michaels, 2013, again in Brazil's context, find that increases in local governments' oil revenues did not translate into more social spending and also provide tentative evidence of corruption as a potential mechanism. In contrast, Aragon and Rud, 2013, and Loayza and Rigolini, 2016, discern some positive local effects of a mining boom in Peru on local incomes and consumption. Closer to our paper, Cavalcanti et al., 2016, find that oil discoveries had a beneficial effect on the incomes of municipalities in which they took place.

We contribute to the literature on local effects of natural resource abundance in several ways. First, most of the existing literature focuses on administrative units (see e.g., Brollo et al., 2013, Caselli and Michaels, 2013, Cavalcanti et al., 2016, and Loayza and Rigolini, 2015). However, depending on local geography, spillovers may well cross administrative (municipality or even state) borders. Our finer spatial analysis allows for this possibility. Further, borders of Brazil's municipalities changed several times in the course of the past decades, most significantly in 1990s, when the number of municipalities increased by more than twenty percent, and their endogeneity in response to oil revenue allocations can therefore not be ruled out (see Tomio, 2005, for a detailed account and Caselli and Michaels, 2013, for a further discussion of this issue). Hence, our focus on an exogenous geographically defined unit of analysis is advantageous in terms of identification. Second, while the existing literature focuses on specific outcomes, such as employment, consumption, or corruption, we aim to address an overall measure of eco-

[7]See also Corden, 1984, on the international aspect of Dutch disease.
[8]See, however, Papyrakis and Raveh, 2014, for dissenting evidence in Canada's context.

nomic activity. Third, our measure is supposed to also reflect unreported shares of such activity. It should, therefore, complement existing analyses based on official statistics. Finally, we are able to distinguish between two channels, the oil revenues' channel and the linkages' channels, arguing that the latter plays a role beyond the former.

The rest of the paper proceeds as follows. The next section contains some background on Brazil's oil; on our outcome variable, nighttime light; and on possible channels through which natural resources may affect economic activity. Section 3 then describes the data and our empirical strategy. The main empirical results are presented in Section 4, followed, in Section 5, by various robustness checks. Section 6 focuses on the analysis of a sub-sample of cells, located within a narrow band around the border between oil rich and oil poor Brazilian states. Finally, Section 7 concludes with brief remarks.

2 Background

2.1 Brazil's oil

As noted above, Brazil is among top ten nations in terms of oil production, and its share of world oil output is some four percent – as is the share of the oil sector in Brazil's GDP. Thus, oil is important for Brazil's economy, yet the country is not a price setter in international oil markets. Most of Brazil's oil (above 90 percent) is offshore and located in just three states: Rio de Janeiro, Espírito Santo and São Paulo (see Figure 1 for a map, including the allocation of Brazil's oil revenues). Until 1997, the state-owned company Petrobras had a monopoly over oil exploitation, and to this day it conducts most of it. The increasing importance of oil led to the Oil Law of 1997, which, over a few years, led to the liberalization of the oil market, formally ending the monopoly of Petrobras, and increased royalty payments indexing the reference price to the international oil price.

It is important to note that the oil revenue sharing scheme in Brazil has been dictated by two main considerations, which has shaped its current structure. One, historical, was the move toward fiscal decentralization that took place in 1980s as a consequence of transition from dictatorship to democracy. Consequently, in Brazil about one half of all oil revenues (and some sixty percent of oil royalties) accrues to the states and municipalities, whereas the federal state, the Union, obtains another half.[9] This represents a relatively high degree of fiscal decentralization by international standards. Further, the states and the municipalities receive about thirty percent each of oil royalties.

Additionally, and importantly, geographical factors determine the distribution of oil revenues. Consequently, more than three quarters of oil royalties accrue to the state of Rio de Janeiro, and three coastal – and better economically developed – states collect the vast majority of oil revenues; see Figure 1 for an illustration. Further, the apportionment of oil revenues to the various municipalities is done proportionately to the fractions of oil fields within the municipality's

[9]Very recently, there have been mounting demands for more redistribution across the states.

jurisdiction. The reader is referred to Caselli and Michaels, 2013, and Monteiro and Ferraz, 2014, for additional details on the structure of the oil industry in Brazil.

2.2 Nighttime light

Our main outcome measure of economic activity is nighttime light across Brazil's localities, as recorded from space, in particular, across cells in Brazil's grid; some further details are provided below. Chen and Nordhaus, 2011, Henderson et al., 2012, and Michalopoulos and Papaioannou, 2013, advocate its use, especially in contexts where official output measures may be subject to measurement errors. For example, Henderson et al., 2012, document strong correlations between officially reported GDP measures and nighttime light. In particular, a panel analysis across countries in Henderson et al., 2012, indicates an elasticity of about one fourth between annual changes in nighttime light and GDP growth. Another advantage of this measure for our purposes is that it is available at a fine geographic resolution enabling us to study local effects of oil-related windfall gains. Further, importantly, it enables us to use plausibly local exogenous geographic units of analysis, as opposed to administrative ones (municipalities), whose borders changed and could be endogenous in the studied period. Figure 2 shows the distribution of average nighttime light across Brazil's grid, and Figure 3 shows the changes in nighttime light across the studied period.

We find that the positive association between nighttime light and income detected across countries and regions of the world can be confirmed for localities across Brazil. As reported below, cell luminosity and municipality level GDP are highly significantly correlated; and this holds regardless of whether these are measured in levels or in changes, linearly or on a logarithmic scale. The significant correlation between local GDP across more than 5,000 Brazilian municipalities and nighttime light, while accounting for municipality-fixed effects, is consistent with, and complements, existing findings on such correlations at more aggregated levels. This indicates that our outcome measure, broadly a proxy for economic activity, can be interpreted in terms of local income.

2.3 Conceptual factors

Possible effects of resource windfalls on economic activity have been explored both theoretically and empirically in the literature. In particular, recent theoretical work extends earlier research done in the context of international effects to a local, within-country context. We here provide a very brief review of this work, without an attempt at exhaustive coverage.

One important potential mechanism is the local equivalent of a "Dutch disease", and the argument goes as follows. An immediate consequence of resource wealth is likely to be that of raising wages in this sector. This, in turn, should lead to an increase in demand for non-tradable goods, reflecting the income effect (see Moretti, 2011, Aragon and Rud, 2013). The price effect, however, may depress the tradable sector, creating a local Dutch disease, analogous to that of the international trade literature, see Corden and Neary, 1982. Agglomeration may then further amplify the former effect by inducing positive spillovers into the tradable sector. On the other hand, the learning-by-doing channel in that sector could lead to a persistent slumping effect.[10] Allcott and Keniston, 2015, present an elegant model capturing the interplay between these elements and generate a nuanced view on the effect of resource abundance, which ultimately entails a tradeoff between these various factors.[11] Ultimately, the existence of a resource curse in their model – whether aggregate outcome will deteriorate or not – hinges upon the relative strength of agglomeration versus the learning-by-doing factor. In particular, in a multi-period extension of the model with oil booms followed by oil busts, a resource curse results whenever the latter factor is more significant than the former one.

Another important potential mechanism is related to the political effects of government oil revenues. As has been pointed out in cross country analyses (Arezki and Brueckner, 2011, Tsui, 2011), in the context of other countries (Vicente, 2010) and, specifically, in Brazil's context (Brollo et al., 2013, Caselli and Michaels, 2013, and Monteiro and Ferraz, 2014), oil-related revenue windfall gains may cause intensified rent seeking, lack of democratic accountability and corruption; and, in the case of Brollo et al., 2013, selection of less qualified politicians into office. Such misallocations, in turn, may potentially have adverse consequences for economic growth (Mauro, 1995, Murphy et al., 1991; see, however, Dreher and Gassebner, 2013, and the references cited there for a dissenting view regarding the effect of corruption on growth). Relatedly, but perhaps less relevant for the particular case at hand, resource revenues may cause intensified civil conflict (Dube and Vargas, 2013, Lei and Michaels, 2014).[12]

All this suggests that, depending on the circumstances, a resource curse may or may not be realized. Empirical analyses is called for to settle the issue in each specific case.

3 Data and empirical approach

3.1 Data

In this subsection, we explain the data and the main variables used in the analysis. Table 1 presents summary statistics of our main variables.

Dependent variables

Our main dependent variables are nighttime light and local GDP. These variables are explained in more detail in the following.

Nighttime light

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[10]Specifically, if the tradable sector gets depressed during a bust, to the extent that learning by doing in this sector is important, it will not be able to fully recover during the boom that follows.

[11]Their empirical analysis, in the US context, ultimately uncovers positive effects of resource abundance, in support of earlier studies (Black et al., 2005, and Michaels, 2009) in this regard.

[12]Interestingly, in 2013-14, a series of protests erupted in Brazil demanding a more aggressive interstate redistribution of oil revenues; see The Economist, *Counting the barrels*, March 9, 2013. (So far, this has not resulted in a substantial policy change, however.)

Data on nighttime light is maintained and processed by the National Oceanic and Atmospheric Administration (NOAA). Satellites orbit the Earth every day, capturing images of every location between 65 degrees south latitude and 65 degrees north latitude at a resolution of 30 arcseconds (approximately 1 square km at the equator). The images are then aggregated to the yearly level and processed to remove cloud cover, snow and ephemeral lights.[13] Furthermore, each pixel (approximately 1 square kilometer) in the luminosity data is transformed into a digital number (DN), ranging from 0 to 63 representing its luminosity; see Henderson et al., 2012, and Pinkovskiy, 2016, for further details and discussion of these data. While pixels with DN equal to 0 or 63 may be censored, Pinkovskiy, 2016, argues that the resulting measurement error is small.

Based on these data, for the purpose of our empirical analysis we construct a grid of cells covering all of Brazil. The grid consists of some 45km × 45km cells, with an average cell area of about 2,000 square kilometers, resulting in around 4,200 Brazilian cells. Light intensity in a cell for a given year is the proxy for the economic activity within that cell in that year. Consequently, our main dataset consists of an almost balanced panel of such cells over the 1992–2013 period, resulting in some 88,000 cell-year observations.

Municipality-level GDP

These data come from censuses conducted by the Brazilian Institute for Geography and Statistics, and is enhanced in Monteiro and Ferraz, 2014. They consist of 5,565 municipalities (as defined in 2010) and covers the years 1999–2012.[14] Because of reasons outlined above, we use these data primarily to validate the use of nighttime light data as a proxy for economic activity.

Municipality-level royalties

We have obtained municipality level data on oil royalties for the studied time period. Their source is the ANP ("Agência Nacional do Petróleo", or the National Petroleum Agency of Brazil).

Independent variables

The main independent variables consist of the distance to the nearest oil field, the yearly world oil price, and their interaction.

Distances to the nearest oil field are based on the map of oil fields from Caselli and Michaels, 2013 (excluding gas fields). The great-circle distances are calculated for each cell (by the Haversine formula) from the interior centroid of the cell to the nearest interior centroid of the oil field in the data.

Our additional independent variable is the world oil prices, given by the average of the Dubai, Brent, and Texas price reports that cover the period 1992–2013, UN Conference on Trade and Development Commodity Statistics (UNCTAD, 2014).

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[13]The data can be downloaded at http://www.ngdc.noaa.gov/dmsp/downloadV4composites.html.

[14]We thank Claudio Ferraz for making the data available to us.

Furthermore, we include a range of both spatial control variables interacted with yearly world oil prices as well as temporal control variables interacted with our oil access measures, including the distance to the nearest oil field.

3.2 Empirical approach

Our empirical approach focuses on the differential effects of oil price changes related to the local access to oil and rely on fixed-effects panel regressions. We are primarily interested in estimating the following generic equation:

$$\Delta L_{ct} = \beta_0 \Delta Pt + \Delta P_t \boldsymbol{A}_c \boldsymbol{\beta}_1' + \Delta P_t \boldsymbol{S}_{ct} \boldsymbol{\beta_2}' + d_c + u_{ct}, \quad (1)$$

where ΔL_{ct} is the annual difference in luminosity in cell c in year t (i.e., L_{ct} - $L_{ct\text{-}1}$), ΔP_t is the annual difference the log oil price in year t, A_c is a vector of measures of a cell's accessibility to oil, $\boldsymbol{S}_{ct}$ is a vector of spatial characteristics, d_c is a cell-specific fixed effect, i.e., a cell-specific trend in luminosity, and u_{ct} is an error term.

One of our main measures of access to oil is the distance from a particular cell to the nearest oil field in the beginning year of our panel, 1992. In this case, equation (1) would assume the following form:

$$\Delta L_{\text{ct}} = \beta_0 \Delta Pt + \beta_1 \Delta P_t D_c + \Delta P_t \boldsymbol{S}_{ct} \boldsymbol{\beta_2}' + d_c + u_{ct}, \quad (2)$$

where D_c is a cell's distance to the nearest oil field. A positive estimate of β_1 would indicate a local resource curse while a negative value would suggest a positive relative effect of windfall gains on economic activity.

Our other main oil access measure is placement in an oil rich – as opposed to an oil poor – state. Using this measure instead of the distance measure, equation (1) would be modified as follows:

$$\Delta L_{\text{ct}} = \beta_0 \Delta Pt + \beta_1 \Delta P_t R_c + \Delta P_t \boldsymbol{S}_{ct} \boldsymbol{\beta_2}' + d_c + u_{ct}, \quad (3)$$

where R_c equals 1 if a cell belongs to one of the oil rich states and 0 otherwise. An estimated negative value of β_1 would again indicate the existence of a local resource curse. In all the specifications, we cluster standard errors at the cell level.[15]

Our approach is, therefore, similar in spirit to difference-in-difference estimation, with changes in international oil prices oil interacted with oil access measures as treatment variables. In particular, the analysis exploits the differential effects of oil price changes depending on the access-to-oil measures. The identification assumption that will need to be subsequently addressed is that, absent oil price changes, luminosity changes would not systematically differ depending on oil access measures. Ours is a reduced form estimation: because of data limitations, we cannot plausibly explore the channels through which nighttime light is differentially affected in grid cells. Still, the results provide a compelling causal evidence on the overall issue of the effect of oil windfalls on local development – which, as discussed above, is still very much controversial.

[15] As explained in Section 5.2, the main results are robust to using spatially and temporally clustered standard errors.

The motivation for using differenced specifications is provided by the time series properties of both international oil prices and nighttime light in Brazil. As is illustrated in Appendix Figures A1 and A2, the levels of these variables seems to follow I(1) processes, whereas their annual differences seem stationary. Indeed, while conventional formal tests cannot reject the hypothesis of an absence of a unit root for the time series of both variables in levels, respectively, they almost universally reject it for their differences. Appendix Table A1 presents formal tests confirming these results.

4 Main results

4.1 Nighttime light and the GDP

As a first step, we would like to validate our use of nighttime light in Brazil as a proxy for economic activity. To this end, we assembled municipality level data on GDP between the years 1999–2012 and matched it to our panel.[16] Table 2 presents correlations between levels and changes in nighttime light on one hand and municipal GDP on the other hand, exploring both untransformed and logarithmically transformed variables. As can be seen from the table, these variables are highly correlated; this is further illustrated in Figure 4 for the levels of both variables. The estimated elasticity between nighttime light and GDP, of some 0.20, is in the lower range of the cross-country elasticity of between 0.20–0.30 in Henderson et al., 2012. Appendix Table A2 further explores the relationship between nighttime light and GDP by including municipality and year fixed effects (Appendix Figure A3 providing an illustration) and establish correlations in changes of these variables. All the correlations are significantly positive, and these fixed effects and nighttime light explain some 90 percent of the variation in municipalities' GDP. This finding serves as reassuring evidence that nighttime light is highly correlated with GDP and can, therefore, be conceived as a plausible measure of economic activity in Brazil, a useful alternative to the officially reported GDP. This, in turn, is essential for our approach, which rules out the use of municipality level data because of endogeneity concerns.

4.2 Oil royalties, oil prices, and oil access

The National Petroleum Agency of Brazil collects data on oil royalties received by the various municipalities. Linking them to states, we observe that only ten states receive any such royalties, and out of them the three oil rich states receive more than ninety percent of the royalties (see Figure 1 for an illustration). Further, in Appendix Table A3 we run municipality based regressions of equation (1)'s type, where the left-hand side is the amount (or the annual change) of annual oil revenues. As can be seen from that table, our measures of oil access are highly significant, indicating that oil access is well correlated with oil revenues. This holds both when oil access is based on a state (oil rich versus oil poor) and when it is based on a distance from the

[16] Most changes in the definition of municipal borders occurred in 1990s and in early 2000s.

nearest oil field. This indicates that oil access measures that we use are highly relevant for generated oil revenues.

4.3 A broad perspective on the data

We first take a look at the data using a cross section perspective. Table 3 presents simple OLS regressions, in which the dependent variable is cell luminosity over the studied period. It shows that the three oil rich states are associated with significantly larger nighttime light than the other states. It can also be seen that cells that are more remote from the nearest oil field have significantly less nighttime light. The table also shows that geography matters: being more remote from the coastal area or from the largest city, San Paulo, is detrimental for nighttime light. Finally, larger population concentration is associated with more light. These observations make sense, as Brazil's coastal areas are indeed more economically developed, more urbanized, and contain larger populations than more distant areas.

Accounting for these variables reduces the effect of oil access. For example, the coefficient of the oil rich state indicator is being halved, from 4.55 to 2.33, while the coefficient of the distance to the nearest oil field is reduced (in absolute value) from 5.66 to 5.07. Still, they continue being highly significant even in the presence of these other variables capturing spatial aspects; this suggests that oil access matters independently. These results motivate our empirical strategy as they illustrate the confounding effects of geographic factors for economic activity and indicate that cross-sectional correlations between proximity to oil fields and nighttime light may be hard to interpret in causal terms.

In Appendix Figure A4 we take a temporal view of nighttime light. The figure establishes a high dispersion of the distribution of annual cell-specific changes in luminosity within oil rich states. Additionally, as a motivating prelude to the main analysis which is based on the artificial grid of cells, we conduct a state-level estimation of equations (1)–(3) in Table 4. More precisely, we now use as our observation unit the average nighttime light in a state in a given year – which yields some 567 observations in our panel. Column 1 in Table 4 shows that the increase in oil prices is associated with a larger increase in nighttime light in oil rich rather than in oil poor states; and the result in column 2 is interpreted as suggesting that state location close to oil fields is associated with a larger increase in light as a result of an increase in oil price.[17] Columns (3) and (4) introduce forward oil prices as well: their interactions with measures of oil access turn out to be insignificant, however, whereas the effect of the impact variables remains almost intact.

We then consider broad differential changes in nighttime light in Brazil across the entire sample period. As over this period oil prices more than doubled, we would like to interpret those in the light of this increase. In Appendix Table A4, the outcome variable, therefore, is the change in nighttime light over the entire period; the independent variables are our oil access measures, in addition to initial luminosity – which is included to address the convergence issue.

[17] Distances to the nearest oil field in the table are defined as the average distance across cells within a state.

Interpreting the coefficients, we find that the coefficient of initial luminosity is positive, indicating divergence in luminosity across locations over the studied period. Further, the coefficients of oil access measure indicate that nighttime light increased more in locations with better access than otherwise. Hence, even accounting for the divergent trend in luminosity, as oil prices went up, luminosity increased more in locations with better oil access across our panel. Also to be noted is the fact that about a quarter of the variance in the changes in nighttime light during the studied period is explained by the included variables.

4.4 Main estimation

Table 5 estimates models based on equations (1)–(3). The most interesting part of these tables are the interaction variables. For example, the regression results in column 2 tell us that annual changes in international oil prices have a significantly larger positive effect on nighttime light in cells within oil rich than within oil poor states. Recalling that the average luminosity in our sample is around 0.69, the estimated coefficient of 0.374 indicates that as the oil price doubles, the increase in luminosity in oil rich states is on average more than 50 percent larger than in oil poor states. This result, distinguishing between cells within and outside of oil rich states, is consistent with both oil revenues affecting economic activity and with economic linkages and transportation costs that fade with distance. To try and shed more light on these different mechanisms, we next incorporate distance to oil fields.

The regression in column 3 suggests that the effect of such changes on nighttime light decreases with the cell distance to the nearest oil field. Not only is this effect highly significant statistically, it is also large quantitatively. Recalling that the average distance of a cell to the nearest oil field in our sample is 0.09 (of 10,000 kilometers), the coefficient of -.581 in column 3 of Table 5 can be interpreted as indicating that a 100 percent increase in the oil price increases nighttime light in locations nearest to an oil field by some 5–6 percent more relative to the locations with the average distance to an oil field.

Results in columns 4 and 5 reinforce this conclusion using various distance thresholds. For example, the estimated coefficient of 0.258 implies that, as the oil price doubles, the average increase in luminosity in cells located less than 100 kilometers from the nearest oil field is about 30 percent larger than in more remotely located cells.

Additionally, column 6 explores this issue differentiating between oil rich and oil poor states. The coefficient of the triple interaction term in its last row suggests that the importance of distance to the nearest oil field in mediating the effect of oil prices on nighttime light is greater in oil rich relative to oil poor states. Taken together, these results indicate that economic linkages are important, beyond the effect of oil revenues.

Finally, in all regressions the coefficient of the oil price itself is positive, between 0.06–0.12. This constitutes yet another suggestion that the effect of oil prices on luminosity in our data is positive. Quantitatively, these estimates imply that, as oil price doubles, average nighttime light in Brazil increases by between 10–20 percent. In a related study that applies a different methodology on a different time period, Cavalcanti et al., 2016, also detect a positive income effect of oil, at the municipality level in Brazil.[18]

4.5. The linkage channel

Having established that rising oil prices generally have a more beneficial effect on locations with better access to oil, we now explore whether this is due to larger oil revenues (i.e., royalties) at locations with better oil access, or to an alternative mechanism. In particular, we investigate if our finding of a distance-related effect of oil prices on luminosity is present even when we account for the association between distance to oil fields and oil revenue (as established in Table A.3). We interpret a distance-related variation in the effect of oil prices that occur independently of oil revenues as an indicative of the existence of a possible economic linkage effect.

Municipality level oil revenue data are available in the period 1999 to 2013. To conduct a joint analysis of the oil revenue effect and the economic linkages effect, we first match our grid cells to municipality boundaries.[19] We construct, for each merged municipality-cum-cell, a binary variable indicating if it is oil revenue receiving or not.[20] Analogously to our main interaction variable of interest, we now construct an interaction variable of the annual change in oil price and the oil receiving indicator. Our first objective is to see whether our main variable of interest remains significant after controlling for this new interaction. The results are exhibited in Table 6. The first column replicates our basic result for the current sample. The second column substitutes the revenues interaction for the oil access interaction, showing that the former significantly impacts luminosity and that oil prices also have a positive impact on luminosity even outside of revenue-receiving cells. Thus, while the effect of oil prices on luminosity is larger in royalty-receiving cells, as we would have expected, these results already suggest that oil prices have an effect on luminosity in Brazil that is independent on oil revenues. More interestingly, column 3 includes both interactions, and shows that both are significant; our interpretation is that rising oil prices positively affect luminosity both through the direct revenue mechanism and through the indirect economic linkages mechanism. Column 4 includes, in addition to the previous interactions, also a triple interaction of oil price changes; distance to the nearest oil field; and whether the cell is in the revenues receiving municipality. Its (negative) sign indicates that the effect of distance is stronger in oil receiving cells. Finally, column 5 includes the differenced log of royalties.[21] Importantly, this column establishes that the distance interaction remains highly signifi-

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[18] While our results are qualitatively similar to those of that study, it is hard to compare them quantitatively because of the different methodologies used. Still, Cavalcanti et al., 2016, find very large income effects of oil discoveries, consistent with our results.

[19] We match cells to municipalities based on the location of the centroids of the cells.

[20] The former is defined as one that received direct oil revenue in the first year of our revenue data, 1999. Table A5 in the appendix show the same results using a definition of revenue-receiving that is based on royalties in any year over our sample period, 1999-2013.

[21] The results are robust to the use of the difference in the level, rather than the log, of royalties (results are available upon request).

cant even when controlling for the royalties received. Furthermore, the fact that the triple-interaction term remains significant even when controlling for the changes in the actual levels of royalties suggests that the distance-effect within revenue-receiving cells cannot be attributed to a correlation between distance and the changes in royalties within this subset of cells. Therefore, these results indicate that even within royalty-receiving cells, the distance to oil fields modify the effect of oil prices on luminosity. All this indicates to us that, beyond the potential direct effect of oil revenues, rising oil prices generate more intense economic activity at locations that have better access to oil via a potential linkage effect.

5 Robustness analyses

We carry out several different sets of robustness checks. We first explore our identified effect controlling for additional commodity prices that may be correlated with oil prices. We then control for spatial characteristics that were identified in the cross-section analysis to have a bearing on our outcome measure. We also take a look at sub-periods, in particular conducting a separate analysis of the post-2002 period. Finally, we enhance the grid cell resolution, thereby increasing the number of cells in the sample; address the potential confounding factor of flaring near oil fields; conduct separate analyses of offshore and onshore oil fields; and explore long term effects of oil price shocks.

5.1 Controlling for commodity prices

The specifications of Tables 7 and 8 are robustness checks pertaining to, respectively, columns 2 and 3 of Table 5, that account for additional main commodity prices; the rationale, obviously is alleviation of a potential concern that these prices may be correlated with oil prices and are the actual driving force behind the found effect. These controls are calculated and introduced in a similar manner to oil prices: as independent changes and as interactions with the oil access variables. Comparing the estimated coefficients in row 2 of Table 7 with those in row 2, column 2 of Table 5, we observe that the results do not differ much: the effect of oil price changes on nighttime light is significantly stronger in oil rich states, and the sizes of the coefficients are qualitatively similar. This is also the case when, as shown in column 5, we control for five-year state dummies interacted with the distance to the nearest oil field, which reflects the entire gamut of period-related changes in oil-rich versus oil-poor states. Likewise, from comparing the results in Table 8 with those in Table 5 we observe that the mediating effect of distance to the nearest oil field is preserved when controlling for other commodity prices.[22]

5.2 Controlling for spatial characteristics

[22] In the appendix, these results are reinforced by controlling for additional commodity prices as well; see Appendix Tables A6 and A7.

Table 9 conducts robustness analysis of spatial characteristics around our finding in Table 5, column 2. We view this as essential because of the earlier established fact that spatial characteristics are an important determinant of nighttime light in Brazil. When controlling for the distance to the coast; distance to San Paolo; and population density (via interactions with oil price changes) the basic coefficient of 0.374 remains hardly changed, reinforcing our conclusion that nighttime light increases more in oil rich than in oil poor states in response to oil price increases. When controlling for the interaction of initial luminosity with oil price changes, this coefficient is halved in magnitude, to 0.17, but remains highly statistically significant. Likewise, Table 10 carries out robustness checks around our finding in Table 5, column 3. Depending on the precise nature of the spatial characteristic, the estimated baseline coefficient of -0.581 changes up or down, yet invariably remaining highly statistically significant throughout.[23]

We have also calculated alternative standard errors, primarily to address the potential issue of spatial autocorrelation. To do so, we clustered standard errors at the municipal level and also applied the Conley procedure to control for serial and spatial correlation.[24] The results, presented for the former case in Appendix Table A8 and for the latter case in Appendix Table A9, confirm that the main variables of interests continue to be significant despite increased standard errors.

5.3 Post–2002 period

As a further robustness check, we split our sample into sub-periods and carry out our main analysis for the post-2002 period. Beyond constituting a half of the sample period, this sub-period is also particularly interesting because the 1997 reform of the oil sector that reorganized the distribution of oil revenues started being implemented a few years afterwards. Appendix Table A10 presents the results. The estimated coefficients of the main variables of interest, the change in oil prices interacted with oil access measures, are generally of the same magnitude and maintain similar significance as for the entire sample. Moreover, with oil access assessed by the distance to the nearest oil field, the coefficients are larger in absolute value than for the entire sample.

5.4 Different cell size

We have also assessed the robustness of the findings with respect to different cell sizes. Whereas the cell size in the main analysis was chosen so as to roughly correspond to the average municipality area, our data obviously allows us to consider areas with smaller resolutions as well. In Appendix Table A11 we illustrate one such possibility, whereby we reconstruct our grid, so that the average cell size is of about 20km x 20km. The resulting sample size in the resulting new panel is almost 400,000 observations. Comparing the results with those of Table 5, we ob-

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[23]Interestingly, the other spatial characteristics also result in significant coefficient indicating the continued importance as determinants of nighttime light.

[24]We use to this end 50 km and 100 km as the distance cutoff, because any possible overglow phenomenon of nighttime light does not extend above 50 km as discussed below.

serve that the estimated coefficients remain virtually unchanged and highly statistically significant.

5.5 Excluding cells adjacent to oil fields and offshore fields

We now replicate our baseline analysis while excluding cells near oil fields.[25] There are at least two important reasons for doing so. One, robustness issue, is in order to address the concern that gas flaring near oil fields may artificially boost nighttime light. Another, equally important advantage of this analysis is that such an exclusion enables us to focus on localities that are relatively similar in terms of oil revenues' receipts. Our results are presented in Appendix Table A12. It can be seen that, while the coefficient of interest becomes somewhat smaller in absolute value relative to our main analysis, it continues to be significant. The general pattern of our findings is quite similar to that exhibited in the main analysis. Further, the triple interaction's coefficient in column 6 is highly significant, indicating continuing robust support for the linkages channel.

Additionally, we have conducted our analysis separating offshore and onshore oil fields. Appendix Table A13 presents results for the former type.[26] Again, while the coefficient of interest is reduced in absolute value, it continues being strongly significant in the relevant specifications.

5.6 Long term effects

We next explore long run effects of oil price shocks. To do so, we implement our estimation, using lagged variables of interest to see how they affect contemporary luminosity changes. Since the latter are likely to revert to a long-run growth rate, we estimate a series of dynamic panel models that also account for the lagged change in luminosity. This is accomplished using a variety of dynamic panel models, both with and without including lagged values of the oil price variables and their interaction with our baseline oil access measure, namely the oil rich state dummy.

Appendix Table A14 presents the results of such dynamic panel models under different specifications and using a variety of estimation methods. The table provides two main insights. First, the table shows that our main finding of a differential effect of oil price changes depending on oil access measures, is robust to accounting for the past change in economic activity, as proxied by the change in luminosity. Furthermore, the table shows that, while oil prices appear to generate a reverse differential effect in the short run (i.e., on the first lag), the cumulated differential effect of oil price changes over several years is invariably consistent with our main estimation results. The reverse estimate of the differential effect on the first lag with an overall consistent cumulat-

[25] We have chosen to exclude cells located 50 km and less to the nearest oil field, as this is the distance over which flares can interfere (see Pinkovskiy, 2016). Beyond avoiding possible spuriousness, this exclusion enables us to focus on localities that are more similar in terms of oil revenues receipts.

[26] It should be recalled that the former constitute a vast majority in our sample. Results for the onshore oil are qualitatively similar and are available from the authors.

ed coefficient can indicate a possible temporary catch-up effect of oil poor areas that is nevertheless dominated by a positive effect of oil prices on the increase in economic activity in areas with a better oil access in the long run.

6 Border analysis

One of our main results above has been that the change in international oil prices tends to increase nighttime light in oil rich states more than in oil poor states. However, inasmuch as we have controlled for various confounding factors, cells in the former set of states may be fundamentally different from the latter in ways not accounted for by the use of our control variables – and may for that reason react differently to oil price changes.

We, therefore, now conduct a somewhat different type of analysis in support of our findings. Specifically, we consider administrative borders between oil rich and oil poor states as potentially introducing a discontinuity in the effect of oil prices on nighttime light. More formally, we create a band on both sides of these borders, so that our sample now consists of locations around the band on both sides of the border. The underlying assumption is that cells located near the border are more similar to each other, compared to cells that are located far from each other, except with respect to their access to oil. We exploit this spatial homogeneity as a way to control for spatial features that may otherwise be confounders in our context. It is important to keep in mind that the panel structure of our data enables us to furthermore account for cell-specific fixed effects as well as cell-specific trends. This border-related identification strategy is based on Brazil's institutional arrangement whereby oil rich states are the primary beneficiaries of oil revenues. Our hypothesis is that, in response to an increase in oil prices, nighttime light increases more in cells within the oil rich than within the oil poor states in the band. Because the cells on each side of the band differ little spatially, this analysis would provide a further reinforcement for the previous results.

One decision that has to be made is the definition of the bandwidth. The choices we make balance a tradeoff between two conflicting considerations. One is that we would like to include locations that are as similar as possible geographically, yet on two sides of the border between oil rich and oil poor states; this would militate in favor of narrow bands. Another consideration, however, is minimizing the effects of overglow and blooming related to measures of nighttime light. It has been found that this may result in a measurement error over a distance of 50 kilometers (see Pinkovskiy, 2016, for a detailed discussion of this issue and further references). This would imply the necessity of broader bands. Consequently, as a resolution of this tradeoff, we define bandwidths by a distance of 75; 100; and 125 kilometers to the oil rich/oil poor state border of a cell's centroid. In other words, a cell in our entire sample belongs to the band if its centroid is within the specified distance to the nearest point on the border between oil rich and oil poor states.[27] To generate the distances from cells to the border between the oil rich and the neighboring states, we calculate for each cell the geodesic distance from its centroid to the nearest node on the border.[28] Additionally, to eliminate the possibility of a cell being impacted by light from the wrong side of the border we exclude cells within 25 km from either side of it.[29] Depending on the bandwidth, this definition yields some 250–350 cells on either side of the border. The results of this analysis are presented in Tables 11 and 12.

Table 11 establishes that cells on the oil rich side of the band are brighter than those on the oil poor side; it, therefore, constitutes a qualitative extension of the results in Table 3 presented for the entire sample. By controlling for a variety of functions of latitude and longitude, we attempt to separate the discontinuous effect of crossing the border from the oil rich states to their neighboring states from the smooth effects of geographic location. In particular, we control for cubic polynomials in latitude, longitude, distance to San Paolo, and distance to the border. The table establishes that the oil rich side is brighter, even conditional on these spatial characteristics as well as year-fixed effects. Not only is this effect highly statistically significant, it is also quantitatively large. With the full set of controls and recalling that the average of nighttime light in our sample is around 0.70, the estimated coefficients imply that cells in the oil rich part of the band are on average three to five times as bright as those in the poor part.

Columns (1), (3) and (5) in Table 12 replicate the estimation results presented earlier for the entire sample in Table 5, column 2, for our current limited sample.[30] The interaction coefficients of around 0.50, although marginally smaller than in Table 5, are all highly significant, indicating that the increase in nighttime light in response to oil price increases is larger in cells on the oil rich side, compared to cells on oil poor side of the bands. Quantitatively, these estimations imply that as the international oil price is doubled, luminosity increases on average by some 30–40 percent more in cells that are close to the border oil rich rather than in oil poor states.

Columns (2), (4), and (6) in Table 12 introduce a triple interaction term of the oil rich state indicator; oil price change; and the distance to the nearest oil field. The coefficients of such interaction terms are always negative, indicating that distance plays a role in mediating the oil price effect on nighttime light more in oil rich than in oil poor parts of the bands; in other words, being far away from an oil field when oil prices go up is much more detrimental for cells within oil rich than in oil poor states. The diminishing statistical significance observed in this table as the band becomes narrower probably stems from the blooming effect of nighttime light, as well as from the decrease in sample size (as is evident from the increase in the standard errors). Note,

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[27]We use the high-resolution database of Global Administrative Areas (GADM) version 2.5 to identify the border between the three oil rich states and their neighboring states.

[28]Since the boundary data is very high resolution, nodes are very densely distributed. The approximation error involved in calculating the distances based on nodes (i.e., beginning/end points of each vector piece of the border), rather than the entire vector border, is therefore negligible.

[29] Results are unchanged when these cells are included and are available from the authors.

[30] In this table, we exclude cells that are located within within 25 km of either side of the border because of the flare effect as implied in Pinkovskiy, 2016; "not for publication" results that include the full set of cells are essentially the same.

however, that these terms invariably remain statistically significant. Thus, we find support both for the oil revenue effect (as the oil rich side of the band gains on average more from oil price increases) and also for the economic linkages effect.

7 Concluding remarks

This paper set out to explore the existence of a local resource curve in the context of Brazil's oil. To this end, we focus on nighttime light across Brazil's localities as a proxy for local economic activity. After establishing that nighttime light is highly correlated with measured income across locations, we examine its annual changes in response to changes in international oil prices. Our identification strategy is based on measures of differential access to oil. The null hypothesis is that an increase in oil prices should reduce overall economic activity in localities with a better access to oil.

In the main specification, an increase in oil prices implies a significantly larger increase in nighttime light in oil rich states and in localities nearer oil fields versus oil poor states and more remote localities. This differential effect is reasonably large in magnitude; for example, as the oil price doubles, the average increase in luminosity in cells located less than 100 kilometers from the nearest oil field is on average about 30 percent larger than in more remotely located cells. These findings survive a variety of robustness tests and are also found in a subset of localities within a relatively narrow band around the border between oil poor and oil rich states. We find tentative support both for the oil revenues effect and also for economic linkages effect, both working to enhance our proxy for economic activity in response to oil price increases. Beyond contributing to the debate of the existence of the resource curse, our results can be potentially useful to quantitatively assess the effect of a recent dip in international oil prices from their peak on the level of economic activity in Brazil.

References

Alexeev, M. and R. Conrad. 2009. "The Elusive Curse of Oil." *Review of Economics and Statistics* 91, 586–598.

Allcott, Hunt and Daniel Keniston, 2014, "Dutch disease or agglomeration? The local economic effects of natural resource booms in modern America," NBER Working Paper 20508.

Aragon, F. and P. Rud, 2013, "Natural Resources and Local Communities: Evidence from a Peruvian Gold Mine," *American Economic Journal: Economic Policy* 5, 1-25.

Arezki, R. and M. Brueckner, 2011, "Oil Rents, Corruption, and State Stability," *European Economic Review* 55, 955-964.

Bhattacharia, S. and R. Hodler, 2010, "Natural Resources, Democracy and Corruption," *European Economic Review*.

Black, Dan, Terra McKinnish, and Seth Sanders. 2005. "The Economic Impact of the Coal Boom and Bust." *Economic Journal*, 115 (503): 449–476.

Brollo, F., Tommaso Nannicini, Roberto Perotti, and Guido Tabellini. 2013. "The Political Resource Curse." *American Economic Review* 103 (5): 1759–1796.

Brückner, M. and M. Gradstein, 2014, "Income Growth, Ethnic Polarization, and Political Risk: Evidence from International Oil Price Shocks," *Journal of Comparative Economics*, 43, 575-594.

Caselli, Francesco, and Guy Michaels (2013). "Do Oil Windfalls Improve Living Standards? Evidence from Brazil," *American Economic Journal: Applied Economics*, 5, 208-238.

Cavalcanti, T., De Mata, D., and F. Toscani, 2016, "Winning the Oil Lottery: The Impact of Natural Resource Extraction on Growth," IMF WP 16/61.

Chen, Xi, and William D. Nordhaus. 2011. "Using Luminosity Data as a Proxy for Economic Statistics," *Proceedings of the National Academy of Sciences* 108(21): 8589–94.

Corden, W. M., 1984, "Booming Sector and Dutch Disease Economics: Survey and Consolidation," *Oxford Economic Papers*, 36, 1984, 359-380.

Corden, W. M. and Peter Neary (1982) "Booming Sector and De-Industrialisation in a Small Open Economy," *Economic Journal*, 92, 825-848.

Dreher, A. and M. Gassebner, 2013, "Greasing the wheels? The impact of regulations and corruption on firm entry," *Public Choice*, 155, 413-432.

Dube, Oeindrila, and Juan F. Vargas. 2013. "Commodity Price Shocks and Civil Conflict: Evidence from Colombia." *Review of Economic Studies* 80 (4): 1384– 1421.

Henderson, V., Adam Storeygard, and David N. Weil, 2012, "Measuring Economic Growth from Outer Space," *American Economic Review*.

Hodler, Roland, 2006. "The Curse of Natural Resources in Fractionalized Countries." *European Economic Review* 50 (6), 1367–1386.

Lederman, D. and W. Maloney, 2008, "In Search of the Missing Resource Curse." *Economıa*, 9, 1–56.

Lei, Y.-H. and G. Michaels, 2014, "Do Giant Oilfield Discoveries Fuel Internal Armed Conflicts?" *Journal of Development Economics*, 110, 2014, 139-157.

Loayza, N. and J. Rigolini, 2016, "The Local Impact of Mining on Poverty and Inequality: Evidence from the Commodity Boom in Peru," *World Development*, 84, 219-234.
Matsuyama, Kiminori (1992). "Agricultural Productivity, Comparative Advantage, and Economic Growth." *Journal of Economic Theory*, 58, 317-334.
Mauro, P. (1995), "Corruption and Growth", *Quarterly Journal of Economics*, 110, 681-712.
Michaels, Guy. 2011. "The Long Term Consequences of Resource-Based Specialization." *Economic Journal*, 121(551): 31–57.
Michalopoulos, S. and E. Papaioannou, 2013, "Pre-colonial Ethnic Institutions and Contemporary African Development," *Econometrica*, 2013, 81(1): 113-152.
Monteiro, J., and C. Ferraz. 2014. "Learning to Punish: Resource Windfalls and Political Accountability in Brazil," mimeo.
Moretti, Enrico. 2011. "Local Labor Markets." Handbook of Labor Economics 4: 1237–1313.
Murphy, Kevin M., Andrei Shleifer, and Robert W. Vishny, "The allocation of talent: Implications for growth," *Quarterly Journal of Economics*, 1991, 106 (2), 503– 530.
Papyrakis, E., and R. Gerlagh (2007) "Resource Abundance and Economic Growth in the United States." *European Economic Review*, 51, 1011-1039.
Papyrakis, Elissaios, and O. Raveh, 2014, "An Empirical Analysis of a Regional Dutch Disease: The Case of Canada," *Environmental and Resource Economics*, 58:179–198.
Pinkovskiy, M., 2016, "Economic discontinuities at borders: Evidence from satellite data on lights at night," *Journal of Economic Growth*, forthcoming.
Ross, M. L. 2001. "Does Oil Hinder Democracy?" *World Politics* 53 (3): 325–361.
Ross, M.L., 2004. "What Do We Know about Natural Resources and Civil War?" *Journal of Peace Research* 41 (3): 337–356.
Sachs, Jeffrey D., and Andrew M. Warner. 1999. "The Big Push, Natural Resource Booms and Growth." *Journal of Development Economics*, 59, 43– 76.
Sachs, Jeffrey D., and Andrew M. Warner. 2001. "The Curse of Natural Resources." *European Economic Review*, 45(4-6): 827–838.
Smith, B. and S. Wills, 2016, "Left in the Dark? Oil and Rural Poverty," mimeo.
Tomio, Fabricio Ricardo de Limas, 2005, "The creation of municipalities after the 1988 constitution," *Revista Brasileira de Ciências Sociais*, 1.
Tsui, K., 2011, "More Oil, Less Democracy: Evidence from Worldwide Crude Oil Discoveries," *Economic Journal*, 121(551): 89–115.
van der Ploeg, F., 2011, "Natural Resources: Curse or Blessing?" *Journal of Economic Literature*, 49, 366-420.
Vicente, P.C. (2010). "Does Oil Corrupt? Evidence from a Natural Experiment in West Africa," *Journal of Development Economics*, 92, 28-38.
Windmeijer, F., "A finite sample correction for the variance of linear efficient two-step GMM estimators." *Journal of Econometrics* 126.1 (2005): 25-51.

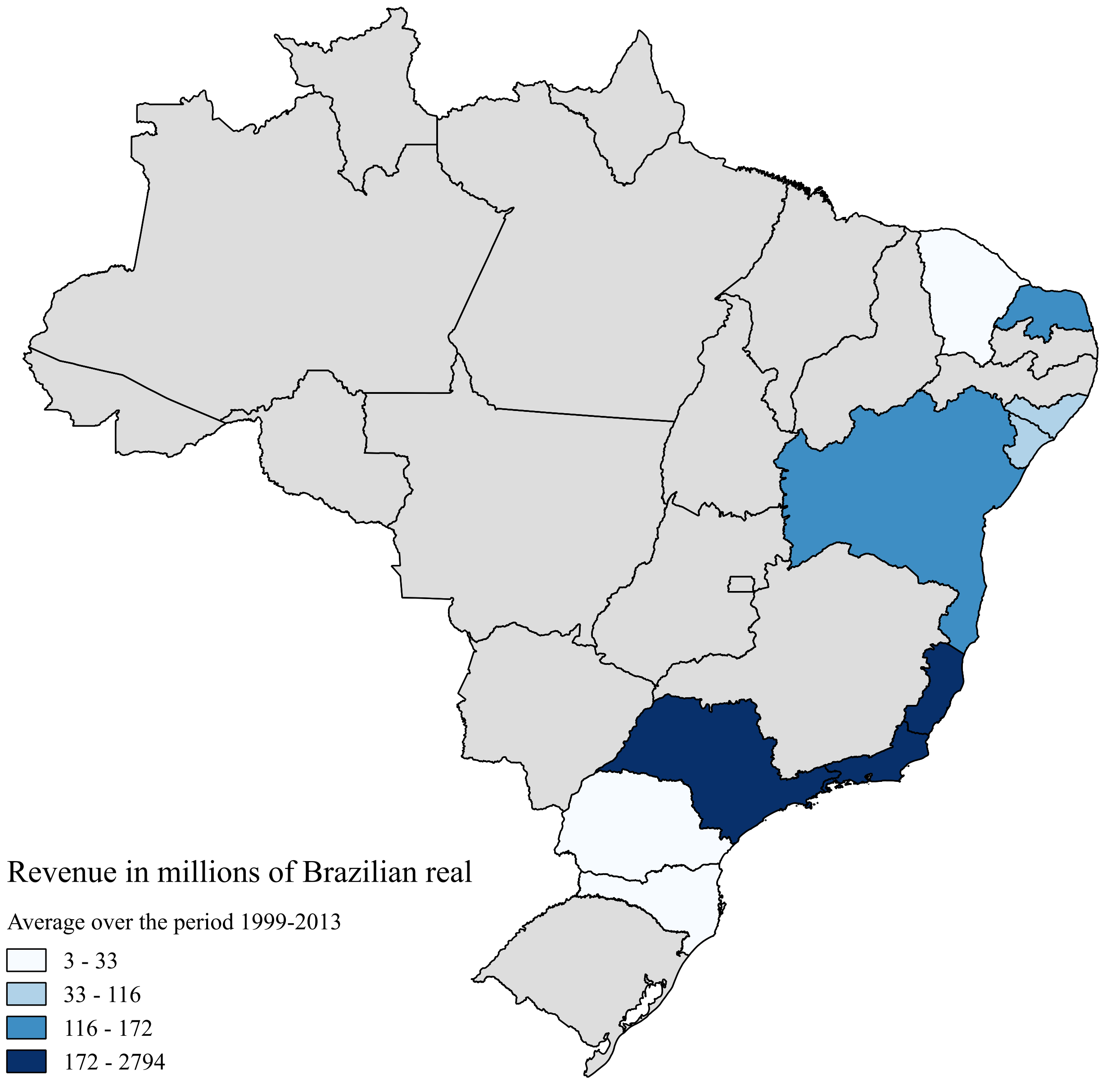

Figure 1: Map of Brazil with Municipality-Based Oil Revenues (Including *part. especial.*) for 1999–2013

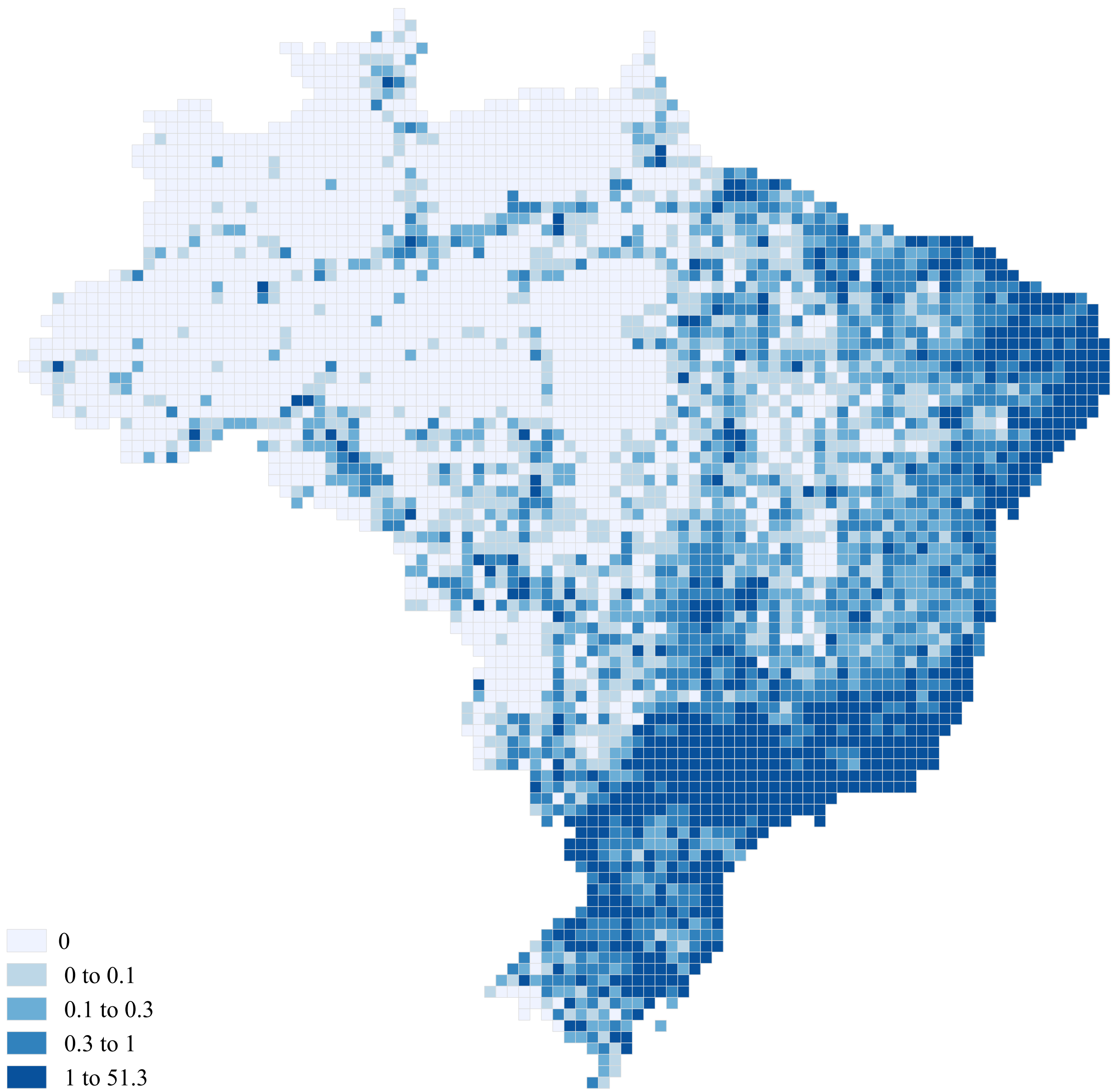

Figure 2: Average Luminosity per Cell (1992–2013)

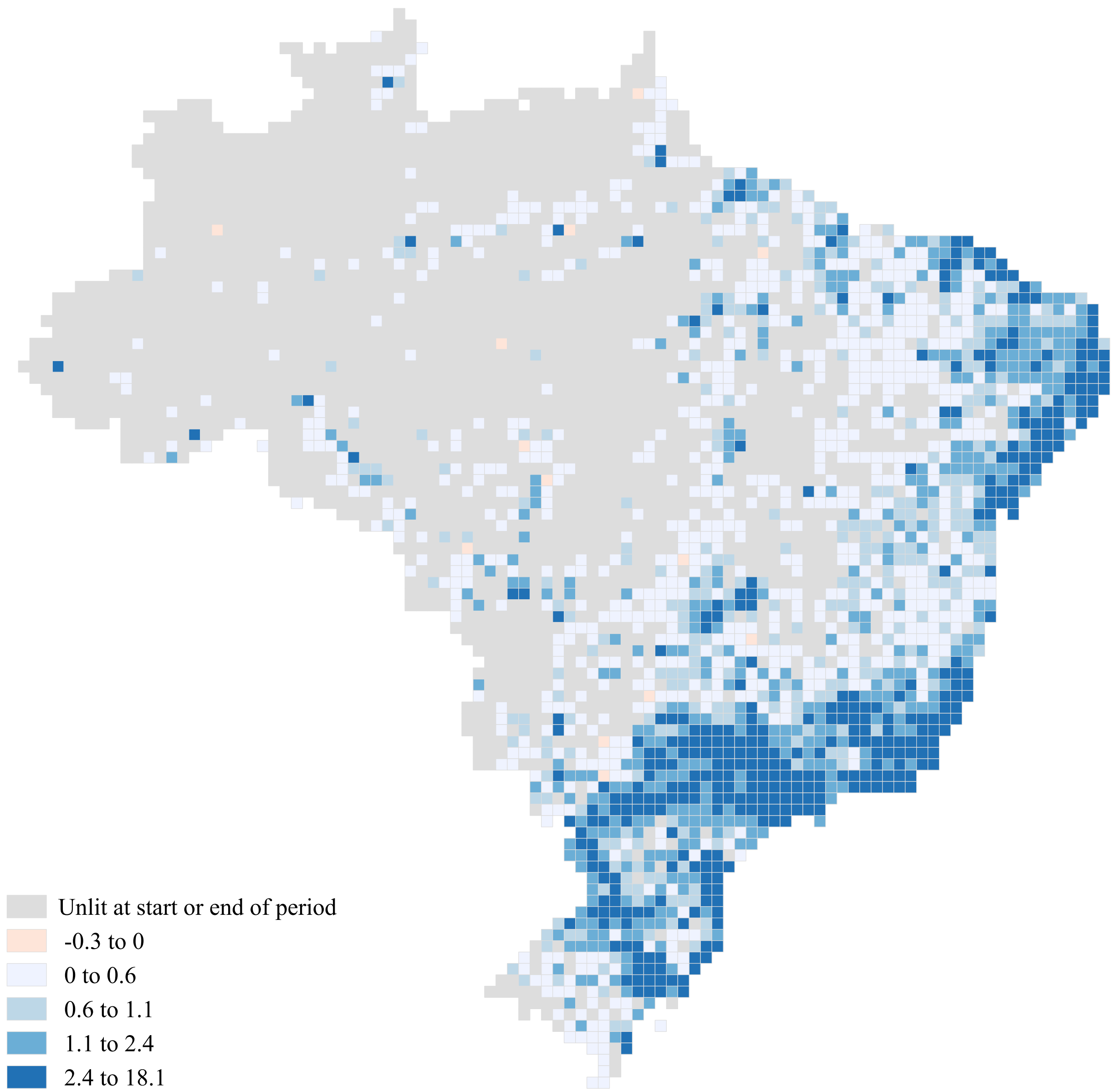

Figure 3: Difference in Luminosity per Cell from 1992 to 2013

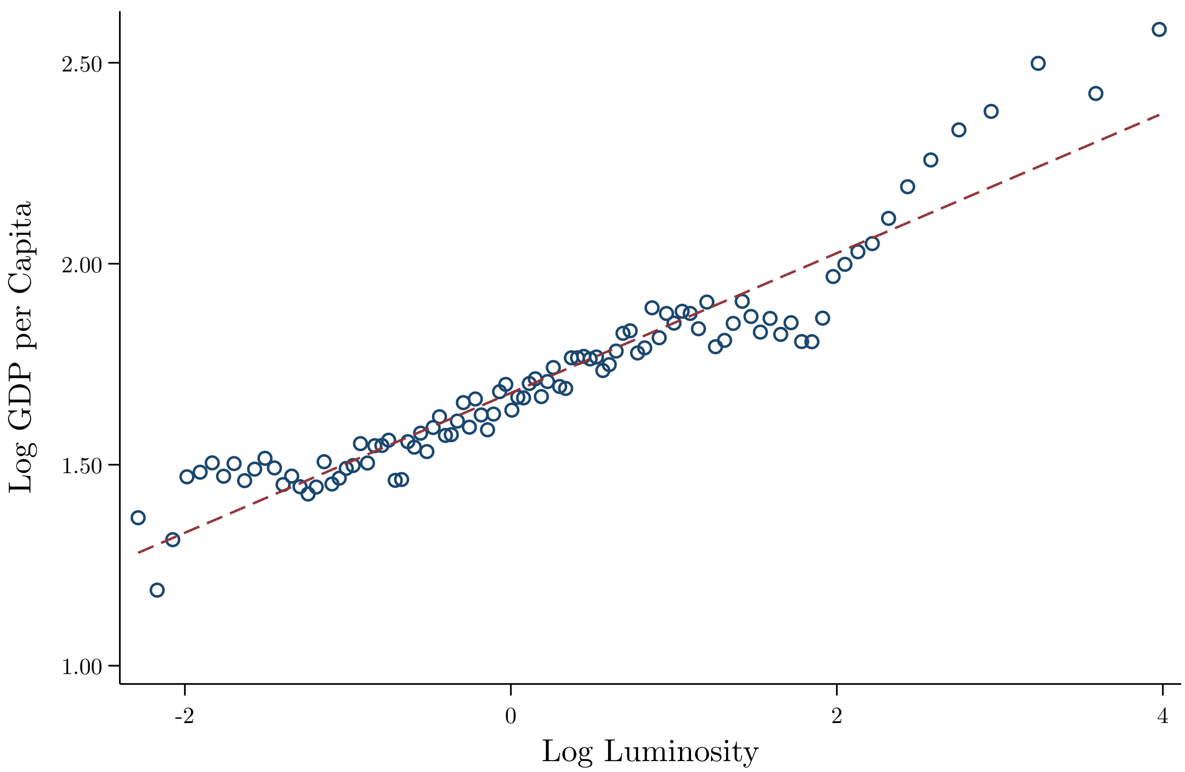

Figure 4: Log GDP per Capita and Log Luminosity (1999–2012)

Table 1: Summary Statistics

	Mean	S.D.	Min	Max
Panel 1: State-Level Dataset ($N = 594$)				
Luminosity	2.27	3.31	0.018	21.6
Distance to Nearest Oil Field (in 10,000 km)	0.07	0.05	0.0054	0.15
Oil-Rich State	0.11	0.31	0	1
Year	2002.50	6.35	1992	2013
Panel 2: Municipality-Level Dataset ($N = 77{,}766$)				
Luminosity	3.44	7.35	0	63
GDP per Capita in 1,000 Brazilian Reals	8.21	10.42	0.49	512.0
Year	2005.51	4.03	1999	2012
Panel 3: Cell-Level Dataset ($N = 92{,}752$)				
Luminosity	0.75	2.56	0	56.3
Cell Permanently Unlit	0.40	0.49	0	1
Cell-Specific Yearly Change in Luminosity	0.03	0.33	-4.88	8.04
Log Oil Price	3.58	0.71	2.57	4.65
Log Gold Price	7.05	0.50	6.54	8.04
Log Timber Price	5.23	0.13	4.94	5.47
Log Sugar Price	-0.57	0.30	-1.07	0.051
Log Soybean Price	6.54	0.24	6.22	7.00
Distance to Nearest Oil Field (in 10,000 km)	0.09	0.04	0.000065	0.18
Distance to Coast (in 10,000 km)	0.08	0.06	0.0000048	0.24
Distance to San Paolo (in 10,000 km)	0.18	0.09	0.0013	0.37
Distance Below 100 km	0.02	0.15	0	1
Distance Below 500 km	0.24	0.43	0	1
Population Density	17.07	107.47	0.070	5569.8
Oil-Rich State	0.04	0.20	0	1
Initial Luminosity	0.45	2.00	0	50.9
Year	2002.50	6.34	1992	2013
Panel 4: Cell-Level Dataset Restricted to 125 km Band Around Border Between Oil Rich and Neighboring States ($N = 7{,}854$)				
Luminosity	3.44	6.03	0	56.3
Cell Permanently Unlit	0.02	0.14	0	1
Distance to Nearest Oil Field (in 10,000 km)	0.07	0.04	0.0015	0.14
Distance to Border between Oil Rich States and Neigboring States (in km)	58.80	36.04	0.19	124.9
Distance to San Paolo (in km)	474.63	218.64	13.4	1009.4
Longitude	-47.14	3.99	-54.3	-39.5
Latitude	-21.40	1.91	-26.0	-17.0
Year	2002.50	6.34	1992	2013

Table 2: GDP per Capita and Luminosity

	GDP p.c.	Log GDP p.c.	Δ GDP p.c.
	(1)	(2)	(3)
Luminosity	0.339***		
	(0.034)		
Log Luminosity		0.174***	
		(0.007)	
Δ Luminosity			0.235***
			(0.026)
Number of Observations	77,766	77,766	72,202
Adjusted R^2	0.057	0.079	0.006

This table presents the results of regression models of municipal GDP on municipal luminosity, in levels, logs, and yearly changes, over the time-period 1992–2013. The unit of observation is a municipality. The results are robust to accounting for municipality-fixed and year-fixed effects (see Appendix Table A2.) Robust standard errors are reported in parentheses. *** Significant at the 1 percent level. ** Significant at the 5 percent level. * Significant at the 10 percent level.

Table 3: Cross-Sectional Analysis

	(1)	(2)	(3)	(4)	(5)	(6)
Oil-Rich State	4.551***				2.330***	
	(0.560)				(0.350)	
Distance to Nearest Oil Field		-5.662***				-5.070***
		(0.663)				(0.870)
Distance Below 100 km			1.397***			
			(0.222)			
Distance Below 500 km				0.394***		
				(0.082)		
Distance to Coast					-2.276***	-2.174***
					(0.572)	(0.555)
Distance to San Paolo					-2.038***	-4.135***
					(0.335)	(0.585)
Population Density					0.014***	0.015***
					(0.004)	(0.004)
Number of Observations	4,100	4,100	4,100	4,100	4,100	4,100
Adjusted R^2	0.162	0.013	0.008	0.006	0.674	0.647

This table presents the results of a series of regression models of the average luminosity for the time period 1992–2013 on a number of factors. The unit of observation is a cell. Robust standard errors are reported in parentheses. *** Significant at the 1 percent level. ** Significant at the 5 percent level. * Significant at the 10 percent level.

Table 4: Panel Analysis at the State Level — Oil Prices Interacted with Oil Access Measures

	(1)	(2)	(3)	(4)
Δ Log Oil Price $\times$ Oil-Rich State	0.319***		0.316***	
	(0.098)		(0.102)	
Δ Log Oil Price $\times$ Distance to Nearest Oil Field		-2.479***		-2.423***
		(0.877)		(0.859)
Forward Δ Log Oil Price $\times$ Oil-Rich State			0.318	
			(0.232)	
Forward Δ Log Oil Price $\times$ Distance to Nearest Oil Field				-1.022
				(0.819)
Year-Fixed Effects	Yes	Yes	Yes	Yes
Δ Log Oil Price	Yes	Yes	Yes	Yes
Forward Δ Log Oil Price	-	-	Yes	Yes
Number of Observations	567	567	540	540
Adjusted R^2	0.414	0.415	0.416	0.416

This table presents the results of a series of fixed-effects panel regression models of the yearly change in luminosity on the yearly change in log world oil prices, and its interaction with a number factors, over the time-period 1992–2013. The unit of observation is a state. Robust standard errors are reported in parentheses. *** Significant at the 1 percent level. ** Significant at the 5 percent level. * Significant at the 10 percent level.

Table 5: Panel Analysis — Oil Prices Interacted with Distance Variables

	(1)	(2)	(3)	(4)	(5)	(6)
Δ Log Oil Price	0.066***	0.050***	0.116***	0.059***	0.053***	0.083***
	(0.003)	(0.003)	(0.008)	(0.003)	(0.003)	(0.008)
Δ Log Oil Price ×		0.374***				0.465***
Oil-Rich State		(0.035)				(0.061)
Δ Log Oil Price ×			-0.581***			-0.371***
Distance to Nearest Oil Field			(0.077)			(0.073)
Δ Log Oil Price ×				0.258***		
Distance Below 100 km				(0.042)		
Δ Log Oil Price ×					0.052***	
Distance Below 500 km					(0.008)	
Δ Log Oil Price ×						-1.546*
Distance to Nearest Oil Field × Oil-Rich State						(0.792)
Number of Observations	88,536	88,536	88,536	88,536	88,536	88,536
Adjusted R^2	0.002	0.005	0.003	0.003	0.002	0.005

This table presents the results of a series of fixed-effects panel regression models of the yearly change in luminosity on the yearly change in log world oil prices, and its interaction with a number factors, over the time-period 1992–2013. The unit of observation is a cell. Robust standard errors are reported in parentheses. *** Significant at the 1 percent level. ** Significant at the 5 percent level. * Significant at the 10 percent level.

Table 6: Panel Analysis — Accounting for Royalties

	(1)	(2)	(3)	(4)	(5)
Δ Log Oil Price	0.169***	0.095***	0.164***	0.148***	0.148***
	(0.011)	(0.004)	(0.011)	(0.010)	(0.010)
Δ Log Oil Price × Distance to Nearest Oil Field	-0.819***		-0.786***	-0.630***	-0.633***
	(0.100)		(0.099)	(0.092)	(0.092)
Δ Log Oil Price × Municipality Receiving Royalties in 1999		0.022***	0.013**	0.110***	0.113***
		(0.007)	(0.006)	(0.028)	(0.029)
Δ Log Oil Price × Distance to Nearest Oil Field × Receiving Royalties				-1.556***	-1.601***
				(0.422)	(0.435)
Δ Log Royalties in Millions of R$					-0.037
					(0.070)
Number of Observations	59,024	59,024	59,024	59,024	59,024
Adjusted R^2	0.004	0.004	0.004	0.004	0.004

This table presents the results of a series of fixed-effects panel regression models of the yearly change in luminosity on the yearly change in log world oil prices, and its interaction with the distance to the nearest oil field as well as a dummy indicating if the centroid of the cell is located in a municipality that received royalties in 1999, over the time-period 1999–2013. Furthermore, the changes in the log of one plus the amount of royalties received, in millions of $R, is also included as a covariate. The unit of observation is a cell. Robust standard errors are reported in parentheses. *** Significant at the 1 percent level. ** Significant at the 5 percent level. * Significant at the 10 percent level.

Table 7: Panel Analysis — Oil Prices Interacted with Distances — Controlling for Various Price Factors — All States

	(1)	(2)	(3)	(4)	(5)	(6)
Δ Log Oil Price	0.039***	0.071***	0.051***	0.059***	0.054***	0.136***
	(0.002)	(0.004)	(0.003)	(0.003)	(0.003)	(0.006)
Δ Log Oil Price ×	0.296***	0.469***	0.382***	0.418***	0.440***	0.934***
Oil-Rich State	(0.032)	(0.046)	(0.035)	(0.035)	(0.037)	(0.074)
Δ Log Gold Prices (with Interaction)	Yes	-	-	-	-	Yes
Δ Log Timber Prices (with Interaction)	-	Yes	-	-	-	Yes
Δ Log Sugar Prices (with Interaction)	-	-	Yes	-	-	Yes
Δ Log Soybeans Prices (with Interaction)	-	-	-	Yes	-	Yes
5-Year Dummies (with Interaction)	-	-	-	-	Yes	Yes
Number of Observations	88,536	88,536	88,536	88,536	88,536	88,536
Adjusted R^2	0.011	0.008	0.007	0.006	0.030	0.070

This table presents the results of a series of fixed-effects panel regression models of the yearly change in luminosity on the yearly change in log world oil prices, and its interaction with an oil rich state dummy, over the time-period 1992–2013, accounting for interactions between the yearly change in various world prices, as well as 5-year dummies, and the oil rich state dummy. The unit of observation is a cell. Robust standard errors are reported in parentheses. *** Significant at the 1 percent level. ** Significant at the 5 percent level. * Significant at the 10 percent level.

Table 8: Panel Analysis — Oil Prices Interacted with Distances — Controlling for Various Price Factors — All States

	(1)	(2)	(3)	(4)	(5)	(6)
Δ Log Oil Price	0.090***	0.173***	0.119***	0.139***	0.123***	0.325***
	(0.008)	(0.013)	(0.009)	(0.009)	(0.008)	(0.019)
Δ Log Oil Price ×	-0.448***	-0.950***	-0.600***	-0.726***	-0.579***	-1.734***
Distance to Nearest Oil Field	(0.070)	(0.112)	(0.078)	(0.084)	(0.077)	(0.168)
Δ Log Gold Prices (with Interaction)	Yes	-	-	-	-	Yes
Δ Log Timber Prices (with Interaction)	-	Yes	-	-	-	Yes
Δ Log Sugar Prices (with Interaction)	-	-	Yes	-	-	Yes
Δ Log Soybeans Prices (with Interaction)	-	-	-	Yes	-	Yes
5-Year Dummies (with Interaction)	-	-	-	-	Yes	Yes
Number of Observations	88,536	88,536	88,536	88,536	88,536	88,536
Adjusted R^2	0.006	0.005	0.003	0.003	0.018	0.042

This table presents the results of a series of fixed-effects panel regression models of the yearly change in luminosity on the yearly change in log world oil prices, and its interaction with the distance to the nearest oil field, over the time-period 1992–2013, accounting for interactions between the yearly change in various world prices, as well as 5-year dummies, and the distance to the nearest oil field. The unit of observation is a cell. Robust standard errors are reported in parentheses. *** Significant at the 1 percent level. ** Significant at the 5 percent level. * Significant at the 10 percent level.

Table 9: Panel Analysis — Oil Prices Interacted with Distances — Controlling for Various Spatial Factors — All States

	(1)	(2)	(3)	(4)
Δ Log Oil Price ×	0.170***	0.332***	0.319***	0.293***
Oil-Rich State	(0.030)	(0.035)	(0.035)	(0.038)
Δ Log Oil Price ×	0.058***			
Initial Luminosity	(0.008)			
Δ Log Oil Price ×		-0.756***		
Distance to Coast		(0.051)		
Δ Log Oil Price ×			-0.362***	
Distance to San Paolo			(0.029)	
Δ Log Oil Price ×				0.001*
Population Density				(0.000)
Δ Log Oil Price	Yes	Yes	Yes	Yes
Number of Observations	88,536	88,536	88,536	86,100
Adjusted R^2	0.011	0.006	0.006	0.007

This table presents the results of a series of fixed-effects panel regression models of the yearly change in luminosity on the yearly change in log world oil prices, and its interaction with an oil rich state dummy, over the time-period 1992–2013, accounting for interactions between various spatial measures and the yearly difference in the world oil price. The unit of observation is a cell. Robust standard errors are reported in parentheses. *** Significant at the 1 percent level. ** Significant at the 5 percent level. * Significant at the 10 percent level.

Table 10: Panel Analysis — Oil Prices Interacted with Distances — Controlling for Various Spatial Factors — All States

	(1)	(2)	(3)	(4)	(5)
Δ Log Oil Price ×	-0.185***	-0.586***	-0.862***	-0.275***	-0.958***
Distance to Nearest Oil Field	(0.065)	(0.073)	(0.080)	(0.074)	(0.121)
Δ Log Oil Price ×	0.063***				
Initial Luminosity	(0.008)				
Δ Log Oil Price ×		-0.987***			
Distance to Coast		(0.056)			
Δ Log Oil Price ×			-0.690***		
Distance to San Paolo			(0.044)		
Δ Log Oil Price ×				0.001**	
Population Density				(0.000)	
Δ Log Oil Price Interacted with State	-	-	-	-	Yes
Δ Log Oil Price	Yes	Yes	Yes	Yes	Yes
Number of Observations	88,536	88,536	88,536	86,100	88,536
Adjusted R^2	0.011	0.004	0.004	0.005	0.009

This table presents the results of a series of fixed-effects panel regression models of the yearly change in luminosity on the yearly change in log world oil prices, and its interaction with the distance to the nearest oil field, over the time-period 1992–2013, accounting for interactions between various spatial measures and the yearly difference in the world oil price. The unit of observation is a cell. Robust standard errors are reported in parentheses. *** Significant at the 1 percent level. ** Significant at the 5 percent level. * Significant at the 10 percent level.

Table 11: Border Cross-Section Analysis — Sample Restricted to Band around Border between Oil Rich and Neighboring States while Excluding Cells Close to Border

	Bandwidth: 125 km				Bandwidth: 100 km				Bandwidth: 75 km			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Oil-Rich State	5.149***	3.925***	2.654***	5.370***	5.221***	3.988***	2.832***	5.650***	4.789***	3.309***	2.749***	4.715***
	(0.866)	(0.862)	(0.701)	(0.903)	(1.041)	(1.046)	(0.838)	(1.045)	(1.186)	(1.133)	(0.922)	(1.110)
Year-Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Longitude Qubic Polynomial	-	Yes	-	-	-	Yes	-	-	-	Yes	-	-
Latitude Qubic Polynomial	-	Yes	-	-	-	Yes	-	-	-	Yes	-	-
Distance to San Paolo Qubic Polynomial	-	-	Yes	-	-	-	Yes	-	-	-	Yes	-
Distance to Border Qubic Polynomial	-	-	-	Yes	-	-	-	Yes	-	-	-	Yes
Number of Observations	5,830	5,830	5,830	5,830	4,422	4,422	4,422	4,422	3,080	3,080	3,080	3,080
Adjusted R^2	0.154	0.278	0.370	0.170	0.135	0.260	0.363	0.165	0.118	0.275	0.370	0.168

This table presents the results of a series of regression models of luminosity for each year in the time period 1992–2013 on an oil rich state dummy and year dummies, accounting for a number of factors, and on a sample restricted to cells located in a narrow band around the border between the oil rich states and their adjacent states. Cells closer than 25 km to the border are excluded to avoid issues related to overglowing (the results are robust to including these cells; see the Appendix). The unit of observation is a cell. Robust standard errors are reported in parentheses. *** Significant at the 1 percent level. ** Significant at the 5 percent level. * Significant at the 10 percent level.

Table 12: Border Panel Analysis — Sample Restricted to Band around Border between Oil Rich and Neighboring States while Excluding Cells Close to Border

	Bandwidth: 125 km		Bandwidth: 100 km		Bandwidth: 75 km	
	(1)	(2)	(3)	(4)	(5)	(6)
Oil-Rich State × Δ Log Oil Price	0.349***	0.580***	0.338***	0.538***	0.266***	0.463***
	(0.050)	(0.084)	(0.058)	(0.091)	(0.061)	(0.105)
Oil-Rich State × Δ Log Oil Price ×		-3.517***		-3.085***		-2.980**
Distance to Nearest Oil Field		(1.025)		(1.149)		(1.337)
Δ Log Oil Price	0.118***	0.085***	0.130***	0.096***	0.135***	0.097**
	(0.018)	(0.030)	(0.022)	(0.035)	(0.027)	(0.043)
Δ Log Oil Price ×		0.432		0.446		0.525
Distance to Nearest Oil Field		(0.397)		(0.459)		(0.628)
Number of Observations	5,565	5,565	4,221	4,221	2,940	2,940
Adjusted R^2	0.010	0.010	0.010	0.010	0.009	0.009

This table presents the results of a series of fixed-effects panel regression models of the yearly change in luminosity on the yearly change in log world oil prices, and its interaction with an oil rich state dummy as well as the distance to the nearest oil field, and their triple-interaction, over the time-period 1992–2013, on a sample restricted to cells located in a narrow band around the border between the oil rich states and their adjacent states. Cells closer than 25 km to the border are excluded to avoid issues related to overglowing (the results are robust to including these cells; see the Appendix). The unit of observation is a cell. Robust standard errors are reported in parentheses. *** Significant at the 1 percent level. ** Significant at the 5 percent level. * Significant at the 10 percent level.

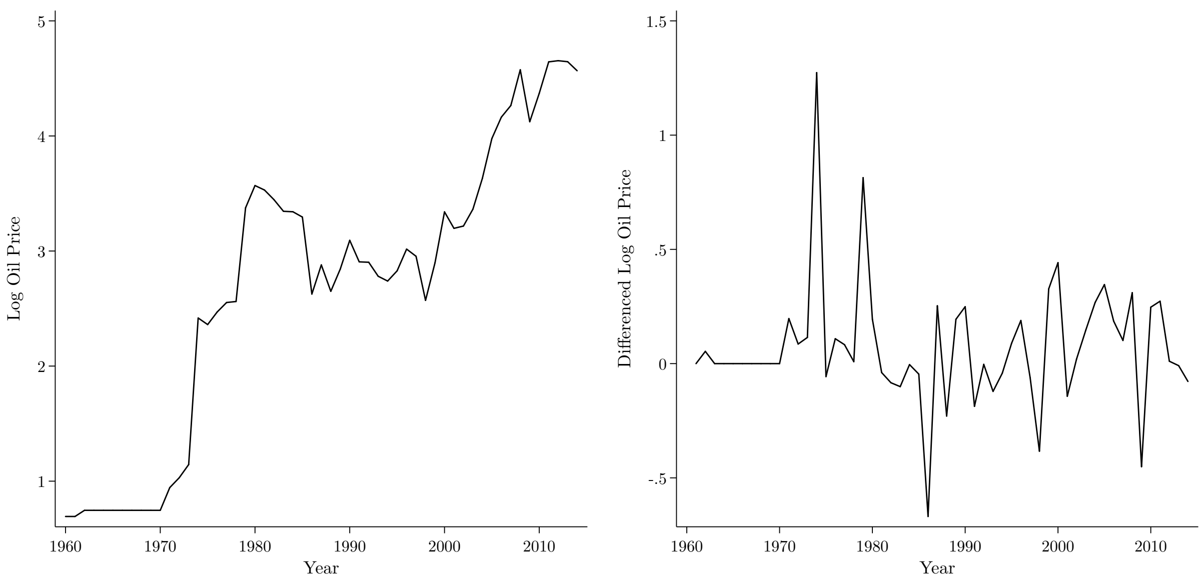

Figure A1: Log Oil Prices and Differenced Log Oil Prices

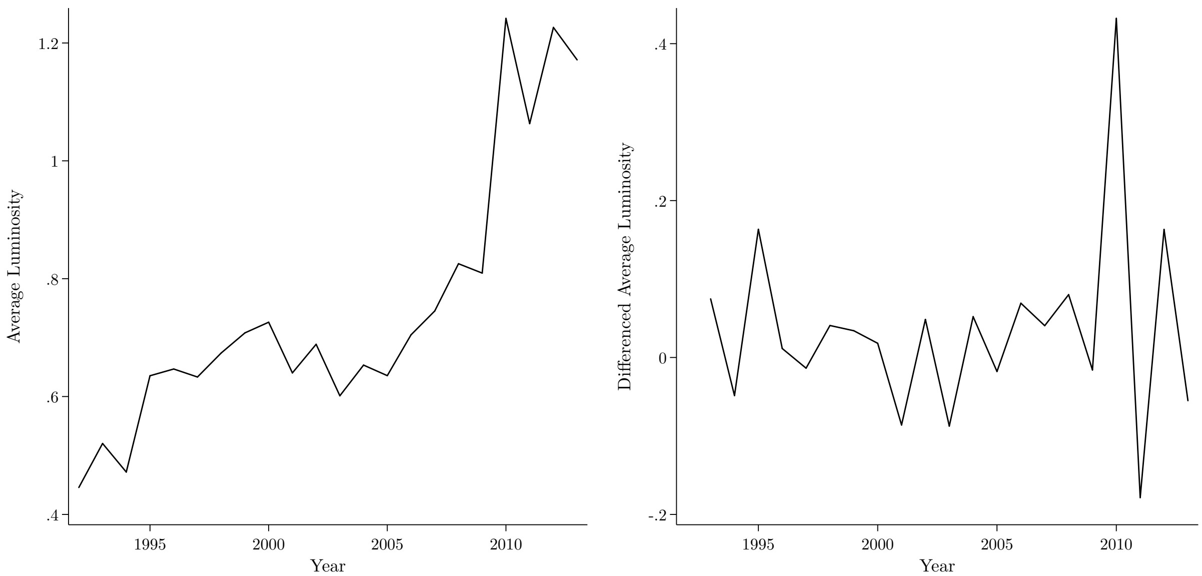

Figure A2: Average Luminosity and Differenced Average Luminosity

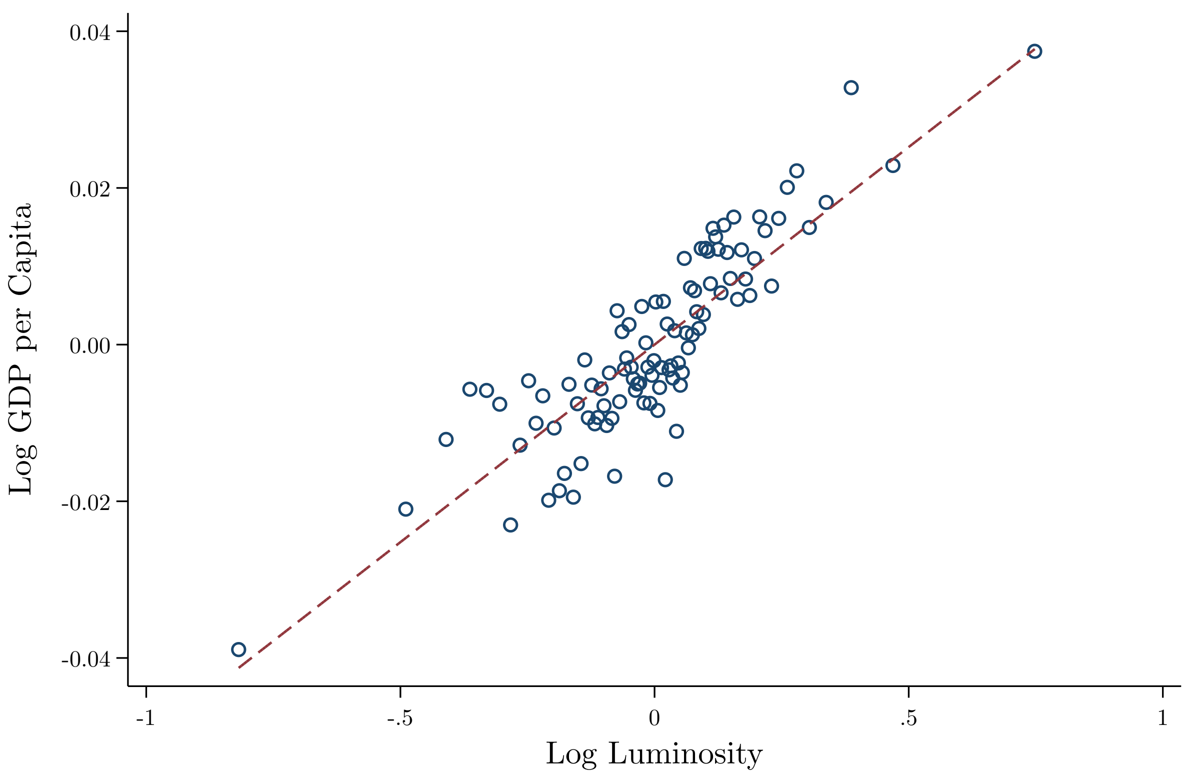

Figure A3: Log GDP per Capita and Log Luminosity (1999–2012), Accounting for municipality and Year Fixed Effects

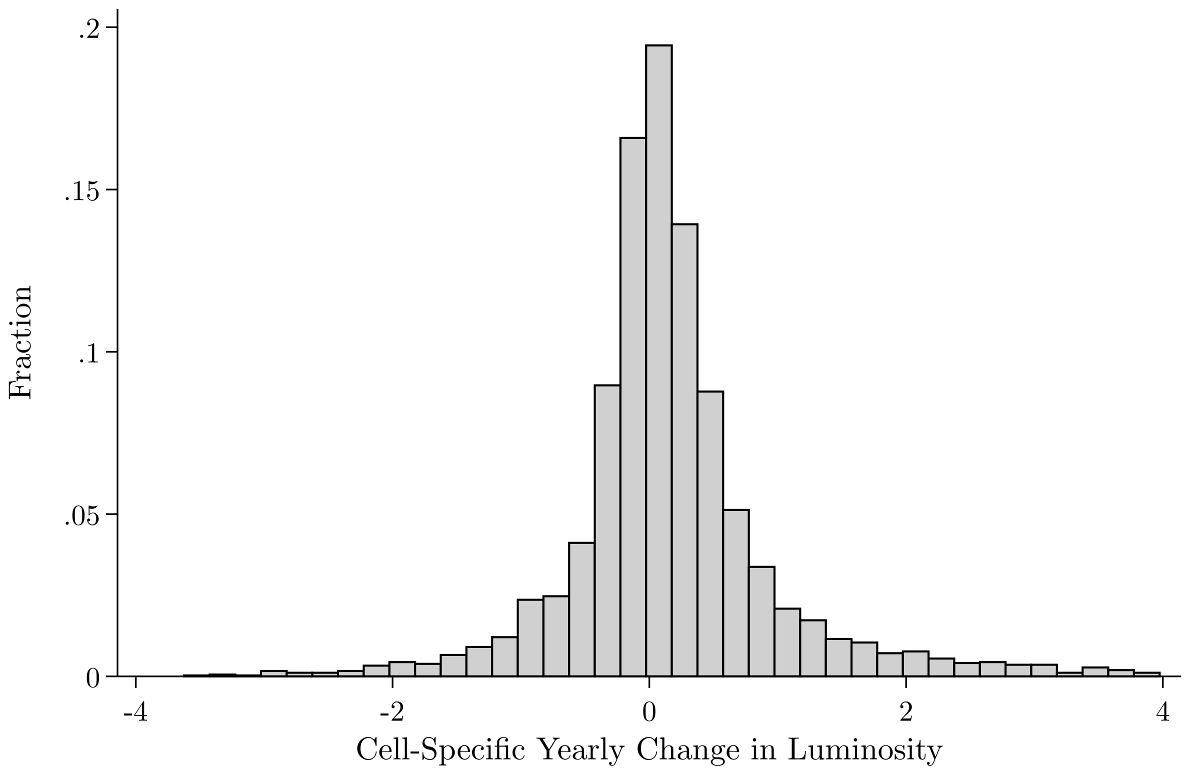

Figure A4: Distribution of Difference in Luminosity — Oilrich States

Table A1: Results of Unit Root Tests

	Log Oil Prices (Time-Series Tests)				Average Luminosity (Time-Series Tests)		State-Specific Luminosity (Panel Data Tests)			
	Entire Brazil				Entire Brazil		Entire Brazil		Oil Rich States	
	1960–2013		1992–2013		1992–2013		1992–2013		1992–2013	
	Level	Diff.	Level	Diff.	Level	Diff.	Level	Diff.	Level	Diff.
Dickey-Fuller[a]	n.s.	***	n.s.	***	n.s.	**	n.s.	***	n.s.	***
Dickey-Fuller-GLS[b]	n.s.	***	n.s.	***	n.s.	n.s.	-	-	-	-
Phillips-Perron[a]	n.s.	***	n.s.	***	n.s.	***	n.s.	***	n.s.	***
Breitung	-	-	-	-	-	-	n.s.	***	n.s.	***
Levin-Lin-Chu	-	-	-	-	-	-	n.s.	**	n.s.	n.s.
Im-Pesaran-Shin	-	-	-	-	-	-	n.s.	***	n.s.	***

This table presents the results of a series of unit root tests of log world oil prices, for the entire oil price data period (1960–2013), as well as average luminosity across all of Brazil, cell-specific luminosity across all of Brazil, and cell-specific luminosity within the oil rich states, for the period with available luminosity data (1992–2013). The tests are performed on the data in levels as well as in yearly differences. Note that the Levin-Lin-Chu and Im-Pesaran-Shin tests could not be performed on the cell level for the entire Brazil. *** Significant at the 1 percent level. ** Significant at the 5 percent level. * Significant at the 10 percent level. [a]For the panel data, we use a Fisher-type test. [b]We use 1 lag, as indicated to be optimal by the SC criterion. We compare the SC criterion across models with at most 4 lags, keeping the sample fixed at the largest size possible with 4 lags. Abbreviation: n.s., not significant at the 10% level.

Table A2: GDP per Capita and Luminosity — Robustness to Accounting for municipality-Fixed and Year-Fixed Effects

	GDP p.c.	Log GDP p.c.	Δ GDP p.c.	GDP p.c.	Log GDP p.c.	Δ GDP p.c.
	(1)	(2)	(3)	(4)	(5)	(6)
Luminosity	1.956***			0.963***		
	(0.109)			(0.148)		
Log Luminosity		0.857***			0.050***	
		(0.010)			(0.008)	
Δ Luminosity			0.184***			0.132***
			(0.020)			(0.024)
Year-Fixed Effects	No	No	No	Yes	Yes	Yes
Number of Observations	77,766	77,766	72,202	77,766	77,766	72,202
Adjusted R^2	0.172	0.330	0.004	0.353	0.902	0.022

This table presents the results of regression models of municipal GDP on municipal luminosity, in levels, logs, and yearly changes, over the time-period 1992–2013. The unit of observation is a municipality. The results are robust to accounting for municipality-fixed and year-fixed effects (see Appendix Table A2.) Robust standard errors are reported in parentheses. *** Significant at the 1 percent level. ** Significant at the 5 percent level. * Significant at the 10 percent level.

Table A3: Royalties, Oil Prices, and Oil Access

	Royalties[a]		Δ Royalties[a]	
	(1)	(2)	(3)	(4)
Log Oil Price	3.233***	3.901***		
	(0.491)	(0.680)		
Log Oil Price × Distance to nearest oil field (in 10,000 km)		-32.072***		
		(9.766)		
Δ Log Oil Price			1.961***	2.464***
			(0.488)	(0.669)
Δ Log Oil Price × Distance to nearest oil field (in 10,000 km)				-24.458**
				(9.621)
Panel-Fixed Effects	No	No	Yes	Yes
Main Effect of Distance	No	Yes	-	-
Number of Observations	12,813	12,813	11,869	11,869
Adjusted R^2	0.004	0.004	0.006	0.006

This table presents the results of a series of cross-sectional and fixed-effects panel regression models of the yearly royalties (including *participações especiais*), measured in millions of R$, or changes in these, on the yearly log world oil prices, or changes in these, and interactions with distance to the nearest oil field, over the time-period 1992–2013. The unit of observation is a municipality. The sample is based on municipalities that received royalties in the time period. The model underlying column 2 also includes the distance to the nearest oilfield. Robust standard errors are reported in parentheses. *** Significant at the 1 percent level. ** Significant at the 5 percent level. * Significant at the 10 percent level.

Table A4: Geographical Variation in the Trend in Luminosity from 1992 to 2013

	Change in Luminosity from 1992 to 2013				
	(1)	(2)	(3)	(4)	(5)
Constant	0.479***	0.433***	0.749***	0.454***	0.415***
	(0.034)	(0.029)	(0.077)	(0.030)	(0.027)
Initial Luminosity	0.553***	0.490***	0.543***	0.539***	0.546***
	(0.092)	(0.092)	(0.092)	(0.091)	(0.091)
Oil-Rich State		1.784***			
		(0.207)			
Distance to Nearest Oil Field			-3.058***		
			(0.552)		
Distance Below 100 km				1.285***	
				(0.253)	
Distance Below 500 km					0.274***
					(0.063)
Number of Observations	4,216	4,216	4,216	4,216	4,216
Adjusted R^2	0.466	0.508	0.472	0.480	0.471

This table presents the results of a series of fixed-effects panel regression models of the change in luminosity from 1992 to 2013 a set of geographical factors. The unit of observation is a cell. Robust standard errors are reported in parentheses. *** Significant at the 1 percent level. ** Significant at the 5 percent level. * Significant at the 10 percent level.

Table A5: Panel Analysis — Accounting for Royalties — Alternative Definition of Royalty-Receiving Cell

	(1)	(2)	(3)	(4)	(5)
Δ Log Oil Price	0.169***	0.083***	0.127***	0.118***	0.118***
	(0.011)	(0.004)	(0.010)	(0.010)	(0.010)
Δ Log Oil Price × Distance to Nearest Oil Field	-0.819***		-0.477***	-0.384***	-0.384***
	(0.100)		(0.093)	(0.091)	(0.091)
Δ Log Oil Price × Municipality Receiving Royalties in 1999–2013		0.186***	0.158***	0.246***	0.254***
		(0.022)	(0.022)	(0.042)	(0.044)
Δ Log Oil Price × Distance to Nearest Oil Field × Receiving Royalties				-2.414***	-2.489***
				(0.922)	(0.932)
Δ Log (1 + Royalties in Millions of R$)					-0.053
					(0.069)
Number of Observations	59,024	59,024	59,024	59,024	59,024
Adjusted R^2	0.004	0.005	0.005	0.005	0.005

This table presents the results of a series of fixed-effects panel regression models of the yearly change in luminosity on the yearly change in log world oil prices, and its interaction with the distance to the nearest oil field as well as a dummy indicating if the centroid of the cell is located in a municipality that received royalties in 1999-2013, over the time-period 1999–2013. Furthermore, the changes in the log of one plus the amount of royalties received, in millions of $R, is also included as a covariate. The unit of observation is a cell. Robust standard errors are reported in parentheses. *** Significant at the 1 percent level. ** Significant at the 5 percent level. * Significant at the 10 percent level.

Table A6: Panel Analysis — Oil Prices Interacted with Distances — Controlling for Additional Various Price Factors — All States

	(1)	(2)	(3)	(4)	(5)
Δ Log Oil Price	0.040***	0.054***	0.156***	0.031***	0.151***
	(0.002)	(0.003)	(0.007)	(0.002)	(0.007)
Δ Log Oil Price ×	0.304***	0.421***	1.130***	0.243***	1.119***
Oil-Rich State	(0.033)	(0.036)	(0.090)	(0.033)	(0.095)
Δ Log Precious Metals Prices (with Interaction)	Yes	-	-	-	Yes
Δ Log Agricultural Prices (with Interaction)	-	Yes	-	-	Yes
Δ Log Natural Gas Prices (with Interaction)	-	-	Yes	-	Yes
Δ Log Other Raw Materials Prices (with Interaction)	-	-	-	Yes	Yes
Number of Observations	88,536	88,536	88,536	88,536	88,536
Adjusted R^2	0.009	0.006	0.029	0.011	0.038

This table presents the results of a series of fixed-effects panel regression models of the yearly change in luminosity on the yearly change in log world oil prices, and its interaction with an oil rich state dummy, over the time-period 1992–2013, accounting for interactions between the yearly change in various world prices, as well as 5-year dummies, and the oil rich state dummy. The unit of observation is a cell. Robust standard errors are reported in parentheses. *** Significant at the 1 percent level. ** Significant at the 5 percent level. * Significant at the 10 percent level.

Table A7: Panel Analysis — Oil Prices Interacted with Distances — Controlling for Additional Various Price Factors — All States

	(1)	(2)	(3)	(4)	(5)
Δ Log Oil Price	0.093***	0.131***	0.401***	0.071***	0.414***
	(0.008)	(0.009)	(0.024)	(0.007)	(0.026)
Δ Log Oil Price ×	-0.474***	-0.680***	-2.285***	-0.354***	-2.493***
Distance to Nearest Oil Field	(0.071)	(0.080)	(0.208)	(0.062)	(0.223)
Δ Log Precious Metals Prices (with Interaction)	Yes	-	-	-	Yes
Δ Log Agricultural Prices (with Interaction)	-	Yes	-	-	Yes
Δ Log Natural Gas Prices (with Interaction)	-	-	Yes	-	Yes
Δ Log Other Raw Materials Prices (with Interaction)	-	-	-	Yes	Yes
Number of Observations	88,536	88,536	88,536	88,536	88,536
Adjusted R^2	0.004	0.003	0.017	0.006	0.021

This table presents the results of a series of fixed-effects panel regression models of the yearly change in luminosity on the yearly change in log world oil prices, and its interaction with the distance to the nearest oil field, over the time-period 1992–2013, accounting for interactions between the yearly change in various world prices, as well as 5-year dummies, and the distance to the nearest oil field. The unit of observation is a cell. Robust standard errors are reported in parentheses. *** Significant at the 1 percent level. ** Significant at the 5 percent level. * Significant at the 10 percent level.

Table A8: Standard Errors accounting for Clustering in the Panel Analysis — Oil Prices Interacted with Distance Variables

	(1)	(2)	(3)	(4)	(5)	(6)
Δ Log Oil Price	0.066***	0.050***	0.116***	0.059***	0.053***	0.083***
	(0.004)	(0.003)	(0.012)	(0.004)	(0.004)	(0.010)
Δ Log Oil Price ×		0.374***				0.465***
Oil-Rich State		(0.035)				(0.062)
Δ Log Oil Price ×			-0.581***			-0.371***
Distance to Nearest Oil Field			(0.103)			(0.090)
Δ Log Oil Price ×				0.258***		
Distance Below 100 km				(0.047)		
Δ Log Oil Price ×					0.052***	
Distance Below 500 km					(0.012)	
Δ Log Oil Price ×						-1.546*
Oil-Rich State × Distance to Nearest Oil Field						(0.803)
Number of Observations	88,536	88,536	88,536	88,536	88,536	88,536
Adjusted R^2	0.002	0.005	0.003	0.003	0.002	0.005

This table presents the results of a series of fixed-effects panel regression models of the yearly change in luminosity on the yearly change in log world oil prices, and its interaction with a number factors, over the time-period 1992–2013. The unit of observation is a cell. Standard errors accounting for clustering within municipalities are reported in parentheses. *** Significant at the 1 percent level. ** Significant at the 5 percent level. * Significant at the 10 percent level.

Table A9: Standard Errors accounting for Spatial and Serial Correlation in the Panel Analysis — Oil Prices Interacted with Distance Variables

	(1)	(2)	(3)	(4)	(5)
Δ Log Oil Price ×	0.374***				0.465***
Oil-Rich State	(0.085)				(0.165)
Δ Log Oil Price ×		-0.581***			-0.371**
Distance to Nearest Oil Field		(0.164)			(0.154)
Δ Log Oil Price ×			0.258***		
Distance Below 100 km			(0.089)		
Δ Log Oil Price ×				0.052***	
Distance Below 500 km				(0.018)	
Δ Log Oil Price ×					-1.546
Distance to Nearest Oil Field × Oil-Rich State					(2.095)
Number of Observations	88,536	88,536	88,536	88,536	88,536
Adjusted R^2	0.003	0.000	0.001	0.000	0.004

This table presents the results of a series of fixed-effects panel regression models of the yearly change in luminosity on the yearly change in log world oil prices, and its interaction with a number factors, over the time-period 1992–2013. The unit of observation is a cell. Standard errors accounting for spatial correlation with a bandwidth of 100 km, and serial correlation across all time periods, are reported in parentheses. *** Significant at the 1 percent level. ** Significant at the 5 percent level. * Significant at the 10 percent level.

Table A10: Panel Analysis — Oil Prices Interacted with Distance Variables — Post-2002-Period

	(1)	(2)	(3)	(4)	(5)	(6)
Δ Log Oil Price	0.081***	0.071***	0.139***	0.070***	0.068***	0.123***
	(0.004)	(0.004)	(0.012)	(0.004)	(0.004)	(0.012)
Δ Log Oil Price ×		0.257***				0.098
Oil-Rich State		(0.042)				(0.072)
Δ Log Oil Price ×			-0.661***			-0.599***
Distance to Nearest Oil Field			(0.112)			(0.113)
Δ Log Oil Price ×				0.455***		
Distance Below 100 km				(0.061)		
Δ Log Oil Price ×					0.054***	
Distance Below 500 km					(0.012)	
Δ Log Oil Price ×						2.248*
Distance to Nearest Oil Field × Oil-Rich State						(1.148)
Number of Observations	46,376	46,376	46,376	46,376	46,376	46,376
Adjusted R^2	0.002	0.003	0.002	0.004	0.002	0.003

This table presents the results of a series of fixed-effects panel regression models of the yearly change in luminosity on the yearly change in log world oil prices, and its interaction with a number factors, over the time-period 2003–2013. The unit of observation is a cell. Robust standard errors are reported in parentheses. *** Significant at the 1 percent level. ** Significant at the 5 percent level. * Significant at the 10 percent level.

Table A11: Higher Resolution Data in the Panel Analysis — Oil Prices Interacted with Distance Variables

	(1)	(2)	(3)	(4)	(5)	(6)
Δ Log Oil Price	0.067***	0.052***	0.119***	0.061***	0.054***	0.087***
	(0.002)	(0.002)	(0.005)	(0.002)	(0.002)	(0.005)
Δ Log Oil Price ×		0.381***				0.476***
Oil-Rich State		(0.022)				(0.040)
Δ Log Oil Price ×			-0.597***			-0.394***
Distance to Nearest Oil Field			(0.046)			(0.044)
Δ Log Oil Price ×				0.224***		
Distance Below 100 km				(0.023)		
Δ Log Oil Price ×					0.054***	
Distance Below 500 km					(0.005)	
Δ Log Oil Price ×						-1.611***
Distance to Nearest Oil Field × Oil-Rich State						(0.535)
Number of Observations	365,757	365,757	365,757	365,757	365,757	365,757
Adjusted R^2	0.002	0.004	0.002	0.002	0.002	0.004

This table presents, on a higher-resolution dataset with four times the number of cells than in the baseline data, the results of a series of fixed-effects panel regression models of the yearly change in luminosity on the yearly change in log world oil prices, and its interaction with a number factors, over the time-period 1992–2013. The unit of observation is a cell. Robust standard errors are reported in parentheses. *** Significant at the 1 percent level. ** Significant at the 5 percent level. * Significant at the 10 percent level.

Table A12: Panel Analysis on Sample Restricted to Cells more than 50 km from an Oil Field — Oil Prices Interacted with Distance Variables

	(1)	(2)	(3)	(4)	(5)	(6)
Δ Log Oil Price	0.062***	0.047***	0.102***	0.059***	0.053***	0.067***
	(0.003)	(0.002)	(0.008)	(0.003)	(0.003)	(0.007)
Δ Log Oil Price ×		0.382***				0.518***
Oil-Rich State		(0.035)				(0.065)
Δ Log Oil Price ×			-0.451***			-0.224***
Distance to Nearest Oil Field			(0.069)			(0.062)
Δ Log Oil Price ×				0.207***		
Distance Below 100 km				(0.046)		
Δ Log Oil Price ×					0.039***	
Distance Below 500 km					(0.008)	
Δ Log Oil Price ×						-2.142***
Distance to Nearest Oil Field × Oil-Rich State						(0.827)
Number of Observations	87,612	87,612	87,612	87,612	87,612	87,612
Adjusted R^2	0.002	0.005	0.002	0.002	0.002	0.005

This table presents the results of a series of fixed-effects panel regression models of the yearly change in luminosity on the yearly change in log world oil prices, and its interaction with a number factors, over the time-period 1992–2013, on a sample restricted to cells more than 50 km from an oil field. The unit of observation is a cell. Robust standard errors are reported in parentheses. *** Significant at the 1 percent level. ** Significant at the 5 percent level. * Significant at the 10 percent level.

Table A13: Panel Analysis — Oil Prices Interacted with Distance Variables Restricted to Offshore Oil Fields

	(1)	(2)	(3)	(4)
Δ Log Oil Price	0.154***	0.059***	0.048***	0.117***
	(0.008)	(0.003)	(0.003)	(0.007)
Δ Log Oil Price × Distance to Nearest Offshore Oil Field	-0.573***			-0.424***
	(0.033)			(0.029)
Δ Log Oil Price × Distance Below 100 km (Offshore)		0.298***		
		(0.047)		
Δ Log Oil Price × Distance Below 100 km (Offshore)			0.116***	
			(0.012)	
Δ Log Oil Price ×				0.431***
Oil-Rich State				(0.061)
Δ Log Oil Price × × Distance to Nearest Offshore Oil Field				-1.492*
Oil-Rich State				(0.789)
Number of Observations	88,536	88,536	88,536	88,536
Adjusted R^2	0.004	0.003	0.003	0.006

This table presents the results of a series of fixed-effects panel regression models of the yearly change in luminosity on the yearly change in log world oil prices, and its interaction with a number factors, over the time-period 1992–2013. In the calculation of the distance to the nearest oil field, only offshore oil fields are used. The unit of observation is a cell. Robust standard errors are reported in parentheses. *** Significant at the 1 percent level. ** Significant at the 5 percent level. * Significant at the 10 percent level.

Table A14: Panel Analysis — Dynamic Model and Temporal Effects

	Difference GMM (One-step)	System GMM (Two-step)	Difference GMM (One-step)	Difference GMM (Two-step)	System GMM (One-step)	System GMM (Two-step)	Difference GMM (One-step)	System GMM (Two-step)	Difference GMM (One-step)	Difference GMM (Two-step)	System GMM (One-step)	System GMM (Two-step)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
First Lag of Luminosity	-0.519***	-0.429***	-0.508***	-0.505***	-0.413***	-0.412***	-0.510***	-0.404***	-0.517***	-0.514***	-0.422***	-0.421***
	(0.008)	(0.009)	(0.010)	(0.011)	(0.010)	(0.011)	(0.008)	(0.010)	(0.009)	(0.009)	(0.010)	(0.010)
Δ Log Oil Price	0.765***	0.651***	0.588***	0.583***	0.554***	0.524***						
× Oil-Rich State	(0.049)	(0.049)	(0.060)	(0.064)	(0.056)	(0.059)						
First Lag of Δ Log Oil Price			-0.913***	-0.900***	-1.153***	-1.106***						
× Oil-Rich State			(0.071)	(0.075)	(0.066)	(0.077)						
Second Lag of Δ Log Oil Price			1.042***	0.994***	0.914***	0.850***						
× Oil-Rich State			(0.086)	(0.096)	(0.080)	(0.089)						
Third Lag of Δ Log Oil Price			0.680***	0.628***	0.165***	0.136***						
× Oil-Rich State			(0.092)	(0.098)	(0.047)	(0.050)						
Fourth Lag of Δ Log Oil Price			1.307***	1.241***	1.046***	0.973***						
× Oil-Rich State			(0.093)	(0.106)	(0.073)	(0.085)						
Fifth Lag of Δ Log Oil Price			1.137***	1.075***	0.667***	0.626***						
× Oil-Rich State			(0.095)	(0.107)	(0.052)	(0.063)						
Δ Log Oil Price							-1.231***	-0.732***	-0.699***	-0.654***	-0.753***	-0.559***
× Distance to Nearest Oil Field							(0.124)	(0.071)	(0.124)	(0.077)	(0.101)	(0.066)
FirstLag of Δ Log Oil Price									2.334***	1.655***	2.893***	1.663***
× Distance to Nearest Oil Field									(0.231)	(0.155)	(0.208)	(0.130)
Second Lag of Δ Log Oil Price									-2.319***	-0.962***	-1.951***	-1.040***
× Distance to Nearest Oil Field									(0.224)	(0.131)	(0.157)	(0.100)
Third Lag of Δ Log Oil Price									-1.427***	0.116	-0.015	0.244***
× Distance to Nearest Oil Field									(0.263)	(0.140)	(0.090)	(0.059)
Fourth Lag of Δ Log Oil Price									-2.530***	-0.678***	-1.741***	-0.744***
× Distance to Nearest Oil Field									(0.256)	(0.135)	(0.152)	(0.090)
Fifth Lag of Δ Log Oil Price									-3.371***	-0.839***	-2.151***	-0.767***
× Distance to Nearest Oil Field									(0.313)	(0.157)	(0.182)	(0.093)
Δ Log Oil Price	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Oil Rich State Dummy	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	No
Distance to Nearest Oil Fiel	No	No	No	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes
Sum of Lagged Interaction Coefficients			3.842***	3.620***	2.193***	2.002***			-8.013***	-1.363**	-3.718***	-1.202***
Number of Observations	80,104	84,320	63,240	63,240	67,456	67,456	80,104	84,320	63,240	63,240	67,456	67,456

This table presents the results of a series of fixed-effects dynamic panel regression models of the yearly change in luminosity on the conptemporary and lagged yearly change in log world oil prices over the time-period 1992–2013. The unit of observation is a cell. Robust standard errors are reported in parentheses. *** Significant at the 1 percent level. ** Significant at the 5 percent level. * Significant at the 10 percent level.

Appendix not for publication

Table B1: Border Cross-Section Analysis — Sample Restricted to Band around Border between Oil Rich and Neighboring States

	Bandwidth: 125 km				Bandwidth: 100 km				Bandwidth: 75 km			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Oil-Rich State	4.111***	2.786***	2.244***	4.261***	3.976***	2.668***	2.308***	4.167***	3.434***	2.074***	2.141***	3.367***
	(0.656)	(0.563)	(0.511)	(0.667)	(0.739)	(0.622)	(0.576)	(0.734)	(0.759)	(0.689)	(0.587)	(0.699)
Year-Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Longitude Qubic Polynomial	-	Yes	-	-	-	Yes	-	-	-	Yes	-	-
Latitude Qubic Polynomial	-	Yes	-	-	-	Yes	-	-	-	Yes	-	-
Distance to San Paolo Qubic Polynomial	-	-	Yes	-	-	-	Yes	-	-	-	Yes	-
Distance to Border Qubic Polynomial	-	-	-	Yes	-	-	-	Yes	-	-	-	Yes
Number of Observations	7,854	7,854	7,854	7,854	6,446	6,446	6,446	6,446	5,104	5,104	5,104	5,104
Adjusted R^2	0.131	0.265	0.352	0.155	0.114	0.248	0.339	0.150	0.101	0.269	0.338	0.162

This table presents the results of a series of regression models of luminosity for each year in the time period 1992–2013 on an oil rich state dummy and year dummies, accounting for a number of factors, and on a sample restricted to cells located in a narrow band around the border between the oil rich states and their adjacent states. The unit of observation is a cell. Robust standard errors are reported in parentheses. *** Significant at the 1 percent level. ** Significant at the 5 percent level. * Significant at the 10 percent level.

Table B2: Border Panel Analysis — Sample Restricted to Band around Border between Oil Rich and Neighboring States

	Bandwidth: 125 km		Bandwidth: 100 km		Bandwidth: 75 km	
	(1)	(2)	(3)	(4)	(5)	(6)
Oil-Rich State × Δ Log Oil Price	0.294***	0.450***	0.276***	0.404***	0.219***	0.329***
	(0.040)	(0.068)	(0.045)	(0.072)	(0.045)	(0.077)
Oil-Rich State × Δ Log Oil Price ×		-2.423***		-2.026**		-1.734*
Distance to Nearest Oil Field		(0.865)		(0.929)		(1.014)
Δ Log Oil Price	0.125***	0.109***	0.135***	0.122***	0.140***	0.130***
	(0.016)	(0.031)	(0.018)	(0.035)	(0.021)	(0.041)
Δ Log Oil Price ×		0.218		0.178		0.138
Distance to Nearest Oil Field		(0.369)		(0.417)		(0.511)
Number of Observations	7,497	7,497	6,153	6,153	4,872	4,872
Adjusted R^2	0.010	0.010	0.010	0.010	0.009	0.009

This table presents the results of a series of fixed-effects panel regression models of the yearly change in luminosity on the yearly change in log world oil prices, and its interaction with an oil rich state dummy as well as the distance to the nearest oil field, and their triple-interaction, over the time-period 1992–2013, on a sample restricted to cells located in a narrow band around the border between the oil rich states and their adjacent states. The unit of observation is a cell. Robust standard errors are reported in parentheses. *** Significant at the 1 percent level. ** Significant at the 5 percent level. * Significant at the 10 percent level.