Natural Resource Access and Local Economic Growth

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Abstract We explore the existence of a local "resource curse" related to Brazil's oil, using oil price annual changes interacted with measures of local proximity to oil reserves. We find that locations in Brazil that are closer to an oil field are characterized by a higher level of income per capita, when controlling for a range of potentially confounding factors. Furthermore, in a panel setting, we find that better geographical access to oil fields generates a greater positive effect of oil prices on local income per capita. Moreover, this positive impact of oilfield proximity on the effect of oil prices is enhanced in oil rich states. Importantly, these effects appear to be independent of the amount of oil royalties, suggesting the role of an indirect linkage effect.

Keywords Local resource curse, resource access, oil price shocks.

JEL classification O11, O13, Q33, R11.

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1 Introduction

The growth effects of natural resource abundance remain highly disputed. On one hand, many of the richest countries in the world, in terms of income per capita, are large oil and gas producers.[1] Before the era of mass oil exploitation, 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, we contribute to this literature by exploring the local effect of yearly international oil price changes on income per capita and an alternative measure of economic activity, focusing on Brazil in the years 1992–2013.[3] We analyze the case of Brazil for several reasons. One is that Brazil is a significant player in the world oil market, yet not a price maker.[4] Another is that almost the entire source of Brazilian oil is concentrated offshore and is affiliated with just three states in the south-east, which enables a distinction between oil rich and oil poor states within a single country.[5] 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.[6]

Our main proxy for local economic growth is given by annual changes in income per capital across Brazil's municipalities. Furthermore, we establish and exploit a strong association between local GDP per capita and the local intensity of nighttime light across locations in Brazil and use the latter

[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] In analyses restricted by data on local GDP per capita, the data covers the period 1999-2012.

[4] 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/.

[5] 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.

[6] 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.

as a secondary source for measuring economic growth.[7] While each of these measures have advantages and drawbacks, they can in principle complement each other. For example, having in mind potential spillovers and geographical linkages across locations, nighttime light, available at any geographic resolution, can be a useful source of information. Yet, many aspects of economic activity that are captured by GDP are unlikely to be captured by nighttime light. In particular, the nighttime light measure likely captures aspects of economic activity that are mainly related to infrastructure and industrial manufacturing. Therefore, nighttime light is, presumably, a noisy proxy of local economic activity. Differences in the levels of statistical precision, or even in the direction of associations, resulting from the measurement of economic activity by either income per capita or nighttime luminosity, may for this reason provide suggestive evidence regarding the nature of the effects of oil prices on economic activity.

We relate our outcome measures to annual changes in world oil prices, interacted with spatial measures of oil access, such as the proximity to 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.

Contrary to a hypothesized local resource curse, we find that better access to oil enhances the positive effect of oil prices on income per capita. 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 and elevation. Moreover, the effect is economically significant. Our most basic panel estimate suggests that for every 100 km distance to an oil field, the effect of a change in oil prices on a change in income is reduced by 0.99%-points. This should be compared to the baseline effect of a 1% increase in the percentage change in oil prices is associated with a 6.89% increase in the percentage change in GDP. Further, when confining attention to municipalities in narrow bands around the borders between oil rich and oil poor states, we find that the positive impact of oilfield proximity on the effect of oil prices is significantly larger in municipalities located on the oil rich. Our results can be interpreted as lending support to two channels of the effect of natural resources. The main one is the revenue effect, whereby receiving localities (say, municipalities in oil rich states) benefit more from an increase in oil revenues than non-receiving ones. Further, the finding that the impact of proximity to the nearest oil field on the effect of oil prices is greater in oil rich states indicates that economic linkages matter, even beyond the effect of oil revenues. Going beyond that, we find that distance to the nearest oil field remains a significant factor even after controlling for oil revenues, which reinforces our interpretation that linkages have an independent role in mediating the effect of oil prices on economic activity. In addition to contributing to the literature on local effects of natural resource abundance in general, therefore, our analysis enables us to distinguish between the oil revenues' channel and the linkages' channels, arguing in particular, that the former is the main one.

[7] Consistent with Henderson at al., 2012, our analysis establishes a strong correlation between nighttime light and municipality-level income in Brazil, based both on cross-sectional and fixed-effect panel regressions.

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 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, 2018, adjust existing models of Corden and Neary, 1982, and Matsuama, 1992, to exhibit a potentially ambiguous local effect of natural resources.[8] 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, 2018, 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.[9] 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, in a related study that applies a different methodology on a different time period Cavalcanti et al., 2016, find that oil discoveries had a beneficial effect on the incomes of municipalities in which they took place.[10]

The rest of the paper proceeds as follows. The next section contains some background on Brazil's oil; on our outcome variables; 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 multiple robustness checks. Finally, Section 6 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

[8]See also Corden, 1984, on the international aspect of Dutch disease.

[9]See, however, Papyrakis and Raveh, 2014, for dissenting evidence in Canada's context.

[10]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, broadly consistent with our results.

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.[11] 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 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.

Figure 1 shows the location of oil fields in our sample, based on Caselli and Michaels, 2013.

2.2 Outcome variables

We measure income by municipality-level GDP per capita, as reported by the Brazilian Institute for Geography and Statistics (IBGE). Figure 1(b) shows the distribution of income per capita across Brazil's municipalities.

Our additional outcome measure is given by nighttime light across Brazil's localities, as recorded from space; Chen and Nordhaus, 2011, Henderson et al., 2012, and Michalopoulos and Papaioannou, 2013, advocate its use. 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. Figure 1(a) shows the distribution of average nighttime light across Brazil's grid.

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, municipality level GDP and luminosity are highly significantly correlated; and this holds regardless of whether these are measured in levels or in changes, and whether the variables are measured on a linear or a logarithmic scale. The significant correlation between local GDP across Brazilian municipalities

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

and nighttime light, while accounting for municipality-fixed effects, is consistent with, and complements, existing findings on such correlations at more aggregated levels.

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.[12] Allcott and Keniston, 2018, 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.[13] 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).[14]

[12]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.

[13]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.

[14]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.)

All this suggests that, depending on the circumstances, a resource curse may or may not be realized. Empirical analysis 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. The main regression sample consists of data for the 941 royalty-receiving municipalities. We limit our attention to royalty-receiving locations for two reasons. First, variation in the proximity to an oil field is unlikely to have an impact at great distances and royalty-receiving municipalities are all located relatively close to oil fields. Second, a central objective of the research is to investigate the extent to which an impact of oil access measures (i.e., proximity and oil rich state status) on the effect of economic activity is mediated by royalties or can be attributed to potential linkage effects.

Table A.1 in the appendix presents summary statistics of our main variables.

Dependent variables

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

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 a total of 5,565 municipalities (as defined in 2010) and covers the years 1999–2012.[15]

Nighttime light

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 data covers the years 1992–2013. The images are aggregated to the yearly level and processed to remove cloud cover, snow and ephemeral lights.[16] Furthermore, each pixel contains a digital number (DN) value, ranging from 0 to 63 representing its luminosity; see Henderson et al., 2012, and Pinkovskiy, 2016, for further details and discussion of these data. Pixels with DN equal to 0 or 63 may be censored, which could be a concern especially for large urban areas. To address this issue, we employed the corrective procedure from Bluhm and Krause, 2018.[17] All qualitative conclusions are, however, independent of this correction.

Based on the nighttime lights data, we first measure luminosity within each municipality for each year. Furthermore, we construct two grids of cells at high and very high resolutions. The high-

[15]We thank Claudio Ferraz for making the data available to us.
[16]The data can be downloaded at http://www.ngdc.noaa.gov/dmsp/downloadV4composites.html.
[17]We used formula G-1 from Bluhm and Krause, 2018, with the suggested top-coding threshold of 55 and the suggested alpha parameter value of 1.5 to obtain the top-coding-corrected luminosity measure.

resolution grid consists of approximately 20 km × 20 km cells. The very high-resolution grid consists of approximately 7 km × 7 km cells. These grids allow us to investigate the impact of resolution and the use of artificial borders on the findings. Light intensity in a cell for a given year is the proxy for the economic activity within that cell in that year.

Municipality-level royalties

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

Independent variables

The main independent variables consist of the proximity to the nearest oil field; an indicator variable for location in an oil rich state; the yearly world oil price; and their interactions.

Proximities to the nearest oil fields are based on the map of oil fields from Caselli and Michaels, 2013 (excluding gas fields). The great-circle distances are calculated (using the Haversine formula) from the interior centroid of the location (i.e., municipality or cell) to the nearest interior centroid of an oil field initiated before 1992.[18]

The three states Rio de Janeiro, Espírito Santo and São Paulo receive more than ninety percent of the royalties received by any of the ten royalty-receiving states. We therefore define these three states as oil rich states. To test for the robustness of our conclusions to an alternative reasonable definition of oil rich state status, in a robustness test, we define the states Bahía and Rio Grande do Norte as oil rich states, while we exclude our three main oil rich states from the sample (since they should not be part of the comparison group).

Our additional independent variable is the world oil prices, given by the average of the Dubai, Brent, and Texas price reports (in USD) that cover the period 1992–2013, UN Conference on Trade and Development Commodity Statistics (UNCTAD, 2014). (We have also used, for robustness, the price measured in Brazilian Reals. The main results, not reported here but available in the appendix not for publication, remain unchanged.)

Furthermore, we include a range of both spatial control variables and their interactions with yearly world oil prices as well as temporal control variables and their interactions 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. The unit of observation is a location, i.e., either a municipality or a cell. We are primarily interested in estimating the following generic equation:

$$\Delta y_{m,t} = \beta_0 \Delta w_t + \Delta w_t \mathbf{A}_m \boldsymbol{\beta}_1' + \Delta w_t \boldsymbol{S}_{m,t} \boldsymbol{\beta}_2' + \Delta \mathbf{F}_t \mathbf{A}_m \boldsymbol{\beta}_3' + d_m + u_{m,t}, \quad (1)$$

where Δy_{mt} is the annual difference in the measure of economic activity in location m in year t (i.e., $y_{c,t}$ - $y_{c,t\text{-}1}$), Δw_t is the annual difference the log world oil price in year t, $\boldsymbol{A}_c$ is a vector of measures of a

[18]When the date of initiation in not reported in the data, we use the date of discovery.

location's accessibility to oil, $\mathbf{S}_{ct}$ is a vector of spatial characteristics, $\Delta\mathbf{F}_t$ is a vector of annual differences in various price indices and asset prices in year t, d_c is a location-specific fixed effect (i.e., trend in y_m), and u_{mt} is an error term that is clustered on the yearly level as well as on the location-specific level.

Our main measure of access to oil is the proximity to the nearest oil field in the beginning year of our panel; the proximity variable is simply defined as an inverse of the distance, i.e., distance multiplied by -1. In this case, equation (1) assumes the following form:

$$\Delta y_{mt} = \beta_0 \Delta w_t + \beta_1 \Delta w_t p_m + \Delta w_t \mathbf{S}_{mt} \boldsymbol{\beta}_2' + w_m \Delta \mathbf{F}_t \boldsymbol{\beta}_3' + d_m + u_{mt}, \quad (2)$$

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

Our other oil access measure is location 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:

$$\Delta y_{mt} = \beta_0 \Delta w_t + \beta_1 \Delta w_t r_c + \Delta w_t \boldsymbol{S}_{ct} \boldsymbol{\beta}_2' + w_m \Delta \mathbf{F}_t \boldsymbol{\beta}_3' + d_c + u_{ct}, \quad (3)$$

where r_c equals 1 if a location 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.

Finally, we also consider the differential impact of distance on the effect of oil prices between oil rich and oil poor states. In particular, we include a triple-interaction term between world oil prices, proximity to an oil field and location in oil rich state status. A positive coefficient on this term would indicate a larger impact of proximity on the effect of oil prices in oil rich states.

In all the specifications, we cluster standard errors on the yearly level as well as on the location-specific level.[19]

Our approach is, therefore, similar in spirit to difference-in-difference estimation, with changes in international oil prices interacted with oil access measures as treatment variables. The analysis is in a reduced form. Because of data limitations, we cannot plausibly explore the channels through which economic activity is differentially affected in municipalities. Still, the results provide compelling causal evidence on the overall issue of the effect of oil windfalls on local development – which, as discussed above, is still a highly disputed issue.

A central question is whether an impact of oil access on the association between oil prices and income can be attributed to a mediating effect of oil revenues (i.e., royalties) or to an alternative mechanism. We therefore include municipality-and-year-specific oil revenues as an explanatory variable. These data are available in the period 1999 to 2013. We interpret impacts of oil access on the effect of oil prices that occur independently of oil revenues as indicative of the existence of a possible economic linkage effect. If the heterogeneity in the effect of oil prices that is related to oil access is driven entirely by differences in the amount of royalties received, we should expect that controlling for royalties would drive the estimate of the distance-related interaction coefficient to zero.

The motivation for using differenced specifications is provided by the time-series properties of both world oil prices and the measures of economic activity in Brazil. As is illustrated in Figures A.1

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

in the appendix, the levels of these variables appears to follow I(1) processes, whereas their annual differences seem stationary. Indeed, using a Philips-Perron test of unit roots in the world oil price variable, the null hypothesis cannot be rejected. However, the null hypothesis is rejected ($p<0.001$) for the differenced variable. Likewise, using a Harris-Tzavalis test of unit roots in the panels, the null hypothesis cannot be rejected for neither log income nor log luminosity. However, for the differenced variables, the null hypothesis is rejected ($p<0.001$).

The identification of a causal effect of oil prices on income is potentially affected by omitted variable bias. Omitted variable bias occurs if correlates of both our main variable of interest and income are not controlled for. Our empirical strategy addresses this issue in two ways. First, we focus on the *interaction* between changes in log world oil prices and the proximity to the nearest oil field, limiting the scope of potential omitted variables. Second, we control for a range of potentially confounding factors that may be spuriously correlated with both the interaction term as well as the evolution of oil prices. In particular, we control for the prices of various commodities, all in levels as well as interacted with the proximity to the nearest oil field; and we also control for geographical characteristics that could be correlated with our measure of access to oil. Furthermore, we include dummy variables for each 5-year interval and interact these with the proximity to the nearest oil field, thereby accounting for all time-varying unobserved factors that are common to each 5-year interval. Analogously, we interact the latitude and longitude of each municipality with the world oil price, thereby accounting for general latitudinally or longitudinally related factors.

It is important to stress the necessity of clustering the standard errors at the yearly level, in addition to the locational level, for correct statistical inference. If we ignored the fact that the random variation is common to all observations within each year and did not cluster the standard errors on the yearly level, we would obtain overly anti-conservative standard errors (Cameron et al., 2011). As will be established, this has important implications for that part of the panel analysis that uses luminosity as the outcome variable. We therefore calculate two-way cluster-robust standard errors at the yearly level as well as at the location-specific level implemented in the *reghdfe* command for Stata (Correia, 2017a, 2017b). Given the moderate number of years, we also calculated two-way cluster-robust standard errors with the wild cluster bootstrap procedure implemented in the *boottest* command in Stata (Roodman et al., 2019 and MacKinnon et al., 2019) in robustness analyses. The two-way cluster-robust standard errors are not very sensitive to the choice of command.

4 Main results

4.1 Cross-sectional results

We first explore the data using a cross-sectional perspective. Table 1 presents simple OLS regressions, in which the dependent variable is income per capita over the studied period. It shows that locations that are closer to an oil field are associated with significantly higher income per capita. The table also shows that geography matters: being further from the coastal area or from the largest city, San Paulo, is detrimental for income per capita. Furthermore, larger population density is associated with higher income per capita. These observations make sense, as Brazil's coastal areas are indeed more economically developed, more urbanized, and contain larger populations than more distant areas. Moreover, we find that areas with higher elevation tend to be characterized by lower levels of income per capita. In addition, the table establishes a significant cross-sectional association between proximity to an oil field and log luminosity per capita while accounting for the set of control variables.

While the inclusion of the set of control variables tends to reduce the effect of oil access on income, proximity continues being highly significant even in the presence of these other variables capturing spatial aspects. All in all, this suggests that oil access has an independent effect on income. Yet, the findings also motivate our panel-setting 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 carry little information about the underlying causal relationships.

4.2 Panel-data estimation

Table 2 estimates models based on equations (1)–(3) using GDP per capita as the dependent variable. The coefficients of interest in these tables are those on the interaction terms between oil prices, the proximity to the nearest oil field, an oil rich state indicator. Column 1 establishes that greater proximity to an oil field is associated with a larger increase in income as oil prices increase. Since the unit of the proximity-variable is 10,000 km, and since the dependent and independent variables are changes in logged variables, the coefficient of 98.5 in the first column implies that for every 100 km greater proximity to an oil field, a 1% increase in the percentage-wise rise in oil prices are associated, approximately, with an additional 0.99% increase in the percentage-wide rise in income per capita.[20] Furthermore, the regression results in column 2 tell us that annual changes in international oil prices have a significantly larger positive effect on income per capita in cells located in oil rich, rather than oil poor, states. The estimated coefficient of 10.5 indicates that as the percentage-wise change in oil prices rise by 1%, the percentage-wise change in income per capita increases by about 10.5% more in oil rich states than in oil poor states, conditional on the proximity to the nearest oilfield. Moreover, column 3 establishes that the impact of proximity on the effect of oil prices is several times larger in oil rich states. These results are consistent with two possible underlying mechanisms: oil revenues directly affecting economic activity and windfall-related economic linkages fading with distance.

In column 4, we include the change in the log of the municipality-specific oil royalties in a specification that is analogous to the one from column 1. The column establishes a significant positive association between royalties and income per capita. Furthermore, the coefficient on the interaction between oil prices and proximity more than doubles in size.[21] In column 5, we include all three interaction terms with oil prices. The column establishes that all interaction terms with oil prices remain positive and significant.

Overall, the estimates suggest that the effect of yearly changes in oil prices have a significantly larger effect in (*i*) municipalities at greater proximity to an oil field, (*ii*) in oil rich states, and in (*iii*)

[20]This approximation holds when changes in oil prices are small.
[21]If the royalties' variable is excluded in the restricted sample, the coefficient on the interaction between oil prices and proximity is moderately higher than in column 3, i.e., 94.07 (p<0.001).

municipalities located closer to an oilfield within oil rich states, and that these effects are not mediated by changes in oil revenues.

Taken together, Table 2 suggests that the rise in income associated with increases in world oil prices is higher in municipalities that are located a greater proximity to oil fields or in oil rich states, and that the impact of proximity is enhanced within oil rich states. Furthermore, the table establishes that these effects are independent of the amount of royalties received.

As a next step, we investigate the effects of oil price changes on changes in nighttime light. Before we do that, we validate the use of nighttime light in Brazil as a proxy for economic activity. Table 3 presents regression coefficients between levels and changes in municipal GDP on the one hand and levels and change sin nighttime light on other hand. We use both untransformed and logarithmically transformed variables. As can be seen from the table, the measures are highly correlated; this is further illustrated in Figure 2 for the levels of both variables, overlaid with a kernel regression with confidence bands. The estimated cross-municipality elasticity between nighttime light and GDP, of some 0.15, is relatively low compared to the cross-country elasticity of between 0.20–0.30 in Henderson et al., 2012. All the coefficients are significantly positive. However, the adjusted R^2 of the differenced specifications is always below 1%, suggesting that the yearly variation in luminosity can explain little of the yearly variation in income. This finding indicates that changes in luminosity and changes in GDP capture different aspects of changes in economic activity.

The estimates using luminosity as the dependent variable are presented in Table 4. The coefficients all have the same signs as those in Table 2 (except for the interaction term in column 2). However, the estimates are smaller in size and are statistically insignificant when standard errors are properly clustered in two dimensions (within years and within municipalities) – as opposed to one-way clustering.[22]

Overall, the lack of robust significant associations between our oil prices variables and luminosity suggests several interpretations. For example, the effect of oil prices on income may not mediated by those elements of yearly changes in income that are reflected in changes in luminosity, such as infrastructure and manufacturing. Another possibility is that yearly changes in luminosity are simply too noisy to yield significant coefficients while accounting for the clustering of observations within years. The fact that the changes in royalties – a variable that theory strongly suggest should be associated with economic activity – are insignificant, corroborates this notion.

5 Robustness analyses and discussion

We carry out several different sets of robustness checks. We first address some measurement issues. We then explore our identified effect controlling for additional commodity prices that may be correlated with oil prices; and control for additional spatial characteristics, including those identified to have a bearing in the cross-sectional analysis in Table 1. Furthermore, we focus on certain sub-periods of

[22] We have also assessed the robustness of the findings with respect to the use of artificial borders of varying cell sizes (Appendix Table A.3). Furthermore, we have assessed the robustness with respect to the use of luminosity data that has not been adjusted for top-coding and found qualitatively the same conclusions.

the data; explore whether the findings are driven only by municipalities located close to oil fields; and conduct analysis for a sub-sample of areas near the border between oil rich and oil poor states.

5.1 Measurement

The issue of measurement concerns the definition of oil rich states. To test for the robustness of the results relating to the oil rich state division to alternative reasonable definitions of oil rich locations, we alternatively define Bahía and Rio Grande do Norte as oil rich. We exclude our three main oil rich states from the sample, since they should not be part of the comparison group. Column 1 of Table 5 establishes that the positive interaction effect of proximity is robust to the exclusion of the three main oil rich states from the regression sample. Furthermore, column 2 establishes that the interaction between oil prices and distance to the nearest oil field remains higher within these states compared to non-oil-rich states (column 2). We conclude that the interaction effect between proximity and location in an oil rich state is not sensitive to this change in the definition of the set of plausibly oil rich states.

5.2 Sub-periods

As a further robustness check, we split our sample into sub-periods. We first carry out our main analysis for the post-2002 period. This sub-period is particularly interesting because the 1997 reform of the oil sector that reorganized the distribution of oil revenues started being implemented a few years afterwards. Additionally, administrative reorganization that took place in the 1980-90s had ended by the early 2000s. Table 5 presents the results. The main variable of interest, the interaction between the change in oil prices and proximity to an oil field, remains highly significant in this sample. Furthermore, the interaction effect between oil prices and location in an oil rich state remains significant, while the triple interaction term remains positive but insignificant in this sample.

Further, the year 2007 seems to be important for the link between oil and economic development in Brazil, for two reasons. First, some major oil and gas field discoveries (in the so called "pre-salt layer") were made in 2007. Further, 2007 marks the increase in infrastructure investment in Brazil (Amann et al., 2016). To address both issues, we conduct the analysis for the post-2007 sample (Table 5, column 5-6). The main qualitative finding is, again, robust to this sample restriction, establishing that neither pre-salt oil discoveries nor the increase in infrastructure investment are driving forces behind the results.

5.3 Excluding cells adjacent to oil fields

We now replicate our baseline analysis while excluding municipalities near oil fields.[23] We thereby explore whether the results exist only within municipalities at great proximity to oil fields. Our results are presented in Table 5, columns 7 and 8. The estimates in column 7 establishes that the interaction effect between proximity and oil prices remains significant in this sample, implying that our findings are not driven by municipalities located at great proximity to an oil field. Furthermore, the estimates in column 8 establishes that, in this sample, the interaction effect of proximity exists mainly within oil

[23] This exclusion enables us to focus on localities that are more similar in terms of oil revenues receipts.

rich states: the coefficient on the main interaction term between oil prices and proximity to an oil field is insignificant while the triple interaction coefficient remains significant.

5.4 Controlling for commodity prices, exchange rates, and Petrobras stock prices

The specifications of Table 6 are robustness checks pertaining to our main finding of column 1 of Table 2. The robustness specifications account for a wide range of potentially confounding factors. First, the table accounts for additional main commodity prices in order to pursue alleviation of a potential concern that these prices, being correlated with oil prices, 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 proximity variable.

Comparing the estimates of Table 6 with that of Table 2, column 1, we observe that the qualitative conclusion does not change: the effect of oil price changes on income remains significantly higher at closer proximity to an oil field. In particular, in column 1, we account for the change in the log precious metals price index and its interaction with the proximity to the nearest oil field. The oil price interaction remains significant and the precious metals price index interaction is insignificant. In column 2, we account for the change in the log agricultural price index and its interaction. The oil price interaction remains significant. In column 3, we account for the change in a log energy price index and its interaction. Again, the oil price interaction coefficient remains significant and increases substantially in size, suggesting a more negative effect of rising energy prices near oil fields when controlling for the positive effect of oil prices on local income.[24]

We also explore the effect of controlling for Petrobras stock price, and include it as a control variable in a way that is analogous to the commodity prices. The sample is naturally restricted to those years for which Petrobras stock prices are known - it went public in mid-2000, and yearly stock prices are available from 2001. The results can be seen in column 4. The column establishes that the oil price effect remains positive and increases in magnitude.

In column 5, we control for five-year dummy variables interacted with the distance to the nearest oil field. Thus, this specification estimates the interaction effect between oil prices and proximity to the nearest oil field while accounting for all fixed period-specific distance-related effects. The estimates are robust to these additional controls.

In column 6, we measure world oil prices in Brazilian Reais. The results are robust and the effect of proximity increases in magnitude when measuring oil prices in the local currency.

5.5 Controlling for spatial characteristics

Table 6, columns 7–14, establish the robustness of the results to accounting for a range of spatial characteristics interacted with oil prices. When controlling for the distance to the coast; distance to San Paolo; population density and elevation (via interactions with oil price changes) the oil price and proximity-interaction remains rather stable and significant. When controlling for the interaction of initial income with oil price changes, as well as other spatial characteristics, the coefficient remains stable.

[24]We have also conducted similar analyses using other commodities' prices, with similar results.

Finally, to account for general latitudinal or longitudinal confounding effects, we interact oil prices with the latitude and the longitude of the centroid of each municipality. Bearing in mind that the coefficient on the main effect of oil prices can no longer be easily interpreted, the interaction effect between oil prices and the proximity to the nearest oil field remains highly significant and increases in magnitude.

We have also calculated alternative standard errors, primarily to address the potential issue of spatial autocorrelation (Table A.2 in the appendix). To do so, we applied the Conley procedure to control for serial (across all lags) and spatial (across all distances in Brazil) correlation.[25] The results, confirm that the main variables of interests continue to be significant despite increased standard errors.

5.6 Lagged, forwarded and long term effects

In Table 7, we explore the effects of backward and forward lagged oil price shocks. As established in columns 1 and 2, the lagged variables are all insignificant, while the current variables are all highly significant. This suggests that the windfall gains associated with increased oil prices are transitory.[26]

Since we would not expect unanticipated future oil price shocks to affect income, including forward oil price changes serves as a useful "placebo test". In particular, if we find significant associations between forward oil price shocks and current changes in income, it suggests that there may be a problem with our estimation strategy. However, all the forward lagged variables are insignificant, suggesting, in particular, that the oil price shocks exploited in the present analysis are unexpected.

In column 5 we estimate the baseline model using the Arellano-Bond difference GMM estimator. We find that the results are robust to this alternative specification.[27]

The table provides two main insights. First, it shows that neither lagged nor lead oil price changes interacted with proximity to the nearest oil field are associated with changes in income. In particular, the latter effect does not suggest a problem with our estimation strategy. Furthermore, the table establishes that our main finding is robust to accounting for the lagged changes in income.

5.7 Border analysis

One of our main results above has been that the change in international oil prices tends to increase income more in areas with better access to oil. However, inasmuch as we have controlled for various confounding factors, municipalities in oil rich 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. This is particularly an issue for identifying channels via which the effect of oil is manifested.

[25]We use to this end 5000 km as the distance cutoff.
[26]This is consistent with the lack of a robust association between oil prices and luminosity if luminosity mainly represents a sluggish infrastructure-related element of income per capita.
[27]An analogous specification including all three interaction terms yields a similar conclusion. In particular, the interaction terms involving the oil rich state dummy remain significant and the interaction term between oil prices and proximity to an oil field remains positive but insignificant. This indicates that the proximity-related effect is strongest within oil rich states.

We, therefore, now conduct a somewhat different type of analysis to lend cleaner 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 income. 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, income increases more in municipalities within the oil rich than within the oil poor states in the band. Because the municipalities 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 increasing the statistical precision. This would imply the necessity of broader bands. Consequently, as a resolution of this tradeoff, we define bandwidths by a distance of 100; 125; and 150 kilometers to the oil rich/oil poor state border of a municipality's centroid. In other words, a municipality 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. Depending on the bandwidth, this definition yields some 99-207 municipalities near the border.

The analysis, in Table 8, establishes that proximity to an oil field has a greater impact on the effect of oil prices in municipalities that are located in the oil-rich part of the band. This indicates that our findings of a differential effect of proximity in oil rich versus oil poor states are not driven by omitted spatial factors. Furthermore, the analysis establishes that municipalities on the oil rich side of the band may tend to be more affluent than those on the oil poor side, although this effect reaches statistical significance only at a significance level of 10% and only when using the 150 km or 125 km bands. Overall, however, the band analysis strongly corroborates the main findings and indicates that they are not driven by omitted spatial factors.

5.8 Discussion

While much of the above discussion has focused on issues related to statistical significance, we now revisit our findings from a broader perspective. Our most basic panel estimate of Table 2, column 1, suggests that for every 100 km distance to an oil field, the effect of a change in oil prices on a change in income is reduced by 0.99%-points.[28] This should be compared to the baseline effect predicted at

[28] It should be kept in mind that in distances are measured in 10,000 km.

an oil field, where a 1% increase in the percentage change in oil prices is associated with a 6.89% increase in the percentage change in GDP. This distance-related impact is substantial. It is important to realize that long run implications of oil price changes may, in principle, be very much different. For example, increases in oil revenues may result in more corruption (corruption scandals, including bribery at highest levels, involving the Petrobras and linked to the political echelon took place recently and in the time period covered by the paper), increased inequality, and political pressures for deregulations. Any of these factors may have long-run growth implications, potentially running counter to this paper's findings. In this regard, and since the resource curse is typically regarded as a long-run phenomenon, our results do not necessarily rule out its existence.

Additionally, even if changes in oil prices have a positive effect on long run incomes, other developmental outcomes may or may not change in the same direction. Thus, for example, increased pollution associated with oil explorations may have adverse health effects, and an increase in oil revenues may have negative distributional consequences. The bottom line is that welfare implications may be very different from purely material implications and future research may do well to consider those.[29]

6 Concluding remarks

This paper set out to explore the existence of a local resource curse in the context of Brazil's oil. To this end, we focus on municipal GDP per capita as well as municipal and cell-level nighttime light across Brazil as measures of local economic income and activity. We find that closer location to oil fields generates a greater positive effect of oil prices on local income per capita. Moreover, this positive impact of oilfield proximity on the effect of oil prices is enhanced in oil rich states. Importantly, these effects appear to be independent of the amount of oil royalties, suggesting the role of an indirect linkage effect. The effects are also robust to controlling for a wide range of potentially confounding time-varying factors interacted with proximity to oil field as well as spatial factors interacted with oil prices. Finally, the effects can be established in a small set of municipalities located in a narrow band around the border between oil rich and oil poor states.

We also establish that luminosity is highly correlated with measured income across municipalities in Brazil. Yet, there is little evidence that changes in oil prices affect changes in luminosity, suggesting that those aspects of economic activity that are captured by luminosity (presumably, mainly infrastructure and certain types of manufacturing) are more slow-moving and less affected by yearly shocks in oil prices.

We find support primarily for the oil revenues effect but also for an economic linkages effect, both working to enhance income in response to oil price increases. Our analysis of the border municipalities further confirms these findings. Beyond contributing to the debate of the existence of the resource curse, these 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.

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[29] Related work indicates that electrification induces improvement in human development indicators, suggesting that welfare effects could be positive overall, which is consistent with our results, see Bezzera et al., 2017.

Some qualifications to the interpretation of our results are in order. First, the paper addressees relatively short term implications of resource windfalls. To the extent that the resource curse question is a long term concern, more work is needed to address long term growth implications of our analysis. Second, the question addressed in this paper would benefit from future analyses of a broader array of outcomes in order to inform researchers as to additional economic and social effects oil price changes may possibly have. Third, and related to the above points, integration of the various effects of such changes in a full-fledged welfare analysis would be an ultimate goal for future research.

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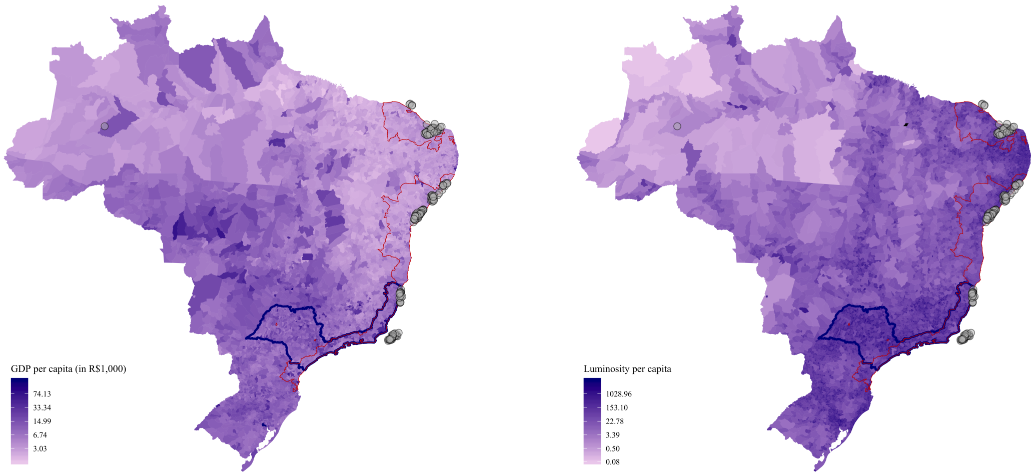


(a) Average GDP per capita (1999–2012)

(b) Average luminosity per capita (1992–2013)

Figure 1: GDP and luminosity across Brazilian municipalities. The blue line represents the outside border of the three oil rich states (Rio de Janeiro, Espírito Santo and São Paulo). The red line indicates the outside border of the revenue-receiving municipalities. The circles represent the location of oil fields.

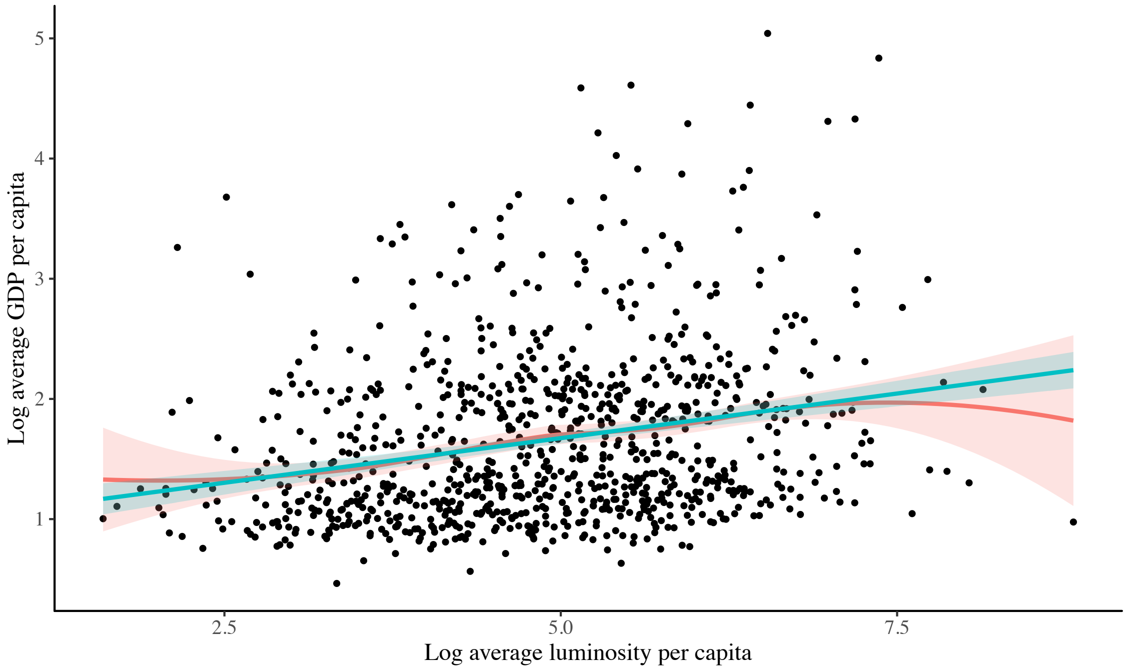
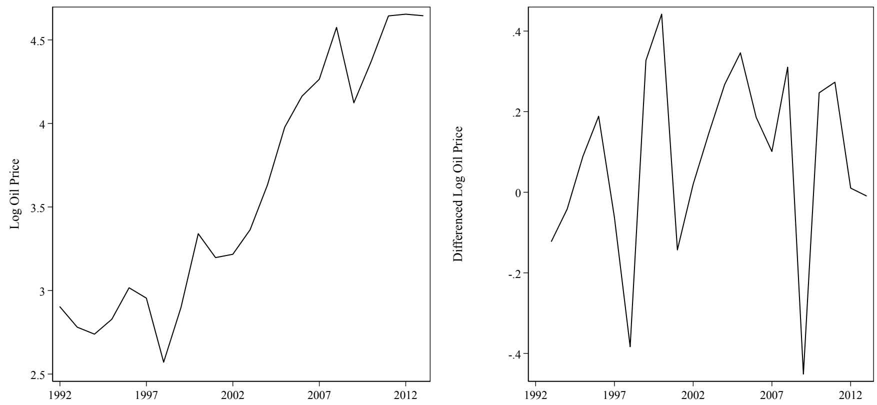
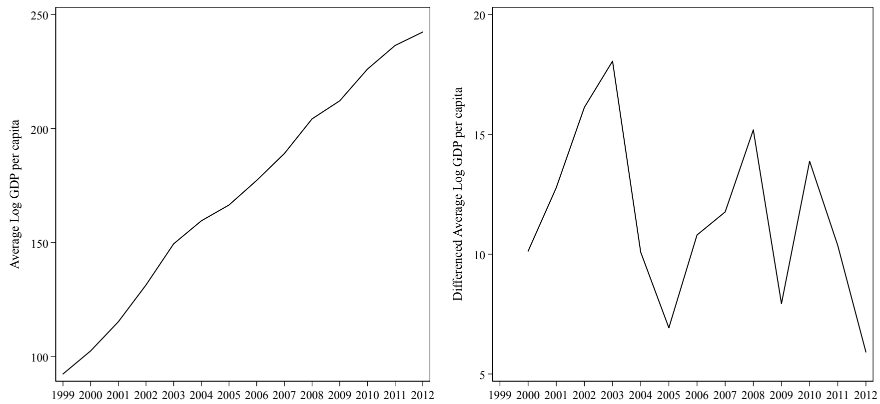


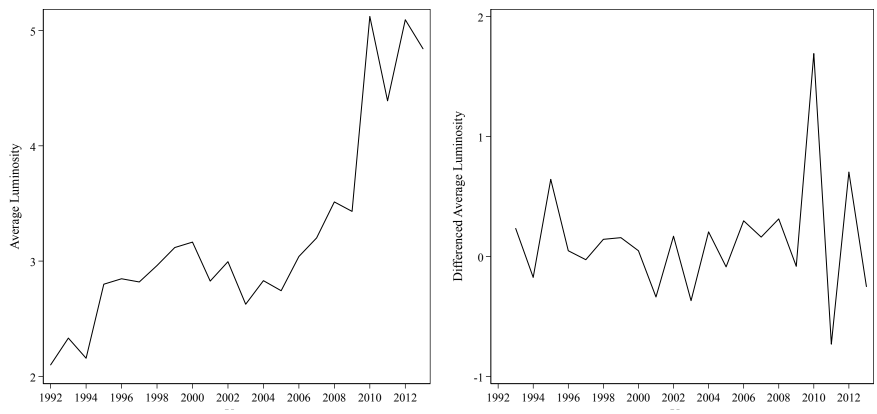
Figure 2: The cross-sectional association between GDP and luminosity across all municipalities in Brazil. The red line represents the locally estimated scatterplot smoothing with a span of 0.75. The blue line represents the fit of a cubic regression spline with three knots. The shaded areas represent the corresponding 95% confidence intervals.



(a) Levels and differences of world oil prices



(b) Levels and differences of log GDP per capita



(c) Levels and differences of luminosity

Figure A.1: Levels and differences in log world oil prices (1992–2013), municipal GDP per capita (1999–2012) and luminosity per capita (1992–2013).

Table 1: Cross-sectional analysis

	Log GDP per capita				Log luminosity per capita
	(1)	(2)	(3)	(4)	(5)
Proximity to oil field	10.8***	6.78**	8.26***	8.26***	19.0***
	(2.60)	(3.05)	(2.91)	(2.91)	(6.05)
Distance to coast		-22.1***	-13.9***	-13.9***	-45.1***
		(3.49)	(3.81)	(3.81)	(8.85)
Distance to San Paolo		-5.33***	-5.81***	-5.81***	4.24
		(1.53)	(1.45)	(1.45)	(3.29)
Elevation			-0.29***	-0.29***	0.33*
			(0.080)	(0.080)	(0.17)
Population density			0.066***	0.066***	0.068
			(0.024)	(0.024)	(0.043)
State FE	Yes	Yes	Yes	Yes	Yes
Number of observations	941	941	941	941	941

This table presents the results of a series of cross-sectional regression models of the average GDP per capita for the time period 1999–2012 on the proximity to the nearest oil field (measured in 10,000 km) and various control variables. The models account for state-specific fixed effects. The unit of observation is a municipality. 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 2: Panel analysis

	Δ Log GDP					
	(1)	(2)	(3)	(4)	(5)	(6)
Δ Log oil price × Proximity to oil field	98.5**	162.6***	72.7**	94.1***	147.0***	155.6***
	(34.5)	(32.5)	(26.3)	(22.7)	(37.3)	(28.2)
Δ Log oil price × Oil rich state		10.5**	19.5***			18.6***
		(3.94)	(5.38)			(5.37)
Δ Log oil price × Proximity to oil field × Oil rich state			322.0***			209.2**
			(83.7)			(74.0)
Δ Log oil price	6.89**	5.28*	3.76	7.28***	6.67***	3.50
	(2.36)	(2.74)	(2.80)	(1.99)	(1.97)	(2.57)
Δ Log royalties					2.05***	2.00***
					(0.40)	(0.34)
Number of observations	12,264	12,264	12,264	10,005	10,005	10,005

This table presents the results of a series of panel-data regression models of the differenced log GDP per capita for the time period 1999–2012 on the differenced log world oil price interacted with the proximity to the nearest oil field (measured in 10,000 km), an oil rich state indicator, and their interaction. The models account for municipality-specific fixed effects. The unit of observation is a municipality. Two-way cluster-robust standard errors, clustered at the levels of years and municipalities, are reported in parentheses. *** Significant at the 1 percent level. ** Significant at the 5 percent level. * Significant at the 10 percent level.

Table 3: GDP and luminosity

	Average GDP per capita		Log average GDP per capita		GDP per capita		Log GDP per capita		Δ GDP per capita		Δ Log GDP per capita	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Average luminosity per capita	0.0038**		0.00026**									
	(0.0019)		(0.00012)									
Log average luminosity per capita		1.69***		0.15***								
		(0.39)		(0.020)								
Luminosity					0.70***		4.90***					
					(0.072)		(0.29)					
Log luminosity						5.93***		70.7***				
						(0.62)		(1.34)				
Δ Luminosity									0.066***		0.068**	
									(0.017)		(0.029)	
Δ Log luminosity										0.54***		3.09***
										(0.075)		(0.36)
Model	Cross-sectional	Cross-sectional	Cross-sectional	Cross-sectional	Fixed effects	Fixed effects	Fixed effects	Fixed effects	Fixed effects	Fixed effects	Fixed effects	Fixed effects
Number of observations	941	941	941	941	13,118	13,116	13,118	13,116	12,172	12,169	12,172	12,169

This table presents the results of a series of cross-sectional and panel-data regression models of GDP per capita for the time period 1999–2012 on luminosity over the same time period. 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 using luminosity as measure of economic activity

	Δ Log luminosity					
	(1)	(2)	(3)	(4)	(5)	(6)
Δ Log oil price × Proximity to oil field	1.42***	1.41***	1.38***	1.38	0.77*	0.77
	(0.30)	(0.32)	(0.38)	(1.75)	(0.39)	(2.74)
Δ Log oil price × Oil rich state		-0.00061	0.0025	0.0025	0.042	0.042
		(0.013)	(0.022)	(0.16)	(0.030)	(0.21)
Δ Log oil price × Proximity to oil field × Oil rich state			0.11	0.11	1.52	1.52
			(0.68)	(2.78)	(0.94)	(3.84)
Δ Log oil price	0.017**	0.017*	0.017*	0.017	0.14***	0.14
	(0.0087)	(0.0091)	(0.0097)	(0.22)	(0.012)	(0.28)
Δ Log royalties					0.0088**	0.0088
					(0.0041)	(0.027)
Clustering of standard errors	One-way	One-way	One-way	Two-way	One-way	Two-way
Number of observations	19,662	19,662	19,662	19,662	9,917	9,917

This table presents the results of a series of panel-data regression models of the differenced log luminosity per capita for the time period 1999–2012 on the differenced log world oil price interacted with the proximity to the nearest oil field (measured in 10,000 km), an oil rich state indicator, and their interaction. The models account for municipality-specific fixed effects. The unit of observation is a municipality. One-way and two-way cluster-robust standard errors, clustered at the level of municipalities or municipalities and years, 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: robustness

	Δ Log GDP							
	Alternative oil rich definition		After 2002		After 2007		100km from field	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
ΔLog oil price × Proximity to oil field	164.7***	139.4**	183.7***	182.2***	192.8**	196.2**	91.3**	31.6
	(38.8)	(51.9)	(28.9)	(36.2)	(52.5)	(48.9)	(39.5)	(35.2)
ΔLog oil price × Oil rich state (alternative definition)		-0.36						
		(5.01)						
ΔLog oil price × Proximity to oil field × Oil rich state (alternative definition)		428.5**						
		(188.8)						
ΔLog oil price × Oil rich state				12.5**		14.4**		20.1***
				(5.19)		(4.84)		(4.85)
ΔLog oil price × Proximity to oil field × Oil rich state				157.4		170.4		252.7**
				(95.7)		(100.9)		(96.1)
ΔLog oil price	3.48	6.50	9.71***	7.57**	9.75**	7.41*	4.43*	-1.84
	(2.58)	(4.02)	(2.02)	(2.69)	(2.24)	(2.78)	(2.40)	(2.64)
ΔLog royalties	2.22***	1.91***	1.83***	1.78***	1.65*	1.47*	1.83***	1.70***
	(0.50)	(0.51)	(0.32)	(0.31)	(0.71)	(0.59)	(0.47)	(0.45)
Number of observations	7,212	7,212	7,840	7,840	4,121	4,121	5,754	5,754

This table presents the results of a series of panel-data regression models of the differenced log GDP per capita for the time period 1999–2012 on the differenced log world oil price interacted with the proximity to the nearest oil field (measured in 10,000 km), an oil rich state indicator, and their interaction. The models account for municipality-specific fixed effects. The unit of observation is a municipality. Two-way cluster-robust standard errors, clustered at the levels of years and municipalities, 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: controls

	Δ Log GDP													
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
Δ Log oil price × Proximity to oil field	92.2**	57.5**	529.4**	128.4**	101.5**		100.1**	163.9***	100.6***	102.0**	104.5**	107.6***	198.0***	477.7***
	(36.7)	(22.2)	(231.7)	(52.3)	(37.4)		(34.4)	(41.1)	(32.8)	(34.0)	(35.4)	(33.0)	(39.1)	(130.9)
Δ Log oil prices in Brazilian Reais × Proximity to oil field						114.7**								
						(47.5)								
Δ Log precious metals price index × Proximity to oil field	171.9													
	(120.9)													
Δ Log agricultural price index × Proximity to oil field		320.5**												
		(107.3)												
Δ Log energy price index × Proximity to oil field			-486.1*											
			(239.9)											
Δ Log Petrobras stock price × Proximity to oil field				-11.9										
				(25.1)										
Δ Log oil price × Distance to coast							-396.5***							
							(90.0)							
Δ Log oil price × Distance to San Paolo								-29.3						
								(21.1)						
Δ Log oil price × Elevation									0.34					
									(4.40)					
Δ Log oil price × Distance to main road (in 10.000 kms)										2702.2				
										(2184.2)				
Δ Log oil price × Distance to railroad (in 10.000 kms)											-765.8***			
											(186.3)			
Δ Log oil price × Population density												0.81*		
												(0.38)		
Δ Log oil price × initiallgdppc													8.90***	
													(1.44)	
Δ Log oil price × Latitude														0.070
														(0.23)
Δ Log oil price × Longitude														-2.79**
														(1.05)
Δ Log oil price	6.47**	3.58*	20.7**	7.65***	7.02**		9.86***	12.2***	6.81**	5.68*	9.58***	6.84**	2.10	-97.0**
	(2.40)	(2.00)	(8.40)	(1.84)	(2.52)		(2.30)	(2.95)	(3.02)	(2.75)	(2.63)	(2.37)	(2.55)	(38.6)
Δ Log oil prices in Brazilian Reais						8.27**								
						(3.04)								
Δ Log precious metals price index	Yes	No	No	No	No	No	No	No	No	No	No	No	No	No
Δ Log agricultural price index	No	Yes	No	No	No	No	No	No	No	No	No	No	No	No
Δ Log energy price index	No	No	Yes	No	No	No	No	No	No	No	No	No	No	No
Δ Log Petrobras stock price	No	No	No	Yes	No	No	No	No	No	No	No	No	No	No
Δ Log oil price × 5-year period indicators	No	No	No	No	Yes	No	No	No	No	No	No	No	No	No
Number of observations	12,264	12,264	12,264	11,324	12,264	12,264	12,264	12,264	12,264	12,264	12,264	12,264	12,220	12,264

This table presents the results of a series of panel-data regression models of the differenced log GDP per capita for the time period 1999–2012 on the differenced log world oil price interacted with the proximity to the nearest oil field (measured in 10,000 km), an oil rich state indicator, and their interaction. The models account for municipality-specific fixed effects. The unit of observation is a municipality. Two-way cluster-robust standard errors, clustered at the levels of years and municipalities, 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: lagged and forwarded oil prices

	Δ Log GDP				
	(1)	(2)	(3)	(4)	(5)
Δ Log oil price × Proximity to oil field	107.3***	85.9**	79.8***	49.2*	110.3***
	(32.3)	(30.5)	(25.5)	(26.2)	(31.6)
Δ Log oil price × Oil rich state		21.2***		21.5***	
		(5.49)		(6.28)	
Δ Log oil price × Proximity to oil field × Oil rich state		315.1***		339.4***	
		(86.4)		(84.6)	
Δ Log oil price	6.15***	2.47	7.64***	3.92	9.02***
	(1.77)	(2.45)	(1.95)	(2.66)	(1.07)
Lagged Δ Log oil price × Proximity to oil field	90.8	104.9			
	(56.1)	(88.7)			
Lagged Δ Log oil price × Oil rich state		2.75			
		(5.45)			
Lagged Δ Log oil price × Proximity to oil field × Oil rich state		11.4			
		(124.9)			
Lagged Δ Log oil price	-5.09*	-5.53			
	(2.85)	(3.49)			
Forward lagged Δ Log oil price × Proximity to oil field			-52.4	-89.7	
			(37.1)	(54.9)	
Forward lagged Δ Log oil price × Oil rich state				4.11	
				(5.20)	
Forward lagged Δ Log oil price × Proximity to oil field × Oil rich state				139.5	
				(91.6)	
Forward lagged Δ Log oil price			0.95	0.21	
			(2.14)	(2.66)	
Lagged Δ Log GDP per cap.					-0.11***
					(0.022)
Number of observations	10,311	10,311	10,311	10,311	8,811

This table presents the results of a series of panel-data regression models (using OLS in columns 1–4 and the Arellano-Bond difference GMM estimator in column 5) of the differenced log GDP per capita for the time period 1999–2012 on the differenced log world oil price interacted with the proximity to the nearest oil field (measured in 10,000 km), an oil rich state indicator, and their interaction. The models account for municipality-specific fixed effects. The unit of observation is a municipality. Two-way cluster-robust standard errors, clustered at the levels of years and municipalities, 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: narrow band around border between oil-rich and non-oil-rich states

	Δ Log GDP		
	Max 150 km	Max 125 km	Max 100 km
	(1)	(2)	(3)
Δ Log oil price × Proximity to oil field × Oil rich state	397.9***	372.8**	346.7**
	(119.2)	(133.5)	(159.0)
Δ Log oil price × Oil rich state	23.7*	24.5*	21.5
	(11.2)	(12.2)	(14.3)
Δ Log oil price × Proximity to oil field	-8.53	18.5	17.4
	(43.2)	(39.0)	(69.7)
Δ Log oil price	3.25	3.56	3.12
	(3.66)	(4.46)	(6.57)
Number of observations	2,689	1,846	1,287

This table presents the results of a series of panel-data regression models of the differenced log GDP per capita for the time period 1999–2012 on the differenced log world oil price interacted with the proximity to the nearest oil field (measured in 10,000 km), an oil rich state indicator, and their interaction. The models account for municipality-specific fixed effects. The unit of observation is a municipality. Two-way cluster-robust standard errors, clustered at the levels of years and municipalities, are reported in parentheses. *** Significant at the 1 percent level. ** Significant at the 5 percent level. * Significant at the 10 percent level.

Table A.1: Descriptive statistics

	Mean	S.D.	10th percentile	90th percentile	Known #
Non-oil-rich sample					
Log GDP per capita	128.46	73.84	40.7	217.0	9,460
Log luminosity	0.63	1.30	-0.96	2.29	9,458
Log royalties	9.91	2.48	6.72	14.0	7,997
Δ Log GDP per capita	11.52	12.14	-0.21	23.4	8,784
Δ Log luminosity	0.23	2.20	-0.90	1.44	8,784
Δ Log royalties	0.16	0.71	-0.30	0.71	7,262
Distance to nearest oil field (in km)	168.53	215.94	14.9	302.5	9,460
Distance to coast (in km)	83.60	66.23	10.6	184.3	9,460
Distance to coast (in km)	1691.88	536.97	1098.1	2302.0	9,460
Distance to main road (in km)	4.47	2.84	1.51	8.20	9,460
Distance to railroad (in km)	38.05	40.12	4.67	87.0	9,460
Population density	0.11	0.43	0.016	0.15	9,460
Elevation	0.28	0.21	0.051	0.54	9,460
Oil-rich sample					
Log GDP per capita	219.23	76.98	133.5	321.4	3,748
Log luminosity	1.90	1.54	0.046	4.21	3,658
Log royalties	12.56	3.42	8.54	16.4	3,102
Δ Log GDP per capita	11.06	14.52	-1.73	24.0	3,480
Δ Log luminosity	0.45	4.33	-2.56	4.12	3,388
Δ Log royalties	0.38	0.89	-0.22	0.93	2,827
Distance to nearest oil field (in km)	322.44	213.59	88.1	621.2	3,748
Distance to coast (in km)	49.73	41.00	7.37	94.6	3,748
Distance to coast (in km)	387.60	270.88	33.9	771.8	3,748
Distance to main road (in km)	5.59	3.77	1.95	11.0	3,748
Distance to railroad (in km)	21.56	24.49	2.90	59.5	3,748
Population density	0.80	2.08	0.020	2.03	3,748
Elevation	0.58	0.36	0.11	1.02	3,748
Total sample					
Log GDP per capita	154.22	85.21	50.2	262.5	13,208
Log luminosity	0.98	1.49	-0.81	3.06	13,116
Log royalties	10.66	3.02	6.74	15.3	11,099
Δ Log GDP per capita	11.39	12.86	-0.66	23.5	12,264
Δ Log luminosity	0.30	2.95	-1.17	2.03	12,172
Δ Log royalties	0.22	0.77	-0.29	0.74	10,089
Distance to nearest oil field (in km)	212.20	226.18	22.1	578.3	13,208
Distance to coast (in km)	73.98	62.06	10.0	165.4	13,208
Distance to coast (in km)	1321.77	757.03	208.6	2277.7	13,208
Distance to main road (in km)	4.79	3.18	1.63	8.65	13,208
Distance to railroad (in km)	33.37	37.12	3.99	79.0	13,208
Population density	0.31	1.21	0.016	0.33	13,208
Elevation	0.37	0.29	0.062	0.82	13,208

Table A.2: Panel analysis: standard errors allowing for spatial and temporal correlation

	Δ Log GDP				
	(1)	(2)	(3)	(4)	(5)
Δ Log oil price × Proximity to oil field	98.4***	162.5***	72.6	139.8***	142.3***
	(36.4)	(47.4)	(51.1)	(36.4)	(49.4)
Δ Log oil price × Oil rich state		10.5***	19.5***		18.8***
		(3.76)	(4.90)		(4.84)
Δ Log oil price × Proximity to oil field × Oil rich state			321.8***		225.1***
			(89.5)		(79.8)
Δ Log royalties				1.88***	1.81***
				(0.40)	(0.36)
Number of observations	12,264	12,264	12,264	10,089	10,089

This table presents the results of a series of panel-data regression models of the differenced log GDP per capita for the time period 1999–2012 on the differenced log world oil price interacted with the proximity to the nearest oil field (measured in 10,000 km), an oil rich state indicator, and their interaction. The models account for municipality-specific fixed effects. The unit of observation is a municipality. Standard errors that are robust to spatial and temporal autocorrelation are reported in parentheses. We allow for spatial clustering across 5,000 kms and temporal clustering across any number of lags. *** Significant at the 1 percent level. ** Significant at the 5 percent level. * Significant at the 10 percent level.

Table A.3: Panel analysis using luminosity obtained from artificial grids of high and very high resolutions

	Δ Log luminosity											
	High resolution						Very high resolution					
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Δ Log oil price × Proximity to oil field	1.14***	1.36***	0.71	0.71	0.87	0.87	1.80***	2.30***	1.73***	1.73	1.44***	1.44
	(0.43)	(0.43)	(0.49)	(2.13)	(0.76)	(3.54)	(0.27)	(0.28)	(0.32)	(2.33)	(0.50)	(3.55)
Δ Log oil price × Oil rich state		0.067***	0.13***	0.13	0.14***	0.14		0.12***	0.17***	0.17	0.21***	0.21
		(0.020)	(0.034)	(0.19)	(0.043)	(0.24)		(0.014)	(0.023)	(0.21)	(0.031)	(0.26)
Δ Log oil price × Proximity to oil field × Oil rich state			2.37**	2.37	2.46*	2.46			1.95***	1.95	3.41***	3.41
			(1.02)	(3.50)	(1.33)	(5.29)			(0.63)	(4.68)	(0.97)	(6.20)
Δ Log oil price	0.019	0.0048	-0.0078	-0.0078	0.15***	0.15	0.088***	0.060***	0.049***	0.049	0.22***	0.22
	(0.015)	(0.016)	(0.017)	(0.24)	(0.021)	(0.29)	(0.0093)	(0.0100)	(0.011)	(0.25)	(0.015)	(0.31)
Δ Log royalties					0.024***	0.024					0.012***	0.012
					(0.0050)	(0.036)					(0.0033)	(0.035)
Clustering of standard errors	One-way	One-way	One-way	Two-way	One-way	Two-way	One-way	One-way	One-way	Two-way	One-way	Two-way
Number of observations	25,730	25,730	25,730	25,730	12,935	12,935	124,966	124,966	124,966	124,966	65,518	65,518

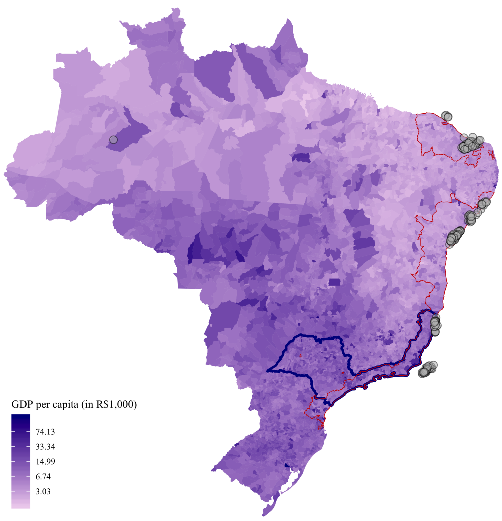
This table presents the results of a series of panel-data regression models of the differenced log luminosity per capita for the time period 1999–2012 on the differenced log world oil price interacted with the proximity to the nearest oil field (measured in 10,000 km), an oil rich state indicator, and their interaction. The models account for cell-specific fixed effects. The unit of observation is a cell. One-way and two-way cluster-robust standard errors, clustered at the level of cells or cells and years, are reported in parentheses. *** Significant at the 1 percent level. ** Significant at the 5 percent level. * Significant at the 10 percent level.

Not for publication

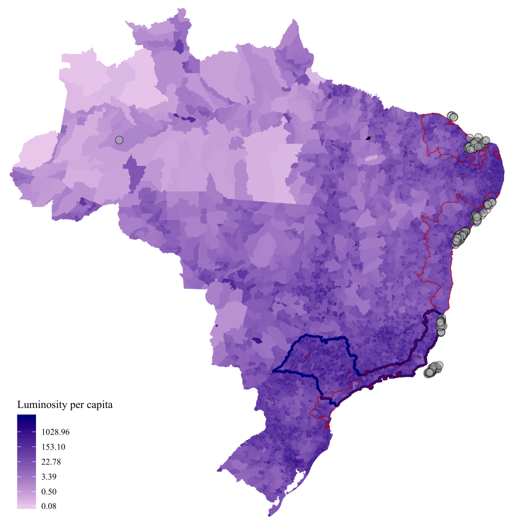
Table B.1: Panel analysis: controls (all coefficients reported)

	Δ Log GDP													
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
Δ Log oil price × Proximity to oil field	92.2**	57.5**	529.4**	128.4**	101.5**		100.1**	163.9***	100.6***	102.0**	104.5**	107.6***	198.0***	477.7***
	(36.7)	(22.2)	(231.7)	(52.3)	(37.4)		(34.4)	(41.1)	(32.8)	(34.0)	(35.4)	(33.0)	(39.1)	(130.9)
Δ Log oil prices in Brazilian Reais × Proximity to oil field						114.7**								
						(47.5)								
Δ Log precious metals price index × Proximity to oil field	171.9													
	(120.9)													
Δ Log agricultural price index × Proximity to oil field		320.5**												
		(107.3)												
Δ Log energy price index × Proximity to oil field			-486.1*											
			(239.9)											
Δ Log Petrobras stock price × Proximity to oil field				-11.9										
				(25.1)										
Five-year period: 2005 to 2009 × Proximity to oil field					16.3									
					(26.4)									
Five-year period: 2010 to 2012 × Proximity to oil field					7.53									
					(37.2)									
Δ Log oil price × Distance to coast							-396.5***							
							(90.0)							
Δ Log oil price × Distance to San Paolo								-29.3						
								(21.1)						
Δ Log oil price × Elevation									0.34					
									(4.40)					
Δ Log oil price × Distance to main road (in 10.000 kms)										2702.2				
										(2184.2)				
Δ Log oil price × Distance to railroad (in 10.000 kms)											-765.8***			
											(186.3)			
Δ Log oil price × Population density												0.81*		
												(0.38)		
Δ Log oil price × initiallgdppc													8.90***	
													(1.44)	
Δ Log oil price × Latitude														0.070
														(0.23)
Δ Log oil price × Longitude														-2.79**
														(1.05)
Δ Log oil price	6.47**	3.58*	20.7**	7.65***	7.02**		9.86***	12.2***	6.81**	5.68*	9.58***	6.84**	2.10	-97.0**
	(2.40)	(2.00)	(8.40)	(1.84)	(2.52)		(2.30)	(2.95)	(3.02)	(2.75)	(2.63)	(2.37)	(2.55)	(38.6)
Δ Log oil prices in Brazilian Reais						8.27**								
						(3.04)								
Δ Log precious metals price index	11.7**													
	(5.13)													
Δ Log agricultural price index		25.9**												
		(9.97)												
Δ Log energy price index			-15.5											
			(9.24)											
Δ Log Petrobras stock price				0.68										
				(1.03)										
Five-year period: 2000 to 2004					1.88									
					(2.06)									
Five-year period: 2005 to 2009					1.04									
					(1.74)									
Number of observations	12,264	12,264	12,264	11,324	12,264	12,264	12,264	12,264	12,264	12,264	12,264	12,264	12,220	12,264

This table presents the results of a series of panel-data regression models of the differenced log GDP per capita for the time period 1999–2012 on the differenced log world oil price interacted with the proximity to the nearest oil field (measured in 10,000 km), an oil rich state indicator, and their interaction. The models account for municipality-specific fixed effects. The unit of observation is a municipality. Two-way cluster-robust standard errors, clustered at the levels of years and municipalities, are reported in parentheses. *** Significant at the 1 percent level. ** Significant at the 5 percent level. * Significant at the 10 percent level.



(a) Average GDP per capita (1999–2012)



(b) Average luminosity per capita (1992–2013)

Figure 1: GDP and luminosity across Brazilian municipalities. The blue line represents the outside border of the three oil rich states (Rio de Janeiro, Espírito Santo and São Paulo). The red line indicates the outside border of the revenue-receiving municipalities. The circles represent the location of oil fields.

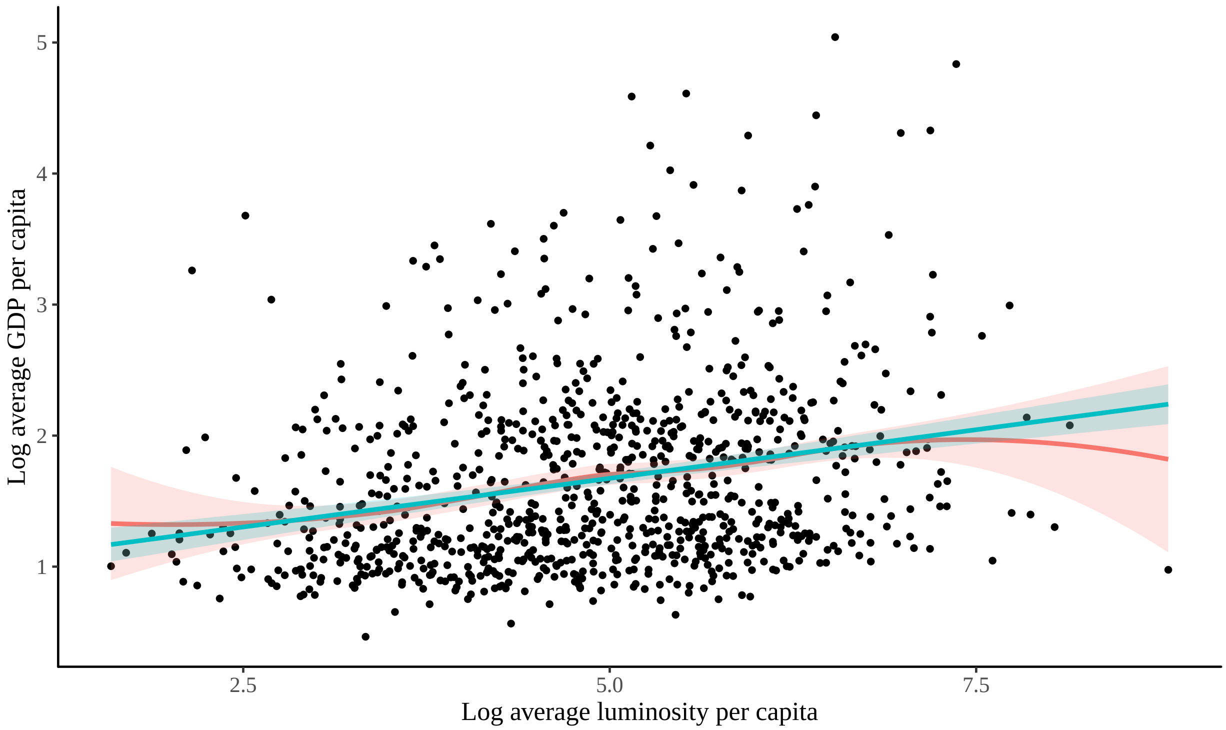
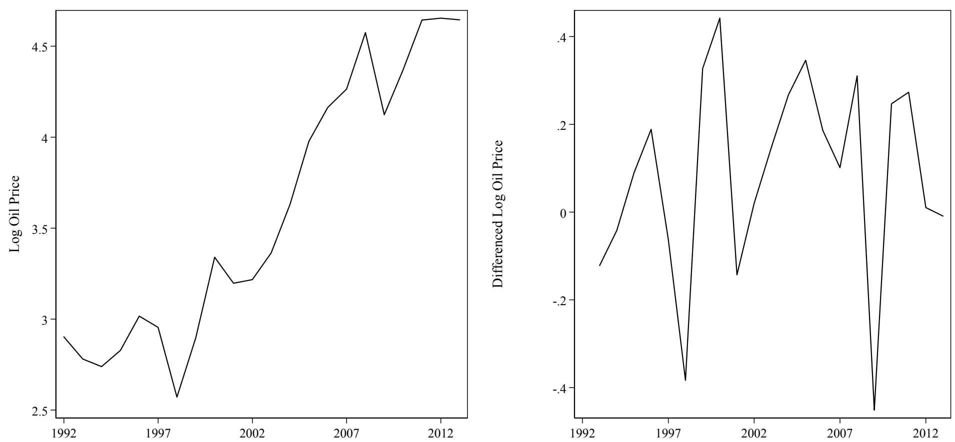
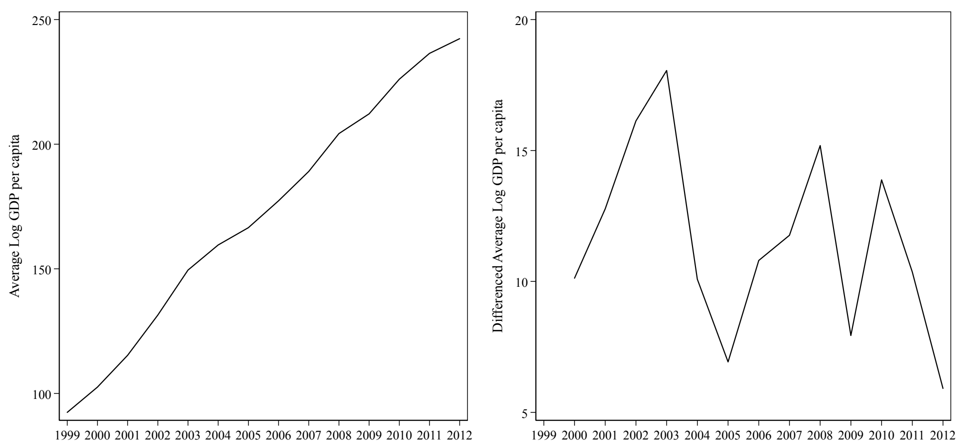


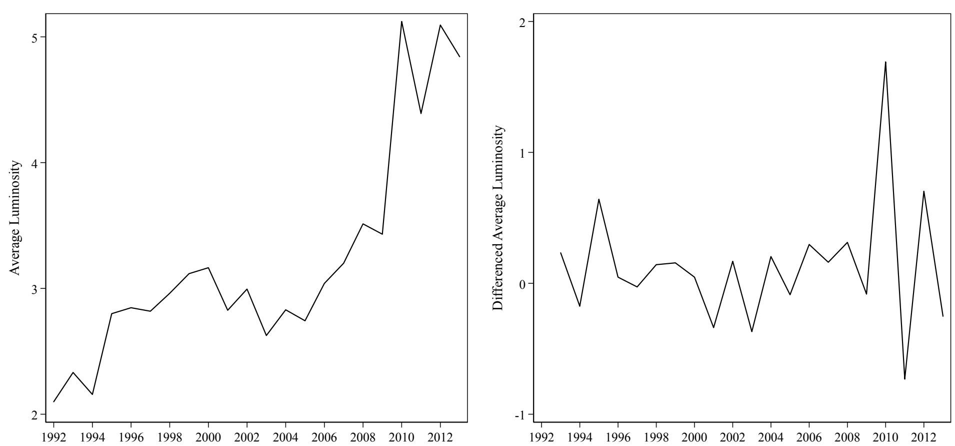
Figure 2: The cross-sectional association between GDP and luminosity across all municipalities in Brazil. The red line represents the locally estimated scatterplot smoothing with a span of 0.75. The blue line represents the fit of a cubic regression spline with three knots. The shaded areas represent the corresponding 95% confidence intervals.



(a) Levels and differences of world oil prices



(b) Levels and differences of log GDP per capita



(c) Levels and differences of luminosity

Figure A.1: Levels and differences in log world oil prices (1992–2013), municipal GDP per capita (1999–2012) and luminosity per capita (1992–2013).

Table 1: Cross-sectional analysis

	Log GDP per capita				Log luminosity per capita
	(1)	(2)	(3)	(4)	(5)
Proximity to oil field	10.8***	6.78**	8.26***	8.26***	19.0***
	(2.60)	(3.05)	(2.91)	(2.91)	(6.05)
Distance to coast		-22.1***	-13.9***	-13.9***	-45.1***
		(3.49)	(3.81)	(3.81)	(8.85)
Distance to San Paolo		-5.33***	-5.81***	-5.81***	4.24
		(1.53)	(1.45)	(1.45)	(3.29)
Elevation			-0.29***	-0.29***	0.33*
			(0.080)	(0.080)	(0.17)
Population density			0.066***	0.066***	0.068
			(0.024)	(0.024)	(0.043)
State FE	Yes	Yes	Yes	Yes	Yes
Number of observations	941	941	941	941	941

This table presents the results of a series of cross-sectional regression models of the average GDP per capita for the time period 1999–2012 on the proximity to the nearest oil field (measured in 10,000 km) and various control variables. The models account for state-specific fixed effects. The unit of observation is a municipality. 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 2: Panel analysis

	Δ Log GDP					
	(1)	(2)	(3)	(4)	(5)	(6)
Δ Log oil price × Proximity to oil field	98.5**	162.6***	72.7**	94.1***	147.0***	155.6***
	(34.5)	(32.5)	(26.3)	(22.7)	(37.3)	(28.2)
Δ Log oil price × Oil rich state		10.5**	19.5***			18.6***
		(3.94)	(5.38)			(5.37)
Δ Log oil price × Proximity to oil field × Oil rich state			322.0***			209.2**
			(83.7)			(74.0)
Δ Log oil price	6.89**	5.28*	3.76	7.28***	6.67***	3.50
	(2.36)	(2.74)	(2.80)	(1.99)	(1.97)	(2.57)
Δ Log royalties					2.05***	2.00***
					(0.40)	(0.34)
Number of observations	12,264	12,264	12,264	10,005	10,005	10,005

This table presents the results of a series of panel-data regression models of the differenced log GDP per capita for the time period 1999–2012 on the differenced log world oil price interacted with the proximity to the nearest oil field (measured in 10,000 km), an oil rich state indicator, and their interaction. The models account for municipality-specific fixed effects. The unit of observation is a municipality. Two-way cluster-robust standard errors, clustered at the levels of years and municipalities, are reported in parentheses. *** Significant at the 1 percent level. ** Significant at the 5 percent level. * Significant at the 10 percent level.

Table 3: GDP and luminosity

	Average GDP per capita		Log average GDP per capita		GDP per capita		Log GDP per capita		Δ GDP per capita		Δ Log GDP per capita	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Average luminosity per capita	0.0038**		0.00026**									
	(0.0019)		(0.00012)									
Log average luminosity per capita		1.69***		0.15***								
		(0.39)		(0.020)								
Luminosity					0.70***		4.90***					
					(0.072)		(0.29)					
Log luminosity						5.93***		70.7***				
						(0.62)		(1.34)				
Δ Luminosity									0.066***		0.068**	
									(0.017)		(0.029)	
Δ Log luminosity										0.54***		3.09***
										(0.075)		(0.36)
Model	Cross-sectional	Cross-sectional	Cross-sectional	Cross-sectional	Fixed effects	Fixed effects	Fixed effects	Fixed effects	Fixed effects	Fixed effects	Fixed effects	Fixed effects
Number of observations	941	941	941	941	13,118	13,116	13,118	13,116	12,172	12,169	12,172	12,169

This table presents the results of a series of cross-sectional and panel-data regression models of GDP per capita for the time period 1999–2012 on luminosity over the same time period. 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 using luminosity as measure of economic activity

	Δ Log luminosity					
	(1)	(2)	(3)	(4)	(5)	(6)
Δ Log oil price × Proximity to oil field	1.42***	1.41***	1.38***	1.38	0.77*	0.77
	(0.30)	(0.32)	(0.38)	(1.75)	(0.39)	(2.74)
Δ Log oil price × Oil rich state		-0.00061	0.0025	0.0025	0.042	0.042
		(0.013)	(0.022)	(0.16)	(0.030)	(0.21)
Δ Log oil price × Proximity to oil field × Oil rich state			0.11	0.11	1.52	1.52
			(0.68)	(2.78)	(0.94)	(3.84)
Δ Log oil price	0.017**	0.017*	0.017*	0.017	0.14***	0.14
	(0.0087)	(0.0091)	(0.0097)	(0.22)	(0.012)	(0.28)
Δ Log royalties					0.0088**	0.0088
					(0.0041)	(0.027)
Clustering of standard errors	One-way	One-way	One-way	Two-way	One-way	Two-way
Number of observations	19,662	19,662	19,662	19,662	9,917	9,917

This table presents the results of a series of panel-data regression models of the differenced log luminosity per capita for the time period 1999–2012 on the differenced log world oil price interacted with the proximity to the nearest oil field (measured in 10,000 km), an oil rich state indicator, and their interaction. The models account for municipality-specific fixed effects. The unit of observation is a municipality. One-way and two-way cluster-robust standard errors, clustered at the level of municipalities or municipalities and years, 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: robustness

	Δ Log GDP							
	Alternative oil rich definition		After 2002		After 2007		100km from field	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
ΔLog oil price × Proximity to oil field	164.7***	139.4**	183.7***	182.2***	192.8**	196.2**	91.3**	31.6
	(38.8)	(51.9)	(28.9)	(36.2)	(52.5)	(48.9)	(39.5)	(35.2)
ΔLog oil price × Oil rich state (alternative definition)		-0.36						
		(5.01)						
ΔLog oil price × Proximity to oil field × Oil rich state (alternative definition)		428.5**						
		(188.8)						
ΔLog oil price × Oil rich state				12.5**		14.4**		20.1***
				(5.19)		(4.84)		(4.85)
ΔLog oil price × Proximity to oil field × Oil rich state				157.4		170.4		252.7**
				(95.7)		(100.9)		(96.1)
ΔLog oil price	3.48	6.50	9.71***	7.57**	9.75**	7.41*	4.43*	-1.84
	(2.58)	(4.02)	(2.02)	(2.69)	(2.24)	(2.78)	(2.40)	(2.64)
ΔLog royalties	2.22***	1.91***	1.83***	1.78***	1.65*	1.47*	1.83***	1.70***
	(0.50)	(0.51)	(0.32)	(0.31)	(0.71)	(0.59)	(0.47)	(0.45)
Number of observations	7,212	7,212	7,840	7,840	4,121	4,121	5,754	5,754

This table presents the results of a series of panel-data regression models of the differenced log GDP per capita for the time period 1999–2012 on the differenced log world oil price interacted with the proximity to the nearest oil field (measured in 10,000 km), an oil rich state indicator, and their interaction. The models account for municipality-specific fixed effects. The unit of observation is a municipality. Two-way cluster-robust standard errors, clustered at the levels of years and municipalities, 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: controls

	Δ Log GDP													
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
Δ Log oil price × Proximity to oil field	92.2**	57.5**	529.4**	128.4**	101.5**		100.1**	163.9***	100.6***	102.0**	104.5**	107.6***	198.0***	477.7***
	(36.7)	(22.2)	(231.7)	(52.3)	(37.4)		(34.4)	(41.1)	(32.8)	(34.0)	(35.4)	(33.0)	(39.1)	(130.9)
Δ Log oil prices in Brazilian Reais × Proximity to oil field						114.7**								
						(47.5)								
Δ Log precious metals price index × Proximity to oil field	171.9													
	(120.9)													
Δ Log agricultural price index × Proximity to oil field		320.5**												
		(107.3)												
Δ Log energy price index × Proximity to oil field			-486.1*											
			(239.9)											
Δ Log Petrobras stock price × Proximity to oil field				-11.9										
				(25.1)										
Δ Log oil price × Distance to coast							-396.5***							
							(90.0)							
Δ Log oil price × Distance to San Paolo								-29.3						
								(21.1)						
Δ Log oil price × Elevation									0.34					
									(4.40)					
Δ Log oil price × Distance to main road (in 10.000 kms)										2702.2				
										(2184.2)				
Δ Log oil price × Distance to railroad (in 10.000 kms)											-765.8***			
											(186.3)			
Δ Log oil price × Population density												0.81*		
												(0.38)		
Δ Log oil price × initiallgdppc													8.90***	
													(1.44)	
Δ Log oil price × Latitude														0.070
														(0.23)
Δ Log oil price × Longitude														-2.79**
														(1.05)
Δ Log oil price	6.47**	3.58*	20.7**	7.65***	7.02**		9.86***	12.2***	6.81**	5.68*	9.58***	6.84**	2.10	-97.0**
	(2.40)	(2.00)	(8.40)	(1.84)	(2.52)		(2.30)	(2.95)	(3.02)	(2.75)	(2.63)	(2.37)	(2.55)	(38.6)
Δ Log oil prices in Brazilian Reais						8.27**								
						(3.04)								
Δ Log precious metals price index	Yes	No	No	No	No	No	No	No	No	No	No	No	No	No
Δ Log agricultural price index	No	Yes	No	No	No	No	No	No	No	No	No	No	No	No
Δ Log energy price index	No	No	Yes	No	No	No	No	No	No	No	No	No	No	No
Δ Log Petrobras stock price	No	No	No	Yes	No	No	No	No	No	No	No	No	No	No
Δ Log oil price × 5-year period indicators	No	No	No	No	Yes	No	No	No	No	No	No	No	No	No
Number of observations	12,264	12,264	12,264	11,324	12,264	12,264	12,264	12,264	12,264	12,264	12,264	12,264	12,220	12,264

This table presents the results of a series of panel-data regression models of the differenced log GDP per capita for the time period 1999–2012 on the differenced log world oil price interacted with the proximity to the nearest oil field (measured in 10,000 km), an oil rich state indicator, and their interaction. The models account for municipality-specific fixed effects. The unit of observation is a municipality. Two-way cluster-robust standard errors, clustered at the levels of years and municipalities, 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: lagged and forwarded oil prices

	Δ Log GDP				
	(1)	(2)	(3)	(4)	(5)
Δ Log oil price × Proximity to oil field	107.3***	85.9**	79.8***	49.2*	110.3***
	(32.3)	(30.5)	(25.5)	(26.2)	(31.6)
Δ Log oil price × Oil rich state		21.2***		21.5***	
		(5.49)		(6.28)	
Δ Log oil price × Proximity to oil field × Oil rich state		315.1***		339.4***	
		(86.4)		(84.6)	
Δ Log oil price	6.15***	2.47	7.64***	3.92	9.02***
	(1.77)	(2.45)	(1.95)	(2.66)	(1.07)
Lagged Δ Log oil price × Proximity to oil field	90.8	104.9			
	(56.1)	(88.7)			
Lagged Δ Log oil price × Oil rich state		2.75			
		(5.45)			
Lagged Δ Log oil price × Proximity to oil field × Oil rich state		11.4			
		(124.9)			
Lagged Δ Log oil price	-5.09*	-5.53			
	(2.85)	(3.49)			
Forward lagged Δ Log oil price × Proximity to oil field			-52.4	-89.7	
			(37.1)	(54.9)	
Forward lagged Δ Log oil price × Oil rich state				4.11	
				(5.20)	
Forward lagged Δ Log oil price × Proximity to oil field × Oil rich state				139.5	
				(91.6)	
Forward lagged Δ Log oil price			0.95	0.21	
			(2.14)	(2.66)	
Lagged Δ Log GDP per cap.					-0.11***
					(0.022)
Number of observations	10,311	10,311	10,311	10,311	8,811

This table presents the results of a series of panel-data regression models (using OLS in columns 1–4 and the Arellano-Bond difference GMM estimator in column 5) of the differenced log GDP per capita for the time period 1999–2012 on the differenced log world oil price interacted with the proximity to the nearest oil field (measured in 10,000 km), an oil rich state indicator, and their interaction. The models account for municipality-specific fixed effects. The unit of observation is a municipality. Two-way cluster-robust standard errors, clustered at the levels of years and municipalities, 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: narrow band around border between oil-rich and non-oil-rich states

	Δ Log GDP		
	Max 150 km	Max 125 km	Max 100 km
	(1)	(2)	(3)
Δ Log oil price × Proximity to oil field × Oil rich state	397.9***	372.8**	346.7**
	(119.2)	(133.5)	(159.0)
Δ Log oil price × Oil rich state	23.7*	24.5*	21.5
	(11.2)	(12.2)	(14.3)
Δ Log oil price × Proximity to oil field	-8.53	18.5	17.4
	(43.2)	(39.0)	(69.7)
Δ Log oil price	3.25	3.56	3.12
	(3.66)	(4.46)	(6.57)
Number of observations	2,689	1,846	1,287

This table presents the results of a series of panel-data regression models of the differenced log GDP per capita for the time period 1999–2012 on the differenced log world oil price interacted with the proximity to the nearest oil field (measured in 10,000 km), an oil rich state indicator, and their interaction. The models account for municipality-specific fixed effects. The unit of observation is a municipality. Two-way cluster-robust standard errors, clustered at the levels of years and municipalities, are reported in parentheses. *** Significant at the 1 percent level. ** Significant at the 5 percent level. * Significant at the 10 percent level.

Table A.1: Descriptive statistics

	Mean	S.D.	10th percentile	90th percentile	Known #
Non-oil-rich sample					
Log GDP per capita	128.46	73.84	40.7	217.0	9,460
Log luminosity	0.63	1.30	-0.96	2.29	9,458
Log royalties	9.91	2.48	6.72	14.0	7,997
Δ Log GDP per capita	11.52	12.14	-0.21	23.4	8,784
Δ Log luminosity	0.23	2.20	-0.90	1.44	8,784
Δ Log royalties	0.16	0.71	-0.30	0.71	7,262
Distance to nearest oil field (in km)	168.53	215.94	14.9	302.5	9,460
Distance to coast (in km)	83.60	66.23	10.6	184.3	9,460
Distance to coast (in km)	1691.88	536.97	1098.1	2302.0	9,460
Distance to main road (in km)	4.47	2.84	1.51	8.20	9,460
Distance to railroad (in km)	38.05	40.12	4.67	87.0	9,460
Population density	0.11	0.43	0.016	0.15	9,460
Elevation	0.28	0.21	0.051	0.54	9,460
Oil-rich sample					
Log GDP per capita	219.23	76.98	133.5	321.4	3,748
Log luminosity	1.90	1.54	0.046	4.21	3,658
Log royalties	12.56	3.42	8.54	16.4	3,102
Δ Log GDP per capita	11.06	14.52	-1.73	24.0	3,480
Δ Log luminosity	0.45	4.33	-2.56	4.12	3,388
Δ Log royalties	0.38	0.89	-0.22	0.93	2,827
Distance to nearest oil field (in km)	322.44	213.59	88.1	621.2	3,748
Distance to coast (in km)	49.73	41.00	7.37	94.6	3,748
Distance to coast (in km)	387.60	270.88	33.9	771.8	3,748
Distance to main road (in km)	5.59	3.77	1.95	11.0	3,748
Distance to railroad (in km)	21.56	24.49	2.90	59.5	3,748
Population density	0.80	2.08	0.020	2.03	3,748
Elevation	0.58	0.36	0.11	1.02	3,748
Total sample					
Log GDP per capita	154.22	85.21	50.2	262.5	13,208
Log luminosity	0.98	1.49	-0.81	3.06	13,116
Log royalties	10.66	3.02	6.74	15.3	11,099
Δ Log GDP per capita	11.39	12.86	-0.66	23.5	12,264
Δ Log luminosity	0.30	2.95	-1.17	2.03	12,172
Δ Log royalties	0.22	0.77	-0.29	0.74	10,089
Distance to nearest oil field (in km)	212.20	226.18	22.1	578.3	13,208
Distance to coast (in km)	73.98	62.06	10.0	165.4	13,208
Distance to coast (in km)	1321.77	757.03	208.6	2277.7	13,208
Distance to main road (in km)	4.79	3.18	1.63	8.65	13,208
Distance to railroad (in km)	33.37	37.12	3.99	79.0	13,208
Population density	0.31	1.21	0.016	0.33	13,208
Elevation	0.37	0.29	0.062	0.82	13,208

Table A.2: Panel analysis: standard errors allowing for spatial and temporal correlation

	Δ Log GDP				
	(1)	(2)	(3)	(4)	(5)
Δ Log oil price × Proximity to oil field	98.4***	162.5***	72.6	139.8***	142.3***
	(36.4)	(47.4)	(51.1)	(36.4)	(49.4)
Δ Log oil price × Oil rich state		10.5***	19.5***		18.8***
		(3.76)	(4.90)		(4.84)
Δ Log oil price × Proximity to oil field × Oil rich state			321.8***		225.1***
			(89.5)		(79.8)
Δ Log royalties				1.88***	1.81***
				(0.40)	(0.36)
Number of observations	12,264	12,264	12,264	10,089	10,089

This table presents the results of a series of panel-data regression models of the differenced log GDP per capita for the time period 1999–2012 on the differenced log world oil price interacted with the proximity to the nearest oil field (measured in 10,000 km), an oil rich state indicator, and their interaction. The models account for municipality-specific fixed effects. The unit of observation is a municipality. Standard errors that are robust to spatial and temporal autocorrelation are reported in parentheses. We allow for spatial clustering across 5,000 kms and temporal clustering across any number of lags. *** Significant at the 1 percent level. ** Significant at the 5 percent level. * Significant at the 10 percent level.

Table A.3: Panel analysis using luminosity obtained from artificial grids of high and very high resolutions

	Δ Log luminosity											
	High resolution						Very high resolution					
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Δ Log oil price × Proximity to oil field	1.14***	1.36***	0.71	0.71	0.87	0.87	1.80***	2.30***	1.73***	1.73	1.44***	1.44
	(0.43)	(0.43)	(0.49)	(2.13)	(0.76)	(3.54)	(0.27)	(0.28)	(0.32)	(2.33)	(0.50)	(3.55)
Δ Log oil price × Oil rich state		0.067***	0.13***	0.13	0.14***	0.14		0.12***	0.17***	0.17	0.21***	0.21
		(0.020)	(0.034)	(0.19)	(0.043)	(0.24)		(0.014)	(0.023)	(0.21)	(0.031)	(0.26)
Δ Log oil price × Proximity to oil field × Oil rich state			2.37**	2.37	2.46*	2.46			1.95***	1.95	3.41***	3.41
			(1.02)	(3.50)	(1.33)	(5.29)			(0.63)	(4.68)	(0.97)	(6.20)
Δ Log oil price	0.019	0.0048	-0.0078	-0.0078	0.15***	0.15	0.088***	0.060***	0.049***	0.049	0.22***	0.22
	(0.015)	(0.016)	(0.017)	(0.24)	(0.021)	(0.29)	(0.0093)	(0.0100)	(0.011)	(0.25)	(0.015)	(0.31)
Δ Log royalties					0.024***	0.024					0.012***	0.012
					(0.0050)	(0.036)					(0.0033)	(0.035)
Clustering of standard errors	One-way	One-way	One-way	Two-way	One-way	Two-way	One-way	One-way	One-way	Two-way	One-way	Two-way
Number of observations	25,730	25,730	25,730	25,730	12,935	12,935	124,966	124,966	124,966	124,966	65,518	65,518

This table presents the results of a series of panel-data regression models of the differenced log luminosity per capita for the time period 1999–2012 on the differenced log world oil price interacted with the proximity to the nearest oil field (measured in 10,000 km), an oil rich state indicator, and their interaction. The models account for cell-specific fixed effects. The unit of observation is a cell. One-way and two-way cluster-robust standard errors, clustered at the level of cells or cells and years, are reported in parentheses. *** Significant at the 1 percent level. ** Significant at the 5 percent level. * Significant at the 10 percent level.

Not for publication

Table B.1: Panel analysis: controls (all coefficients reported)

	Δ Log GDP													
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
Δ Log oil price × Proximity to oil field	92.2**	57.5**	529.4**	128.4**	101.5**		100.1**	163.9***	100.6***	102.0**	104.5**	107.6***	198.0***	477.7***
	(36.7)	(22.2)	(231.7)	(52.3)	(37.4)		(34.4)	(41.1)	(32.8)	(34.0)	(35.4)	(33.0)	(39.1)	(130.9)
Δ Log oil prices in Brazilian Reais × Proximity to oil field						114.7**								
						(47.5)								
Δ Log precious metals price index × Proximity to oil field	171.9													
	(120.9)													
Δ Log agricultural price index × Proximity to oil field		320.5**												
		(107.3)												
Δ Log energy price index × Proximity to oil field			-486.1*											
			(239.9)											
Δ Log Petrobras stock price × Proximity to oil field				-11.9										
				(25.1)										
Five-year period: 2005 to 2009 × Proximity to oil field					16.3									
					(26.4)									
Five-year period: 2010 to 2012 × Proximity to oil field					7.53									
					(37.2)									
Δ Log oil price × Distance to coast							-396.5***							
							(90.0)							
Δ Log oil price × Distance to San Paolo								-29.3						
								(21.1)						
Δ Log oil price × Elevation									0.34					
									(4.40)					
Δ Log oil price × Distance to main road (in 10.000 kms)										2702.2				
										(2184.2)				
Δ Log oil price × Distance to railroad (in 10.000 kms)											-765.8***			
											(186.3)			
Δ Log oil price × Population density												0.81*		
												(0.38)		
Δ Log oil price × initiallgdppc													8.90***	
													(1.44)	
Δ Log oil price × Latitude														0.070
														(0.23)
Δ Log oil price × Longitude														-2.79**
														(1.05)
Δ Log oil price	6.47**	3.58*	20.7**	7.65***	7.02**		9.86***	12.2***	6.81**	5.68*	9.58***	6.84**	2.10	-97.0**
	(2.40)	(2.00)	(8.40)	(1.84)	(2.52)		(2.30)	(2.95)	(3.02)	(2.75)	(2.63)	(2.37)	(2.55)	(38.6)
Δ Log oil prices in Brazilian Reais						8.27**								
						(3.04)								
Δ Log precious metals price index	11.7**													
	(5.13)													
Δ Log agricultural price index		25.9**												
		(9.97)												
Δ Log energy price index			-15.5											
			(9.24)											
Δ Log Petrobras stock price				0.68										
				(1.03)										
Five-year period: 2000 to 2004					1.88									
					(2.06)									
Five-year period: 2005 to 2009					1.04									
					(1.74)									
Number of observations	12,264	12,264	12,264	11,324	12,264	12,264	12,264	12,264	12,264	12,264	12,264	12,264	12,220	12,264

This table presents the results of a series of panel-data regression models of the differenced log GDP per capita for the time period 1999–2012 on the differenced log world oil price interacted with the proximity to the nearest oil field (measured in 10,000 km), an oil rich state indicator, and their interaction. The models account for municipality-specific fixed effects. The unit of observation is a municipality. Two-way cluster-robust standard errors, clustered at the levels of years and municipalities, are reported in parentheses. *** Significant at the 1 percent level. ** Significant at the 5 percent level. * Significant at the 10 percent level.