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Winning the Oil Lottery: The Impact of Natural Resource Extraction on Growth

by Tiago Cavalcanti, Daniel Da Mata, and Frederik Toscani

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Winning the Oil Lottery: The Impact of Natural Resource Extraction on Growth

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Abstract

This paper provides evidence of the causal impact of oil discoveries on development. Novel data on the drilling of 20,000 oil wells in Brazil allows us to exploit a quasi-experiment: Municipalities where oil was discovered constitute the treatment group, while municipalities with drilling but no discovery are the control group. The results show that oil discoveries significantly increase per capita GDP and urbanization. We find positive spillovers to non-oil sectors, specifically, an increase in services GDP which stems from higher output per worker. The results are consistent with greater local demand for non-tradable services driven by highly paid oil workers.

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Contents **Page**

I. Introduction 4

II. Background 7
A. Oil Drilling 7
B. A First Look at Oil in Brazil 8

III. Research Design..9
A. Data..9
B. Treatment Assignment 12
C. Assessing the Design 13
IV. Estimation 16

V. Results.. 17
A. Baseline Results.. 17
B. Further Results.. 21
C. Explaining the Mechanism.. 23

VI. Conclusion 27

References.. 32

Tables
1. Number of Discoveries by Decade 10
2. Number of Wells by Category 11
3. Discoveries, Conditional on Drilling 14
4. Overlap of Treatment and Control Group.. 15
5. Intention-to-Treat Effect of All Oil Discoveries: Socio-Economic Outcomes 17
6. Intention-to-Treat Effect of True Oil Discoveries: Socio-Economic Outcomes................................ 18
7. Intention-to-Treat Effect of Oil Discoveries: Sectoral GDP per Capita.. 19
8. Intention-to-Treat Effect of Oil Discoveries: Sectoral Output per Worker 20
9. Onshore versus Offshore Discoveries 1 22
10. Onshore versus Offshore Discoveries 2.. 22
11. Oil Discoveries, Wages, Worker Density, and Firm Density 24
12. Oil Discoveries, Worker Density and Firm Density by Sector.. 24
13. Oil Discoveries and the Services Sector.. 25
14. Oil Discoveries and Labor Informality 26

Figures
1. Events and Oil Drilling 1940–2011..8
2. GDP Per Capita in Oil and Non-Oil Municipalities..9
3. Oil Wells in Brazil 1940–2000.. 13
4. Treatment and Control Groups 16
A.1. Distribution of Royalties: 1994–2000 30

Appendices
1. Summary Statistics 29
2. Using Microdata from RAIS and the Population Census.. 31

"No other business so starkly and extremely defines the meaning of risk and reward— and the profound impact of chance and fate." Yergin (2008)

I. Introduction

What are the effects of oil discoveries on economic development? Although there is a long tradition in economics of studying the impact of natural resource abundance, no clear consensus has emerged in the literature. Should the discovery of oil lead to a prosperous period of high growth in both the short and long run or should countries fear the much-discussed Dutch disease? Nominal exchange rate appreciation and rent seeking can have adverse effects, as can volatility of revenues, but the large fiscal windfall associated with resource revenue can also foster development. Even when we abstract from nominal exchange rate movements and the impact of oil rents, the pure effect of the physical presence of a natural resource sector might drive up local prices—and therefore crowd out the development of other economic activities, bringing about negative effects on growth. On the other hand, it might also increase demand for workers and attract new activities, which can lead to agglomeration effects, with a positive impact on productivity and income (Michaels, 2011).

This paper uses the quasi-experiment generated by the random outcomes of exploratory oil drilling in Brazil in order to investigate the causal effect of natural resource discoveries on local development.[2] Specifically, we compare economic outcomes in municipalities where the national oil company, Petrobras, drilled for oil but did not find any, to outcomes in those municipalities in which it drilled for oil and was successful.[3] Drilling attempts were carried out in many locations with similar geological characteristics, but oil was found in only a few places. The "treatment assignment" is related to the success of drilling attempts: Places where oil was found were assigned to treatment, while places with no oil are part of the control group. The treatment assignment resembles a "randomization", since (conditional on drilling taking place) a discovery depends mainly on luck. Therefore, places with oil discoveries are the "winners" of the "geological lottery." Since there were no significant royalty payments to municipalities in Brazil until several decades after the first discoveries, we are able to isolate the direct impact of oil extraction from the effect of fiscal windfalls. Since we are conducting a within-country study, there cannot be any nominal exchange rate response by construction.

Our analysis uses novel data on the drilling of approximately 20,000 oil wells in Brazil from 1940 to 2000. The dataset covers the universe of wells drilled since exploration began in the country and provides information on three stages regarding oil extraction and production: drilling, discovery, and upstream production. We use this detailed information to distinguish those municipalities which were assigned to treatment from those which constitute the control group. Since we view production

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[2] Oil and gas are also called petroleum or hydrocarbons. Throughout this paper, we use the term oil to refer to oil and gas. The oil industry is loosely divided into two segments: upstream and downstream. Upstream refers to exploration and production of oil, while downstream refers to processing and transportation (refineries, terminals, etc).

[3] There are three administrative levels in Brazil: federal government, states, and municipalities. Municipalities are autonomous entities that are able, for instance, to set property and service taxes. They are roughly equivalent to counties in the United States. We use the terms municipality, local government and local economy interchangeably.

as the treatment, and discovery as the assignment to treatment, our focus is on an Intent-to-Treat (ITT) analysis, where we regress our outcome variables of interest directly on discoveries.[4]

The baseline results show that locations in which oil was discovered had a 24.6–25.9 percent higher per capita GDP over a span of up to 60 years compared to those in the control group. Furthermore, we document an increase in both manufacturing and services GDP per capita but no impact on agricultural GDP. While the measure of manufacturing GDP includes natural resource extraction (and as such an increase is not surprising), the increase in services indicates spillover effects of oil production impacting the rest of the economy. Additionally, we find evidence for an increase in urbanization of about 4 percentage points. This increase in urbanization is consistent with the increase in services we document. We do not find any effect on population density. Using historical data on sectoral employment, we calculate a measure of sectoral output per worker and show that oil discoveries increase GDP mainly by increasing output per worker. We also show that while both onshore and offshore discoveries increase manufacturing GDP (potentially in a mechanical way, since manufacturing includes oil production), only onshore discoveries increase services GDP and urbanization. We hypothesize that demand from well-paid oil workers is responsible for the observed increase in services and urbanization. Oil municipalities become local service and commerce hubs which benefit from improved output per worker. The treatment intensity analysis suggests that major oil discoveries have a disproportionately larger impact on the local economy.

In order to shed light on whether our results are mainly driven by local price effects or real changes in the economy, we look at recent microdata from the Brazilian employment and population censuses. We find that municipalities in which oil was discovered have larger services firms, a higher density of formal services workers, and a lower fraction of workers employed in the subsistence agricultural sector than the control group. The move from rural informal work to the formal services sector explains the observed increase in urbanization and services GDP per capita. We also show that wages in the services sector adjust upwards. Consequently, we find evidence for both nominal and real effects. Lastly, the density of non-oil manufacturing firms and workers is not affected by oil discoveries.

Our findings, therefore, do not provide support for either the deindustrialization hypothesis of natural resource discoveries or positive agglomeration effects in the manufacturing sector. However, they do show that oil production has important real effects on the local economy and, in particular, on the services sector. Since in our setting there are is no nominal exchange rate effect and no rents accrue to the municipalities, our results can be viewed more generally as testing for the impact of an investment and consumption shock in mostly rural municipalities.

Our results are robust to a variety of control groups and different control variables. We show that municipalities with oil discoveries have a higher probability of hosting major downstream oil facilities than the control group. To check whether our results are driven by these downstream facilities, we re-run the regressions excluding those municipalities which host them and find that this is not the case. This suggests that upstream production not only impacts the local economy via downstream production but also has a direct effect.

[4] Some municipalities discover oil but do not extract it.

We also restrict the sample period to 1940–1996 to show that results are driven by direct market effects, as from 1997 onwards royalty payments became an important part of municipal income. In theory, even before 1997 oil discoveries could have impacted local revenues via taxation. However, the most important taxes in Brazil are either federal or state-level and their redistribution to municipalities are basicaly unrelated to oil activity.[5] Historically, only property taxes and a small services tax have been levied at the municipal level. The most important services tax is levied at the state level and only a small fraction of this is redistributed to the municipality which generated the tax. Furthermore, income taxes and taxes on manufacturing are federal. In practice, the indirect impact of oil discoveries on municipal revenue is thus likely to have been minimal.[6]

Since oil is one of the world's biggest industries and is at the center of the production network in many countries, its impact on the economy has been studied extensively. The usual approach to understanding the effects of oil relies on cross-country evidence. Several papers have shown correlations between natural resources and adverse outcomes. For instance, Sachs and Warner (1995) show that resource-exporting countries tend to have lower growth rates, while Isham, Woolcock, Pritchett, and Busby (2005) point out that resource-exporting countries have poorer governance indicators.[7] However, cross-country evidence is sensitive to changing periods, sample sizes, and covariates (for an overview of the literature, see van der Ploeg [2011]).[8] Additionally, cross-country studies usually use very aggregate variables and make it difficult to control for institutional factors as well as for policy variation between different countries.

As a result, the literature has been shifting attention to a more detailed analysis to pin down specific mechanisms of how natural resources impact the economy. Notable papers in an emergent literature which tries to address these problems more directly are, among others, Michaels (2011), Monteiro and Ferraz (2012), Allcott and Keniston (2014), and Caselli and Michaels (2013).[9] Within-country differences in output and wages account for a substantial fraction of worldwide inequality (see, for example, Acemoglu and Dell [2010] and Moretti [2011]), and natural resources may have an important role in explaining this clustering of economic activity. The main empirical challenge, however, is to deal with the endogeneity of natural resource extraction, since many unobservable factors which affect economic development might be correlated with oil production and oil

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[5] For instance, the most important equalizing grant from the federal government to municipalities in Brazil (called FPM) are essentially based on population size rather than income (Da Mata, 2015).

[6] It has been estimated that only 5 percent of tax revenues are local in Brazil.

[7] Also, see Arezki and Brueckner (2011) as well as the IMF's October 2015 *Fiscal Monitor* on issues related to the volatility of commodity revenues.

[8] There is also a large theoretical literature which tries to explain how natural resource abundance

might affect economic and political outcomes (e.g., Caselli and Tesei (2015)).

[9] Caselli and Michaels (2013) focus on the effects of oil windfalls on government behavior and the provision of public goods in Brazil, while Monteiro and Ferraz (2012) also use windfalls in Brazil to study local political and economic outcomes. See also Brollo, Nannicini, Perotti, and Tabellini (2013) for an analysis of fiscal windfalls in Brazil. We study the direct effects of oil discoveries instead of the indirect effect via windfalls. Also, see Acemoglu, Finkelstein, and Notowidigdo (2013) and Dube and Vargas (2013) on the local effects of resource wealth.

discoveries (for example, see Cust and Harding (2014) for analysis of the influence of institutions on oil exploration).[10]

Our paper stands out from the existing literature in at least two important respects: firstly, our novel identification strategy of comparing areas with oil drilling and discoveries to those with drilling but no discoveries allows us to estimate the impact of oil discoveries on local development using a (quasi-experimental) difference-in-difference approach. Secondly, we examine the entire history of oil exploration in Brazil, while the literature limits attention mostly to post-discovery periods. Lastly, the use of worker-level data makes it possible for us to look in more detail at the exact mechanism through which oil discoveries impact local economic development. In terms of design and results, our paper is also related to the literature on agglomeration externalities, especially the branch which investigates the impact of interventions on the concentration of economic activity (important contributions include Davis and Weinstein [2002] and Greenstone, Hornbeck, and Moretti [2010]). Similarly to our research, these papers are motivated by insights into the importance of within-country differences in output and wages. Lastly, our focus on sectoral GDP links the paper to studies on the determinants of structural transformation, particularly the ones focusing on the role of the oil sector (Kuralbayeva and Stefanski [2013]; and Stefanski [2014]).

We find that oil discoveries benefits local economic development. It is important to stress, however, that, as mentioned previously, we cannot comment on the aggregate impact of oil discoveries on the country as a whole. Compared to national economies, municipalities are much more open and face macroeconomic policies which are invariant to their idiosyncratic conditions. By construction, our research design rules out any effect which operates through the nominal exchange rate and rents accrue outside the producing municipalities.

The remainder of this paper proceeds as follows. Section II provides background on oil drilling and on the key institutional aspects of oil exploration in Brazil. Section III details the research design used to identify the impact of oil on growth. We combine several datasets which are detailed in a subsection of Section III. Section IV discusses the estimation strategy. Section V shows the results and robustness checks. Section VI concludes.

II. BACKGROUND

A. Oil Drilling

Oil and gas exploration is a risky business. Oil companies aim to find an oil field, which corresponds to a contiguous geographic area with oil, and they thus search for areas with specific geological characteristics to drill for oil. For instance, oil companies search for areas that contain geological structures (subsurface contortions and specific rocks) for potential trapping of hydrocarbons. Geology and related disciplines provide guidance on where to search for oil traps, and estimating the probability of discovery prior to drilling is an important aspect of petroleum exploration. However, only by drilling can the company be certain that hydrocarbon deposits really exist. Even with modern technology, the only direct way of confirming the hypothesis of oil presence is by drilling a well. Oil

[10] While institutional differences might be more pronounced at a cross-country level, they are still important at a within-country level (see Acemoglu and Dell [2010]).

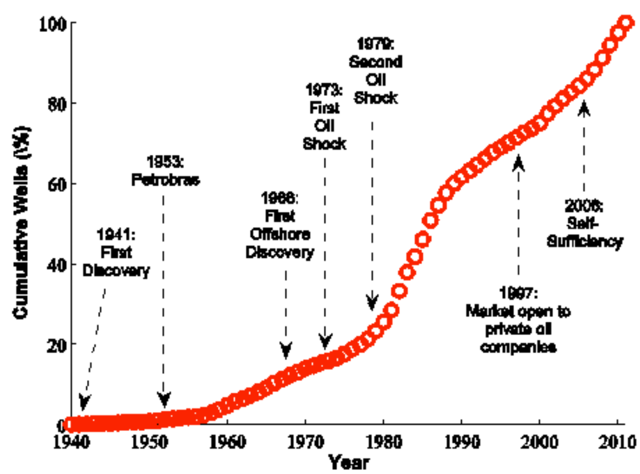
companies may invest substantially in acquiring information, only to end-up with either no discoveries or none that are profitable.

Drilled wells are classified according to the result of the attempt to find oil. A drilled well can be classified, among other categories, as a discovery well, a producer well, a dry hole, or an abandoned well (e.g., because of an accident). The likelihood of finding oil from drilling can be low, even in areas with appropriate geological characteristics, and learning-by-doing is an important aspect of the petroleum industry (Kellogg, 2011). Testing by drilling is expensive and may not reduce the uncertainty regarding the existence of oil. Numbers vary, but in a newly explored area the likelihood of successfully drilling for oil can be very low, and subjective probabilities are widely accepted in the petroleum industry (Harbaugh, Davis, and Wendebourg, 1995). Today, an exploration well (wildcat well[11]) can have a probability as low as 10 percent of yielding viable oil, while a rank wildcat [12] has an even smaller chance of finding oil. Therefore, even with modern technology, drilling is not a "safe bet," since there is no guarantee that a company will find oil after drilling. Given the features of drilling, oil discovery depends both on geological characteristics and on "luck."[13] Our data support the idea that discovering oil is a kind of "lottery": For every exploration well drilled which was successful, there were many more unsuccessful ones.

B. A First Look at Oil in Brazil

The Brazilian oil sector has experienced substantial development from 1940 onwards. In 1939, the first onshore field (which was non-commercial) was discovered, and in 1941 the first onshore commercial producer well was drilled. The first oil discovery from an offshore well took place in 1968. In 2011, Brazil was the world's thirteenth largest producer of oil and gas, with 2.2 millon barrels per day, which represents 2.6 percent of the total produced worldwide. Brazil has the world's fourteenth largest proven petroleum reserves in the same year (ANP, 2012). The oil sector is important for the Brazilian economy: In 2011, the oil sector represented 12 percent of the total Gross Domestic Product (CNI, 2012). Figure 1 summarizes domestic and international events related to oil exploration and production in Brazil.

Figure 1. Events and Oil Drilling 1940-2011



Sources: ANP and authors' calculations.
Note: Figure shows key events and the cumulative percentage of oil wells drilled in Brazil during the period from 1940 to 2011.

Figures 2(a) and 2(b) show GDP per capita for the period 1940–2000 in the states of Rio de Janeiro and Sergipe (two important oil-producing states), respectively. For each state, the graphs illustrate

[11] A well drilled a mile or more from an area of existing oil production.

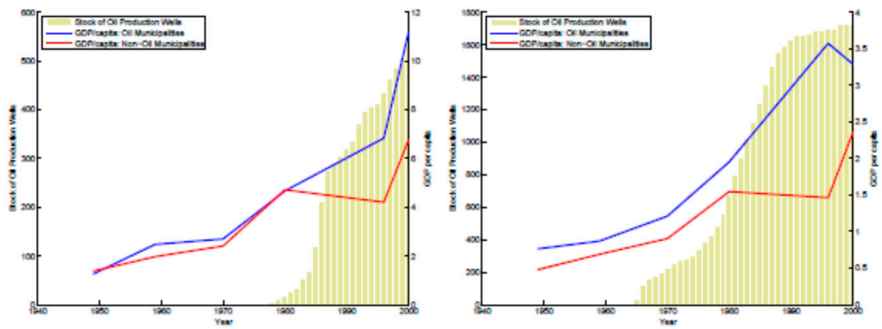
[12] A well drilled in an area where there is no existing production.

[13] According to Harbaugh, Davis, and Wendebourg (1995), "luck is obviously a major factor in exploration."

the evolution of GDP of municipalities with and without oil. It can be seen that a wedge in GDP per capita between oil-producing municipalities and those without oil production emerged over the years. Furthermore, the timing appears to correspond quite closely to the development of the oil sector in each state. At first glance, oil production appears to have substantially increase local GDP. Two questions naturally arise from this. Firstly, is the observed correlation causal? And secondly, how did the non-oil sector develop? Since oil extraction is a high-value-added activity, local GDP increases mechanically when oil is produced, bar any extreme "Dutch Disease" effect. We are interested in assessing whether the spillovers of oil production to other sectors are positive or negative.

In the next section, we discuss the identification strategy used to retrieve the effect of oil discoveries on growth of local economies in Brazil.

Figure 2. GDP Per Capita in Oil and Non-Oil Municipalities



(a) GDP *per capita* in Rio: 1940–2000 (b) GDP *per capita* in Sergipe: 1940–2000

Sources: ANP, IPEA and authors' calculations.

Note: Figure shows *per capita* GDP in municipalities of the states of (a) Rio de Janeiro and (b) Sergipe in which oil was discovered during the period 1940 to 2000 (blue line) and those in which it was not (red line).

III. Research Design

We study the impact of oil by defining the analysis in terms of the treatment evaluation literature, where we see oil production as our treatment of interest and oil discoveries as the assignment to treatment. In this section, we detail our research design, which is based on exploiting the quasi-random nature of oil discoveries. Our research design exploits unconfounded assignment, and we perform several exercises to guarantee adequate overlap between the treatment and control groups (strong ignorability, as in Rosenbaum and Rubin [1983]). We start by describing the data and then discuss the exogeneity of oil discovery and its relation to the treatment assignment.

A. Data

The data on drilling are from *Agência Nacional do Petróleo, Gás Natural e Biocombustíveis* (ANP), the Brazilian oil and gas industry regulator. The well dataset contains detailed information on the drilling of 20,052 wells in Brazil spanning the years from 1940 to 2000. The dataset contains the location (latitude and longitude) of each well, the exact date of the drilling, and the result (whether oil was found, whether the well is a dry hole, whether only water was found, or whether the well was abandoned because of an accident).[14] Furthermore, we have information on the viability of exploring the oil deposit (when oil was found), and on whether the oil company started production.

The richness of the well dataset allows us to study several possibilities regarding the stages of oil extraction and production (the upstream oil industry). From the data, we are able to separate places where drilling took place ($J = 1$) from places with no drilling ($J = 0$). We are also able to obtain information on places with oil discoveries (Z) and with oil production (D). As a first step, we created a dummy variable for drilling (J), two different dummy variables for discovery (Z), and a dummy for well production (D). The dummies for drilling and production follow immediately from the well data. The drilling dummy is set equal to one when at least one well was drilled in the municipality, and the production dummy is set equal to one when there is at least one producer well in the municipality. In terms of discoveries, there are several possibilities, as the data allow us to differentiate between a field discovery, a subfield (reservoir) discovery, and a field extension discovery. We define two different discovery dummies as follows. The first dummy ("All Discoveries") is set equal to one when at least one field, subfield, or field extension discovery was made in the municipality. The second dummy ("True Discoveries") is set equal to one when at least one field or subfield discovery and at least one field extension discovery were made in the municipality. The rationale for the latter is that any substantial discovery includes a field or subfield discovery and subsequent field extension discoveries to delineate the size of the oil field. For now, we will use the "All Discoveries" dummy to start with the most general possible definition of discoveries.[15]

Table 1 shows the number of wells discovered by decade. It contains information on the total number of discoveries, and on onshore and offshore discoveries. It also has information on the total number of units assigned to treatment over time.

Table 1. Number of Discoveries by Decade

	# of Wells: Discoveries			Units Assigned to Treatment		
Decade	Total	Onshore	Offshore	Total	Onshore	Offshore
1940	9	9	0	3	3	0
1950	48	48	0	8	8	0
1960	212	206	6	19	18	1
1970	203	117	86	13	4	9
1980	671	434	237	15	7	8
1990	285	158	127	6	2	4

Sources: ANP and authors' calculations.
Note: The units assigned to treatment are Minimum Comparable Areas (MCAs). MCAs consist of sets of municipalities whose borders were constant over the study period.

[14] We obtained more the 50 different classifications from the dataset, but we were able to aggregate all of them into a few major categories (see Table 2). The data differentiate between oil well, gas well, and oil and gas well. One limitation of the dataset is that it does not include information on the amount of oil produced by each individual producer well during the period of interest. Data on well production are available only from the the 2000 onward.

[15] See the supplementary appendix (available on request) for a comparison of the two discovery dummies.

Table 2 shows the number of wells by category. Wells are classified broadly as exploratory wells and development wells. Exploratory wells are drilled to test for the presence of oil, while wells drilled inside the known extent of the field are called development wells (e.g., producer wells).[16] Unsuccessful drilling is classified as a dry hole in both exploratory and development categories. Our unit of analysis is the Minimum Comparable Area (MCA) which consists of sets of municipalities which had constant borders over the study period (see supplementary appendix for more details). We have the following numbers regarding oil discoveries in Brazil:

- Total number of MCA units = 1,275
- All Discoveries MCAs = 64
- True Discoveries MCAs = 45
- Dry hole MCAs = 158
- Neighbors of discovery MCAs = 156

Table 2. Number of Wells by Category

Classification	Category of Well	Offshore	Onshore	Total
Exploratory Wells	Discovery of New Field	129	304	433
	Discovery of New Subfield (Reservoir)	88	234	322
	Discovery of Field Extension (Step-out)	258	419	677
	Dry Hole	1,067	2,556	3,623
Development Wells	Producer	1,368	9,101	10,469
	Carries Oil or Gas	7	1	8
	Production Not Feasible	327	521	848
	Injection of Water, Steam, or Gas	201	774	975
	Dry Hole	73	1,017	1,090
Other	Abandoned	421	554	975
	Special	62	369	431
	Missing Category	30	171	201
	Total	4,031	16,021	20,052

Sources: ANP and authors' calculations.

Note: Wells are classified broadly as exploratory wells and development wells. Exploratory wells are drilled to test for the presence of oil. If the exploratory drilling was proven unsuccessful, the well is classified as a dry hole. Wells to delineate the extension of the oil field (step-out wells) are also classified as exploratory wells. Every well drilled inside the known extent of the field is called a development well (e.g., producer wells and injection wells). In the development well category, unsuccessful drilling is also classified as a dry hole. Special wells are water wells or the ones used for mineral research and experiments.

We work with three main outcome variables: population density, the urbanization rate,[17] and *per capita* GDP (overall as well as sectoral). Data on total population, population located in urban areas,

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[16] Note that the two instruments (true discoveries and all discoveries) apply to exploratory wells.

[17] The urbanization rate is the proportion of the population living in urban areas.

total area of the municipality, as well as data on employment (total and sectoral) come from historical population censuses. Data on municipal gross domestic product (GDP) and on the shares of manufacturing, agriculture, and services in GDP are from Ipeadata.[18] Using this information, we construct our outcome variables to obtain a panel from 1940 to 2000. In 1941, the first well started to produce oil, so 1940 is our pre-treatment year. The panel data are balanced, and we do not observe any attrition.

Additionally, we collected data on average temperature, average rainfall, and average altitude from Ipeadata.[19] Further data comprise the latitude and longitude of each MCA as well as geographical indicators of its location (on the coast, in the Amazon region, and in the semiarid region).[20] Table A.1 in Appendix 1 shows the summary statistics of the variables used in the analysis. In further analysis we use microdata from the employment and population censuses. The Brazilian Ministry of Labor's RAIS (Relação Anual de Informações Sociais) provides matched employer–employee microdata (see data description in Appendix 2).

B. Treatment Assignment

Municipalities in which oil was discovered are assigned to treatment. The untreated (control) group comprises the locations with drilling but no oil discoveries. Our treatment assignment process is very similar to a randomization: Several attempts to drill oil were made, but nature has endowed only some places with oil. Drilling took place in locations with selected geological characteristics, with little room for influence by local governments. Figure 3(b) shows that oil drilling in Brazil is concentrated in sedimentary basins. Since the locations of oil reserves are determined by geology, selection into treatment is unlikely or impossible. In other words, municipalities had no control over the assignment mechanism and thus could not influence their treatment regime.

Note that there is some noncompliance with the assigned treatment, that is, in some locations oil was discovered (Z = 1) but no oil was produced (D = 0). We have information on whether a discovered oil field is economically viable to begin production. Viability depends to the largest extent on the characteristics of the oil field but potentially also on some local characteristics. Part of the costs of producing oil may be systematically correlated with unobservable local characteristics. For instance, existing infrastructure and institutional support from the local and state governments might influence the decision to produce oil at the margin. As a result, the research design implies random assignment of locations to treatment and control groups, but allows for non-random selection of

[18] The GDP calculations are detailed in Reis, Tafner, Pimentel, Serra, Reiff, Magalhaes, and Medina (2004). The GDP is deflated using the national implicit price deflator. In subsection V.A, we use the composition of GDP to argue that we capture a variation in real local GDP instead of a price effect by showing that oil municipalities undergo an important structural transformation.

[19] Temperature is measured in degrees Celsius, precipitation in millimeters per month, and altitude in meters.

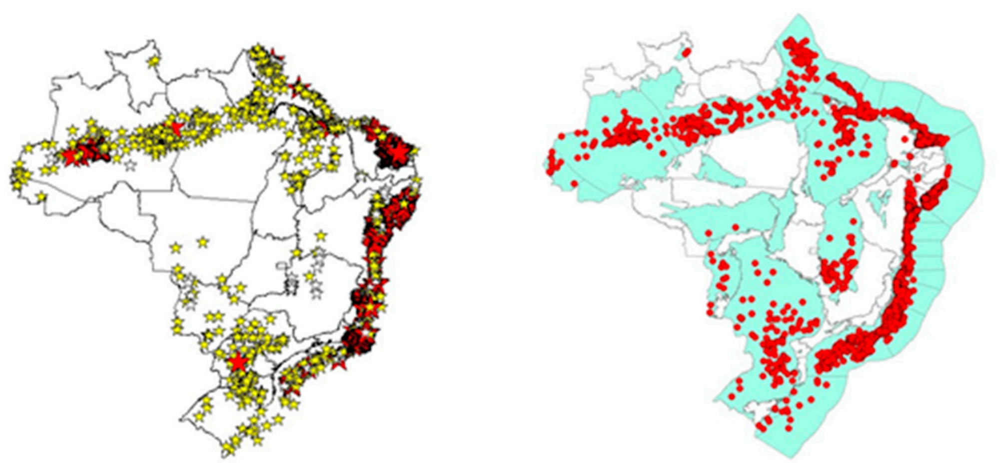
[20] To construct the shapefile of 1940 MCAs, we combined the shapefile of 1997 municipalities with the matching between the 1940 MCAs and the corresponding 1997 municipalities. From the shapefile of 1940 MCAs, we constructed latitudes, longitudes, and geographical indicators.

participants into treatment (once assigned to treatment). As part of our empirical strategy, we thus use discoveries as an instrumental variable for production.[21]

C. Assessing the Design

For our identification strategy to be valid, we need assignment to treatment to be random, in other words we need to show that (the intensity of) drilling attempts are exogenous to local characteristics (conditional on appropriate geographical controls) and that (conditional on drilling taking place) the discovery of oil is a "lottery."

Figure 3. Oil Wells in Brazil 1940-2000



a) Oil Wells: Discovery (red) vs. dry (yellow) (b) Sedimentary Basins (light green)

Sources: ANP and authors' mapping.

Note. The figures show the locations of approximately 20,000 drilled wells (the universe of wells drilled in Brazil during the period from 1940 to 2000). In Figure 3(a), wells with Oil Discovery are in red, Dry wells are in yellow, and others are in white. Figure 3(b) shows the locations of sedimentary basins in Brazil (in light green).

To show this, we restrict the sample to only those municipalities which drilled for oil, and we find that both the number of discoveries and the ratio of successful drilling to unsuccessful drilling are unrelated to local economic characteristics. Table 3 shows that (conditional on drilling taking place) pre-treatment economic characteristics do not influence drilling success. It is in fact particularly reassuring that the success ratio is uncorrelated with all controls, that is, conditional on drilling taking place, success is truly a lottery.

However, the overlap in terms of observable geographic characteristics between the assigned to treatment and control groups is not ideal if we use the whole dry drilling group. To improve overlap we construct an alternative control group using a propensity matching technique – we pick the 64 control municipalities which most resemble the discovery municipalities and call this the the

[21] Part of the non-compliance is due to MCAs discovering oil towards the end of our sample period but not starting production until after 2000

"matched dry drilling" control group (see Table 4).[22] Results are robust to using either of the control groups. Figure 4 shows a map with the discovery, dry drilling and matched dry drilling MCAs.

Table 3. Discoveries, Conditional on Drilling

Dependent variable:	Number of Discovery Wells		Drilling Success Ratio
Estimation:	Linear Probability	Poisson	Linear Probability
Urbanization in 1940	0.524	-0.844	0.121
	(9.766)	(1.478)	(0.125)
Pop. Density in 1940	0.435	0.108	-0.00255
	(0.912)	(0.169)	(0.0165)
GDP *per capita* in 1949	2.779	0.548	-0.00148
	(2.302)	(0.381)	(0.0300)
Semiarid Indicator	10.53	1.362**	0.104
	(7.595)	(0.562)	(0.0679)
Amazon Indicator	2.499	-0.377	-0.0263
	(3.733)	(0.746)	(0.0586)
Coastal Indicator	10.77**	1.704***	0.0595
	(5.190)	(0.535)	(0.0390)
Constant	0.783	0.834*	0.0622
	(3.059)	(0.471)	(0.052)
Observations	222	222	210
R-squared	0.070	-	0.031

Note: Robust standard errors in parentheses. The regressions are for the 222 Minimum Comparable Areas (MCAs) in which Petrobras drilled for oil. The drilling success ratio is the ratio of exploratory wells with oil to exploratory dry wells. The pre-treatment variables are urbanization rate in 1940, population density in 1940, and *per capita* GDP in 1949. The geographical controls are indicator variables showing whether the MCA is located in the semiarid region, in the Amazon region, or on the coast.

[22] To investigate systematic differences between the group assigned to treatment and the control group we follow Rubin (2001). We use the normalized (or standardized) difference to assess the difference in location in the covariate distributions (Imbens and Wooldridge, 2009). Standardized differences are not influenced by sample size, unlike t-tests and other statistical tests.

The normalized difference (ND) for continuous variables is given by

$$ND = \frac{\mu_t - \mu_c}{\sqrt{\sigma_t^2 - \sigma_c^2}}$$

where μ_t and σ_t^2 are the mean and variance of the treated group, and μ_c and σ_c^2 are the corresponding values for the control group.

The ND for dichotomous variables is defined as

$$ND = \frac{p_t - p_c}{\sqrt{p_t(1-p_t) + p_c(1-p_c)}}$$

where p_t and p_c are the proportions (prevalences) for the treated and control groups, respectively.
Imbens and Wooldridge (2009) suggest that for a standardized difference of more than 0.25, "linear regression methods tend to be sensitive to the specification" (p. 24).

Table 4. Overlap of Treatment and Control Group

Variable		(I) Oil Discovery	(II) Dry Drilling	(III) Matched Dry Drilling
Pop Density 1940	Mean	32.89	30.33	35.09
	S.D.	51.35	132.29	104.47
	Standardized Difference	-	-0.018	-0.019
Urbanization 1940	Mean	0.27	0.22	0.24
	S.D.	0.18	0.18	0.2
	Standardized Difference	-	-0.196	0.111
GDP per capita 1949	Mean	0.67	0.88	0.69
	S.D.	0.42	0.89	0.75
	Standardized Difference	-	-0.213	-0.023
Latitude	Mean	-11.88	-13.72	-12.62
	S.D.	6.44	9.67	8.6
	Standardized Difference	-	-0.158	0.069
Longitude	Mean	-40.65	-46.94	-43.5
	S.D.	6.46	7.31	7.6
	Standardized Difference	-	-0.645	0.286
Coastal Indicator	Poportion	0.59	0.3	0.53
	Standardized Difference	-	-0.431	0.086
Semiarid Indicator	Poportion	0.19	0.15	0.23
	Standardized Difference	-	-0.075	-0.07
Amazon Indicator	Poportion	0.08	0.3	0.17
	Standardized Difference	-	-0.413	-0.194
	Number of MCAs	64	158	64

Note: The table shows the standardized differences for the key variables for the discovery, dry drilling and matched dry drilling MCAs.

Figure 4. Treatment and Control Groups

a) Discovery (Red), Drilling (Yellow)

(b) Discovery (Red) and Matched Dry Drilling Sample (Yellow)

Note: Figure 4 shows maps with the locations of the two most relevant control groups. Figure 4(a) shows the places with discoveries and the set of MCAs where drilling took place and no oil was found. Figure 4(b) displays the matched dry-hole subpopulation.

IV. ESTIMATION

We now briefly discuss the empirical strategy we use to recover the impact of oil discoveries. The estimand of interest is the Intention-to-Treat (ITT): the average impact of being assigned to treatment. Let y_i be the potential outcome for local economy i, and let the indicator of treatment assignment be $Z_i = \{0, 1\}$. The ITT estimand is represented by $ITT = E[y_i|Z_i = 1] - E[y_i|Z_i = 0]$.

In the discussion below, the oil discovery dummy is represented by Z_{it} (treatment assignment), which is set equal to 1 if oil was discovered in MCA unit i in period $t \geq \bar{t}$, where $\bar{t}$ is the time of the discovery. A regression using Z_{it} is an intent-to-treat (ITT) analysis. We assume an additive and linear empirical specification to estimate an ITT effect, as follows:

$$Y_{it} = \alpha + \tau_{ITT} Z_{it} + \beta_t' X_i + \gamma_i + \rho_t + \epsilon_{it} \quad (1)$$

where Y_{it} is the outcome variable, β_t' is the time-varying coefficient of time-invariant MCA characteristics X_i, including the pre-treatment level of the dependent variables, ϵ_{it} is an error term, ρ_t denotes year fixed effects and γ_i denotes MCA fixed effects. The time t ranges from 1940 to 2000. The (exogenous) source of cross-sectional and time variation is given by the discovery of oil in unit i at time t. As a result, the parameter τ should capture an intent-to-treat effect. Note that ITT is a lower bound on the average treatment effect. We add γ_i to capture time-invariant characteristics and ρ_t to capture common aggregate shocks that hit all locations.

We also use a set of additional covariates X_i in equation. Recall that we trim by using the propensity score to create an alternative control group for robustness. After matching by using the propensity score, model dependence is not eliminated but will normally be reduced. Parametric procedures have the potential to improve causal inferences, even after matching when the match is not exact (Ho, Imai, King, and Stuart, 2007). Moreover, the trimming used to create the control groups also helps with the common trend assumption. Lastly, note that policy variation takes place at the MCA level, and errors within the spatial units may be correlated. Therefore, standard errors are clustered at the MCA level in all regressions (Bertrand, Duflo, and Mullainathan, 2004).[23]

V. Results

A. Baseline Results

Results for Socio-Economic Variables. Table 5 shows the baseline ITT results using the "All Discovery" dummy as our treatment assignment. We show results for both our preferred control group (dry drilling) and the matched dry drilling sample. The key independent variable is a dummy, and both *per capita* GDP and population density are expressed as logs. Therefore, the coefficient in those regressions can be interpreted as a percentage change. Urbanization is a rate bounded between 0 and 1, so that the coefficient for oil discoveries can be interpreted as a change in percentage points. GDP *per capita* increased by 12.5–14.6 percent over a 60-year period as a result of oil discoveries. Population density and the urbanization rate are unaffected by oil discoveries in this specification.

Table 5. Intention-to-Treat Effect of All Oil Discoveries: Socio-Economic Outcomes

	Dry Drilling			Matched Dry Drilling		
	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLES	ln Population Density	ln GDP per capita	Urbanization rate	ln Population Density	ln GDP per capita	Urbanization rate
Discovery Dummy	-0.0390	0.125*	0.0283	-0.0400	0.146*	0.0253
	(0.0579)	(0.0728)	(0.0187)	(0.0626)	(0.0783)	(0.0199)
MCA FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1,776	1,332	1,776	1,024	768	1,024
Number of MCAs	222	222	222	128	128	128
Geographical Controls	Yes	Yes	Yes	Yes	Yes	Yes
Initial Conditions	Yes	Yes	Yes	Yes	Yes	Yes
Estimation	FE	FE	FE	FE	FE	FE

Source: Authors' calculations.
Note: Standard errors clustered at the MCA level. Geographical controls and initial conditions have time-varying coefficients.

As discussed earlier, the "All Discovery" dummy has some drawbacks, both conceptually and in terms of its ability to predict oil production. The "True Discoveries" dummy excludes both MCAs where oil was discovered but there were no follow-up discoveries (i.e., the oil field was very small) and MCAs

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[23] Time could threaten identification if discoveries took place in boom periods: Places where oil was discovered during a boom may have had a better opportunity to promote local growth. Our use of year fixed effects helps to alleviate this concern. Additionally, the bulk of drilling activity (and some important discoveries) took place in the 1980s, a decade labeled as the "lost decade" because of its low GDP growth. In other words, important discoveries did not take place during boom periods in Brazil.

where there was no field discovery but only a field extension (i.e., the bulk of the field lies in a different municipality).[24]

Table 6 shows the baseline ITT results using our preferred treatment assignment ("True Discoveries"). Unsurprisingly, the coefficients are markedly higher than in Table 4. The increase in *per capita* GDP is estimated at 24.6–25.9 percent. While population density is not significantly affected, urbanization increases by 4.3–4.4 percentage points over the period as a consequence of oil discoveries. In other words, when we compare municipalities with significant discoveries to municipalities where Petrobras drilled for oil and either did not find any or made no substantial discovery, we find a strong positive impact on *per capita* GDP and urbanization.

Table 6. Intention-to-Treat Effect of True Oil Discoveries: Socio-Economic Outcomes

	Dry Drilling			Matched Dry Drilling		
	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLES	ln Population Density	ln GDP per capita	Urbanization rate	ln Population Density	ln GDP per capita	Urbanization rate
Discovery Dummy	-0.0086	0.246***	0.0443**	-0.0127	0.259***	0.0430**
	(0.0676)	(0.0856)	(0.0202)	(0.0731)	(0.0910)	(0.0213)
MCA FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1,776	1,332	1,776	1,024	768	1,024
Number of MCAs	222	222	222	128	128	128
Geographical Controls	Yes	Yes	Yes	Yes	Yes	Yes
Initial Conditions	Yes	Yes	Yes	Yes	Yes	Yes
Estimation	FE	FE	FE	FE	FE	FE

Source: Authors' calculations.
Note: Standard errors clustered at the MCA level. Geographical controls and initial conditions have time-varying coefficients.

Robustness. In the interest of space tables for the various robustness exercises are relegated to a supplementary appendix (available upon request). Among other checks, we verify that changing the time period to 1940–1996 does not change the results. This is important, because it supports the claim that our findings are driven by the direct effect of oil production rather than the indirect effect through royalties. The results are also both quantitatively and qualitatively robust to using alternative control groups. Our additional control groups are all non-oil MCAs in oil discovery states, dry-drilling MCAs which are not adjacent to discovery MCAs (which we call dry drilling, no neighbor), all MCAs which are adjacent to discovery MCAs, and a matched subsample of adjacent MCAs (matched neighbors). The results for the dry drilling, no neighbor control group are reassuring in the sense that any potential spillovers should be particularly limited for this group.[25] Overall, the results are

[24] Implicitly, other recent papers on the impact of oil abundance have also defined relevant discoveries. For example, Michaels (2011) uses a threshold of 100 million barrels of reserves, and Allcott and Keniston (2014) use a cutoff in production of US$100 per inhabitant.

[25] We also explicitly checked whether there are any measurable effects on neighbors of discovery municipalities. No statistically significant impact was found.

remarkably similar across control groups, perhaps highlighting that our controls and the parametric fitting (the linear and additive specification represented by Equation (1)) are doing a good job in providing a precise estimate of the effects of oil on the municipalities in Brazil.[26] The estimate for *per capita* GDP ranges from 19.5–27.7 percent while urbanization is estimated to increase 3.6–5.2 percent as a consequence of oil discoveries.[27] Our baseline results are also robust to including the additional geographical controls which are available, namely, average temperature and average rainfall over the last 50 years, average altitude of the MCA, and a dummy for being located in a semiarid region.

Sectoral GDP Results. While the results for urbanization point in a different direction, there might be a concern that the increase in GDP *per capita* is purely mechanical, in the sense that there are no spillovers from oil production to other sectors of the economy. To investigate this, Table 7 shows the impact of oil discoveries on sectoral GDP. GDP is broken up into manufacturing, services, and agriculture. Natural resource extraction is included in the manufacturing sector.

Table 7. Intention-to-Treat Effect of Oil Discoveries: Sectoral GDP *per Capita*

	Dry Drilling			Matched Dry Drilling		
	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLES	Manufacturing GDP per capita	Services GDP per capita	Agriculture GDP per capita	Manufacturing GDP per capita	Services GDP per capita	Agriculture GDP per capita
Discovery Dummy	0.449**	0.213**	0.0569	0.456**	0.215**	0.0664
	(0.182)	(0.0968)	(0.107)	(0.189)	(0.104)	(0.109)
MCA FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1,325	1,321	1,328	765	764	765
Number of MCAs	222	222	222	128	128	128
Geographical Controls	Yes	Yes	Yes	Yes	Yes	Yes
Initial Conditions	Yes	Yes	Yes	Yes	Yes	Yes
Estimation	FE	FE	FE	FE	FE	FE

Source: Authors' calculations.
Note: Standard errors clustered at the MCA level. Geographical controls and initial conditions have time-varying coefficients. Discovery is defined as "True Discovery".

While ideally we would like to decompose this further, the available data does not allow us to do so. As such, it is not surprising or particularly insightful that manufacturing GDP increases significantly with oil discoveries. Importantly, however, services GDP increases by about 20 percent, while agricultural GDP is unaffected. These results are interesting for two reasons. First of all, it is reassuring (in terms of our research design) that agricultural GDP is not affected. An increase in agricultural GDP might have raised doubts that we are mainly picking up local price effects rather than changes in real municipal GDP. Secondly, the results suggest that there are spillovers from oil

[26] The results are also robust to the exclusion of major urban centers, i.e., state capitals.

[27] We also constructed trimmed (rather than matched) subsamples of the dry-drilling and neighbors control groups. The results are robust to using those.

discoveries to the services sector. One candidate for a channel is direct demand from oil firms and high-paid oil workers.

Output per Worker. To investigate the sectoral GDP results in more detail, we used historical censuses to collect data on sectoral employment by municipality going back to 1940. We then constructed a measure of output per worker by dividing sectoral GDP by sectoral employment for every MCA.[28] [29] Table 8 shows that oil discoveries increase output per worker in the manufacturing sector by slightly over 20 percent (recall again that this includes oil production) and by roughly 20 percent in the services sector. The agricultural sector in not affected. While the result is significant for the services sector for both control groups, it is marginally insignificant at conventional levels in one of the two regressions for the manufacturing sector. Comparison of the estimated coefficients with the increases in sectoral GDP *per capita* which we documented in Table 8 seems to indicate that while the increase in services GDP is largely accounted for by increased productivity, the manufacturing sector is also experiencing an increase in employment. These results are consistent with anecdotal evidence. Municipalities in which oil was discovered became local services and commerce hubs for the surrounding area, with these large outfits presenting a significantly higher output per worker than the traditional small-scale service providers.[30]

Table 8. Intention-to-Treat Effect of Oil Discoveries: Sectoral Output per Worker

	Dry Drilling			Matched Dry Drilling		
	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLES	Manufacturing Y/L	Services Y/L	Agriculture Y/L	Manufacturing Y/L	Services Y/L	Agriculture Y/L
Discovery Dummy	0.265*	0.221**	-0.0717	0.222	0.188*	-0.0535
	(0.139)	(0.106)	(0.0881)	(0.143)	(0.113)	(0.0871)
MCA FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1,533	1,542	1,547	883	891	891
Number of MCAs	222	222	222	128	128	128
Geographical Controls	Yes	Yes	Yes	Yes	Yes	Yes
Initial Conditions	Yes	Yes	Yes	Yes	Yes	Yes
Estimation	FE	FE	FE	FE	FE	FE

Source: Authors' calculations.

[28] This is a rough approximation to labor productivity if we assume a Cobb–Douglas production function, for example. Ideally, of course one would like to obtain a clean measure of labor productivity by adjusting for the intensity in the use of capital and average number of hours worked. Unfortunately, this is not possible due to data constraints.

[29] We obtained data on sectoral output per worker for the years 1950, 1960, 1970, 1975, 1980, 1985, 1996, and 2000. Since GDP data is available for 1949 and 1959 but employment data is available for 1950 and 1960, we use the 1949 and 1959 GDP data to get estimates of 1950 and 1960 output per worker, respectively.

[30] The results for sectoral GDP and output per worker are robust to all of the above robustness exercises but we do not report those tables in the interest of space. We also ran regressions adding state fixed effects and clustering at the state level. The baseline results are robust to both additions. Tables are available from the authors upon request.

Note: Standard errors clustered at the MCA level. Geographical controls and initial conditions have time-varying coefficients. Discovery is defined as “True Discovery”.

B. Further Results

In this section, we first split discoveries into onshore and offshore and show that, on average, only onshore discoveries seem to have significant positive spillovers. We then use an alternative empirical strategy and estimate a regression which allows us to retrieve the local average treatment effect of oil production. Lastly, we explore the connection between downstream and upstream oil production and show that our results are robust to the exclusion of municipalities with large processing facilities such as refineries or major storage and transportation hubs.[31]

Onshore versus Offshore Discoveries. We distinguish between onshore and offshore discoveries, since some of the channels which we believe can lead to spillovers (such as the physical presence of well-paid oil workers) might be more obviously present for onshore than for offshore locations. In fact, offshore production is concentrated largely of the coast of Rio de Janeiro, and most personnel associated with offshore production is stationed in the municipality of Macaé.

GDP *per capita* in the manufacturing sector increases significantly in both onshore and offshore municipalities. However, when we focus on our measures of spillovers, namely, productivity in the services sector and the urbanization rate, we see that neither of those is affected by offshore discoveries, but there is a large positive impact of onshore discoveries. Labor productivity in the services sector increases by 28 percent, while the urbanization rate increases by over 5 percentage points (see Tables 9 and 10). The increase in manufacturing GDP shows that offshore discoveries do increase GDP in a mechanical sense. However, we do not find any impact on the local economy. It is also worth noting, however, that the estimated increase in manufacturing GDP is very similar for onshore and offshore discoveries, perhaps indicating that the impact of oil discoveries on non-oil manufacturing is rather limited, even for onshore discoveries.[32]

[31] Tables for the latter two exercises are reported in the supplementary appendix. In the interest of space, we report results for only our preferred control group (matched dry drilling) from this point on, but as before, all results are very stable across different control groups (and are available upon request)..

[32] While assigning onshore discoveries to municipalities is straightforward, the mapping is not as clear for offshore discoveries. To verify whether the offshore result is driven by our measure of offshore discoveries, we used an alternative measure, facing areas, used by the Brazilian Oil and Gas regulator (ANP) to distribute royalties. This is a complex measure, but essentially captures whether a municipality’s maritime borders face an oil field (see Monteiro and Ferraz (2012) for a detailed discussion). The resulting measure is substantially broader than ours, since only one MCA can be the one closest to a well, but many MCAs can potentially face it. It thus is ex-ante less likely to pick up spillovers from production. The correlation between the two measures of offshore discoveries is 0.53. We re-ran the regressions using the alternative measure of offshore discoveries, but the results are unchanged

Table 9. Onshore versus Offshore Discoveries 1

	Matched Dry Drilling			
	(1)	(2)	(3)	(4)
VARIABLES	GDP per capita	Manufacturing GDP per capita	GDP per capita	Manufacturing GDP per capita
Onshore Discovery Dummy	0.3429***	0.5270**		
	(0.106)	(0.2157)		
Offshore Discovery Dummy			0.2081	0.4537*
			(0.1315)	(0.2303)
MCA FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Observations	768	891	768	891
Number of MCAs	128	128	128	128
Geographical Controls	Yes	Yes	Yes	Yes
Initial Conditions	Yes	Yes	Yes	Yes
Estimation	FE	FE	FE	FE

Source: Authors' calculations.
Note: Standard errors clustered at the MCA level. Geographical controls and initial conditions have timevarying coefficients. The control group is the matched dry-drilling sample.

Table 10. Onshore versus Offshore Discoveries 2

	Matched Dry Drilling			
	(1)	(2)	(3)	(4)
VARIABLES	Services Y/L	Urbanization Rate	Services Y/L	Urbanization Rate
Onshore Discovery Dummy	0.280**	0.0542**		
	(0.135)	(0.0237)		
Offshore Discovery Dummy			0.0187	0.0135
			(0.126)	(0.0313)
MCA FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Observations	891	1,024	891	1,024
Number of MCAs	128	128	128	128
Geographical Controls	Yes	Yes	Yes	Yes
Initial Conditions	Yes	Yes	Yes	Yes
Estimation	FE	FE	FE	FE

Source: Authors' calculations.
Note: Standard errors clustered at the MCA level. Geographical controls and initial conditions have timevarying coefficients. The control group is the matched dry-drilling sample.

C. Explaining the Mechanism

In this section we investigate the mechanisms underlying our results in more detail. We aim to shed light on three questions: (i) Are the services sector results driven mainly by local price effects or real economic change? (ii) What happens to non-oil manufacturing? and (iii) What happens to the agricultural sector?

Due to constraints on the availability of microdata, this more in-depth analysis cannot be conducted using our preferred difference-in-difference identification strategy. Thus we exploit a cross-sectional identification. We use matched worker–firm microdata: the Ministry of Labor's RAIS (*Relação Anual de Informações Sociais*). The RAIS dataset has information on each formal worker at each plant in Brazil. Since RAIS looks only at formal workers we complement this data with data on informality from the 2000 population census, collected by the Brazilian Bureau of Statistics. We use cross-sectional data for the year 2000, because this is the first year for which high-quality data from both the employment and population censuses are available.[33] To guarantee maximum comparability with the results reported in previous sections of the paper, we use the same assigned to treatment and control groups. Given that discoveries are random (conditional on drilling) even a cross-sectional comparison of treatment and control groups allows for some insights into at least the qualitative impact of oil discoveries.

We estimate the following equation:

$$Y_i = \alpha + \tau_{CS} Z_i + \beta' X_i + \epsilon_{it} \qquad (3)$$

where Y_i is the outcome variable in 2000, X_i includes the usual controls, and Z_i equals 1 if oil was discovered in the MCA unit between 1940 and 2000.

Table 11 shows the baseline results from the cross-sectional exercise. The first three columns confirm the previous findings: In 2000, the assigned to treatment group has a higher *per capita* GDP and is more urbanized, but population density is not affected by oil discoveries.[34] Additionally, Columns (4)–(6) show that places where oil was discovered have higher average wages and a higher worker density, but firm density is not statistically different between discovery and control groups.[35] MCAs where oil was discovered are thus richer and more urbanized, pay higher wages, and have more formal workers. To investigate which sectors are affected by oil discoveries, we construct sectoral measures of firm and worker density. Importantly, we are able to exploit subsector identifiers in the microdata to obtain a manufacturing sector without extractive activities, which was not possible using the historical data. Table 12 highlights that the manufacturing sector (excluding natural resource extraction) and the agricultural sector are not affected by oil production. We do not find any evidence for a Dutch-disease style crowding-out of the manufacturing sector nor of positive spillovers from oil production to manufacturing. By contrast, the growth in the number of formal workers is driven by an increase in the number of formal workers in services.

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[33] See Appendix 2 for more information on the microdata.

[34] We focus on the matched subsample in this section but results are unchanged when using the full sample of dry drilling MCAs as the control group.

[35] Densities are specified as the number of firms and workers, respectively, per square kilometer.

Table 11. Oil Discoveries, Wages, Worker Density, and Firm Density

	Matched Dry Drilling					
	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLES	ln Population Density	ln GDP per capita	Urbanization rate	ln Worker Density	ln Firm Density	ln Average Wage
Discovery Dummy	-0.0269	0.396***	0.0551*	0.506*	0.384	0.185**
	(0.129)	(0.120)	(0.0301)	(0.287)	(0.285)	(0.0739)
Observations	128	128	128	128	128	128
Number of MCAs	128	128	128	128	128	128
Geographical Controls	Yes	Yes	Yes	Yes	Yes	Yes
Initial Conditions	Yes	Yes	Yes	Yes	Yes	Yes
Estimation	OLS	OLS	OLS	OLS	OLS	OLS

Source: Authors' calculations.
Note: Robust standard errors parentheses. Discovery is defined as "True Discovery". Cross-sectional estimation using microdata for the year 2000. Densities are specified as the number of firms and workers per square kilometer.

Table 12. Oil Discoveries, Worker Density and Firm Density by Sector

	Matched Dry Drilling					
	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLES	ln Manufacturing Firm Density	ln Services Firm Density	ln Agriculture Firm Density	ln Manufacturing Worker Density	ln Services Worker Density	ln Agriculture Worker Density
Discovery Dummy	0.308	0.426	0.274	0.338	0.796**	0.546
	(0.338)	(0.302)	(0.286)	(0.450)	(0.353)	(0.359)
Observations	128	128	128	128	128	128
Number of MCAs	128	128	128	128	128	128
Geographical Controls	Yes	Yes	Yes	Yes	Yes	Yes
Initial Conditions	Yes	Yes	Yes	Yes	Yes	Yes
Estimation	OLS	OLS	OLS	OLS	OLS	OLS

Source: Authors' calculations.
Note: Robust standard errors parentheses. Discovery is defined as "True Discovery". Cross-sectional estimation using microdata for the year 2000. Densities are specified as the number of firms and workers per square kilometer.

Table 13 further disaggregates the data for services (where we verified an impact of oil discoveries). First, we observe that average firm size in the services sector is significantly higher in the assigned to treatment group. We know from the labor literature (see Idson and Oi (1999), for example) that larger establishments tend to be more productive, and this could be a driver for development. Secondly, the numbers of both skilled and unskilled workers in services is higher in oil MCAs, but while the average skilled wage is also significantly higher, the unskilled wage is not affected.[36] An interesting picture thus emerges. In municipalities in which oil was discovered, more workers are

[36] Skilled workers are defined as those who at least completed high school.

employed in the services sector, services firms are larger, and the skilled workers in the services sector receive higher wages. In other words, the local services sector grows with oil discoveries. The fact that the skilled wage is higher but the unskilled wage is not points to differences in the supply curve for skilled and unskilled workers. The elasticity for unskilled workers appears to be so high that more workers can be attracted at virtually no higher pay, while the supply of skilled workers is relatively more inelastic in comparison.

Table 13. Oil Discoveries and the Services Sector

	Matched Dry Drilling All dependent variables for services sector					
	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLES	ln Firm Size	ln Skilled Worker Density	ln Unskilled Worker Density	Skilled Worker Fraction	ln Avg. Skilled Wage	ln Avg. Unskilled Wage
Discovery Dummy	0.370***	0.711*	0.685**	-0.0188	0.168**	0.0860
	(0.118)	(0.363)	(0.346)	(0.0260)	(0.0793)	(0.0611)
Observations	128	128	128	128	128	128
Number of MCAs	128	128	128	128	128	128
Geographical Controls	Yes	Yes	Yes	Yes	Yes	Yes
Initial Conditions	Yes	Yes	Yes	Yes	Yes	Yes
Estimation	OLS	OLS	OLS	OLS	OLS	OLS

Source: Authors' calculations.

Note: Robust standard errors in parentheses. Discovery is defined as "True Discovery." Cross-sectional estimation using microdata for the year 2000. Densities are specified as the number of firms and workers per square kilometer. Skilled workers are defined as those who at least completed high school.

An interesting question is where the new services workers are drawn from. Neither population density increases, nor does formal employment density in non-services sectors decrease. In other words, there is no significant in-migration, and no sectoral relocation of formal workers. While we cannot rule out that there are changes which are on average too small for us to detect, it seems unlikely that these can fully explain the "new services workers". What appears more likely is that they are mainly drawn from the informal sector. In our sample, the informal sector is very large: On average, only 35 percent of workers are formally employed and only 25 percent have a valid work card.[37]

Table 14 uses population census data to show that oil discoveries are associated with a larger fraction of workers employed in the formal sector. The higher formalization rate offers an explanation for where the additional workers in the services sector come from: They move from the informal to the formal sector. Since the pool of workers in the informal sector tends to be predominantly unskilled, this also explains the higher elasticity of labor supply for unskilled workers.

We also check whether labor force participation increases and the fraction of self-employed workers decreases with oil discoveries (as workers from low productivity self-employed services provision move to larger formal services firms, for example). As shown in Columns (3) and (4) of Table 14 we

[37] The definition of formal employment is from the Brazilian Bureau of Statistics and includes workers with a valid work card, those who work in the military or judiciary, and self-employed workers who contribute to social security.

find evidence for a decline in self-employment but no evidence for a higher labor force participation rate.

Table 14. Oil Discoveries and Labor Informality

	Matched Dry Drilling							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
VARIABLES	Percentage of Workers in the Formal Sector	Percentage of Workers with Valid Employment Card	Labor Force Participation Rate	Percentage of Workers who are Self-Employed	Percentage of Workers Employed in Extractive Industries	Percentage of Workers Employed in Agriculture	Percentage of Workers Employed in Manufacturing	Percentage of Workers Employed in Services
Discovery Dummy	4.352**	4.481***	0.0660	-2.627**	0.579***	-5.364**	-0.0206	4.452**
	(1.710)	(1.635)	(0.850)	(1.316)	(0.214)	(2.632)	(0.742)	(2.191)
Observations	128	128	128	128	128	128	128	128
Number of MCAs	128	128	128	128	128	128	128	128
Geographical Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Initial Conditions	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Estimation	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS

Sorce: Authors' calculations.

Note: Robust standard errors in parentheses. Discovery is defined as "True Discovery". Cross-sectional estimation using microdata for the year 2000. Formal employment includes workers with a valid work card, those who work in the military or judiciary, and self-employed workers who contribute to social security.

To gauge from which informal sector workers move to the formal services sector, we use the population census and decompose the overall workforce into broad categories. Column (5) of Table 14 confirms that in the discovery group a significantly larger fraction of the overall workforce is employed in extractive industries than in the control group. Recall that we showed that the density of *formal* employees in the agricultural sector does not differ between treatment and control group. However, column (6) of Table 14 shows that the overall fraction of workers in the agricultural sector is significantly lower in municipalities which discovered oil. The number of *informal* workers in agriculture must therefore be lower. Columns (7) and (8) confirm the earlier results for the manufacturing and services sectors, that is, no impact on employment in the manufacturing sector and an increase in employment in the services sector.

Brazil still had a large subsistence farming sector during our period of analysis, which employed a substantial number of people with very low productivity. In places with oil discoveries, we can observe a move of these informal agricultural workers to an expanding services sector. Our results indicate that this is the main positive externality from oil discoveries. Overall, places which discovered oil have larger, more productive services sectors, probably driven by an increase in local demand for non-tradables from oil workers and the oil-producing firms. The increased demand for labor leads to more workers being pulled into the services sector and an increase in the wage of skilled workers. The unskilled wage does not increase, as there is ample supply of unskilled workers in the informal agricultural sector. This move from rural informal work to the formal sector in urban areas also explains the observed increase in urbanization.

It is worth noting that no impact on the manufacturing sector was found. This might be somewhat specific to the particular situation of a developing country with relatively little large-scale manufacturing in the affected regions. The impact of oil discoveries on wages of skilled workers in the services sector hinted at the possibility that in locations lacking an ample supply of labor in the informal, subsistence agricultural sector, an upward-sloping labor supply curve would drive up manufacturing wages and potentially lead to the local Dutch-disease type effects often hypothesized. On the other hand, positive technological spillovers from oil production might also exist in regions where there is an important nucleus of high-end manufacturing. In the Brazilian case, the presence of an oil sector and the associated increase in local demand for non-tradables had a strong impact on the development of the local services sector and precipitated a decrease in the highly unproductive subsistence farming sector and thus furthered local economic development.[38]

VI. Conclusion

We investigated the effects of natural resource extraction on local economic development and documented a positive growth effect of oil discoveries. We found a positive impact of oil discoveries on urbanization as well as increases in services GDP, services output per worker, and the size of services firms. We did not find evidence of de-industrialization in oil municipalities. By comparing municipalities where drilling turned up dry wells to those where oil was discovered, we constructed a unique control group based on random assignment. Since we examined the entire track of oil discoveries in Brazil, we were able to provide evidence that there were no pre-treatment differences between our treatment and control groups.

It is important to highlight that our results apply to a specific institutional framework, given that we studied the effects of oil discoveries on the local development of only one country. For instance, the U.S. has a more widespread ownership of resources than Brazil. There are thousands of oil companies in the U.S., in contrast to the historical monopoly of Petrobras in Brazil. Because of this market structure, oil services are more likely to be concentrated in just a few places in Brazil. By contrast, in the U.S. an entire chain of small oil services can be located close to the more widespread oil firms. Finally, we cannot rule out the possibility that oil discoveries positively affect local development of oil municipalities but have adverse effects at the national level (through, for example, a nominal appreciation). We show that at the local level, oil discoveries are not a curse per se, and the pure market effect (i.e., in the absence of any fiscal windfalls) benefits development.

[38] We interact the treatment with baseline manufacturing intensity of the local economy to verify how manufacturing base is associated with economic growth. We found no significant effects as, given the small sample size, the regressions are likely under-powered to detect such an effect. The results are available upon request.

Our results show that natural resource extraction can foster local growth. They also raise the question of whether there should be a stronger focus on redistributing rents from natural resource production across local governments. Given that producing municipalities already benefit from a consumption and investment shock there might be an argument to use the fiscal windfall as an equalizing tool. Further research could usefully explore this question.

On the other hand, going forward, the current low price environment and expectations of subdued prices over the coming years are likely to put considerable pressure on oil producing municipalities. Unless prices recover over the medium-term, the reduction in investment, associated reduction in new discoveries and potential reduction in production could signal the beginning of a painful economic rebalancing process in oil producing municipalities.

Appendix 1

Table A.1. Summary Statistics

Category	Variable	Mean	Std. Dev.	Min.	Max.	N
Outcome Variables	Urban Population/Total population	0.458	0.253	0.015	1	10,197
	Log of Population Density	3.199	1.316	-3.222	9.186	10,198
	Log of GDP per capita	0.501	0.985	-4.602	6.38	7,645
	Share of GDP: Manufacturing	0.195	0.169	0	0.971	11,436
	Share of GDP: Services	0.431	0.171	0.001	0.975	11,443
	Share of GDP: Agriculture	0.362	0.232	0	1	11,437
Oil Variables	All Discoveries Dummy	0.024	0.151	0	1	77,775
	Oil Production Dummy	0.017	0.131	0	1	77,775
	True Discoveries Dummy	0.016	0.125	0	1	77,775
	Stock of Producer Wells	2.47	35.322	0	1814	77,775
	Stock of Discovery Wells	0.371	4.761	0	218	77,775
	Stock of Injection Wells	0.252	4.078	0	131	77,775
Geography	Average Altitude	439.119	303.067	0	1278	77,775
	Average Temperature	22.669	2.841	14.965	27.88	77,775
	Average Rainfall	109.93	34.287	34.63	258.358	77,775
	Indicator: Amazon Region	0.073	0.26	0	1	77,775
	Indicator: Semiarid Region	0.231	0.422	0	1	77,775
	Indicator: Coastal MCA	0.107	0.309	0	1	77,775
Pre-Treatment Variables	Log of Population Density in 1940	2.701	1.305	-3.228	7.562	77,714
	Urbanization Rate in 1940	0.219	0.154	0	1	77,775
	Log of GDP per capita in 1949	-0.326	0.854	-4.602	1.828	77,653

Source: Authors' calculations.

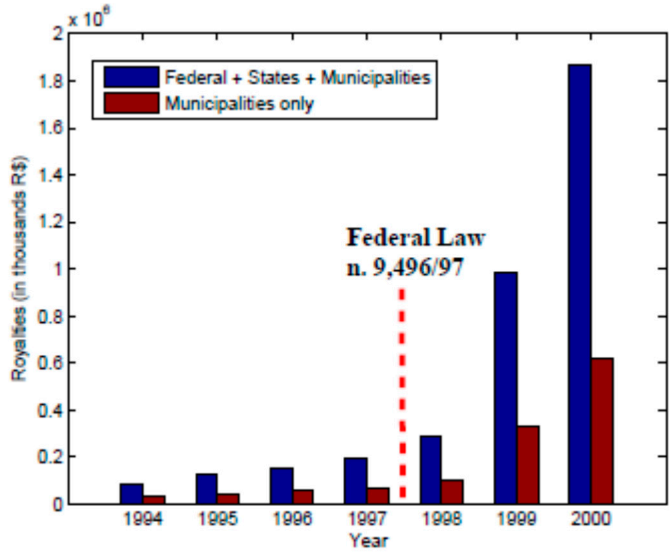
Note: Data from ANP (Brazilian oil and gas industry regulator) and Ipeadata. Data aggregated and treated for 1,275 Minimum Comparable Areas (MCAs). The total number of observations is the product of the number of MCAs and the number of years in our sample (during the period 1940-2000). Temperature is measured in degrees Celsius, precipitation in millimeters per month, and altitude in meters.

A.1.2: Royalties and Oil in Brazil

The distribution of royalties from oil production in Brazil began in 1953. Federal Law n. 2,004/53 stipulated that 5 percent of the revenue from onshore oil production was to be distributed to states (80 percent) and municipalities (20 percent) in the form of royalties. Offshore oil royalties paid to states and municipalities were introduced by 1986. In 1997, Federal Law n. 9,496/97 changed the formula for the distribution of royalties (e.g., the international price of oil was used in the distribution formula for the first time). This led to a huge increase in royalty payments, as illustrated in Figure B.2, transforming it from a minor to a very significant source of income for municipalities.

The 1997 law requires an oil company to allocate between 5 percent and 10 percent of the value of the gross output in the form of royalties. The royalties are then divided among the three administrative levels in Brazil (federal government, states, and municipalities). A municipality is eligible to receive royalties based on (i) geography (if the production takes place within its territory or, in the case of offshore production, if it is a "facing" municipality, that is, there is an oil field that lies inside the municipality's maritime borders), (ii) oil-related infrastructure (if within its borders there is storage, transportation, or landing of oil and gas), and (iii) an equalization rule (there is a "special fund" that allocates part of the revenue from royalties to all the Brazilian municipalities). For some municipalities, royalties represent a significant part of their total revenue (more than half in extreme cases). According to ANP (Brazil's oil and gas industry regulator), over R$4.5 billion (circa US$2.2 billion) in oil windfalls was distributed to the Brazilian municipalities in 2010, which represented on average 2.5 percent of the total revenue of municipalities receiving oil windfalls.

Figure A.1: Distribution of Royalties: 1994–2000



Sources: ANP and authors' calculations.

For a much more detailed description of the history and technicalities of royalty payments in Brazil, see Caselli and Michaels (2013) and Monteiro and Ferraz (2012).

Appendix 2. Using Microdata from RAIS and the Population Census

In Section V.C, we use two sources of data. First, we use a matched worker–firm microdata from the Ministry of Labor's RAIS (*Relação Anual de Informações Sociais*). The RAIS dataset has information on each formal worker at each plant in Brazil. In 2000, there were 36,907,953 formal workers in the dataset. This information was useful to construct measures of average wages, as well as the numbers of workers and firms by skill and sector at the municipal level. We also calculate firm density and worker density, which are specified as the number of firms and workers, respectively, per square kilometer. We complement the analysis by using microdata from the 2000 population census, collected by the Brazilian Bureau of Statistics. The population census data allow us to calculate the fraction of workers employed in the formal sector by municipality, labor force participation, and sectoral employment shares.

In the analysis, we use cross-sectional data for the year 2000, because this is the first year for which high-quality data from both the employment and population censuses are available. The RAIS data have been collected annually since the late 1980s but are considered to have been of high quality only since the mid-1990s. The population census data are collected once per decade, making 2000 the first year in which it overlapped with reliable RAIS data.

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