

Supplementary Material

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

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This document is a companion (online) appendix to our paper “Winning the Oil Lottery: The Impact of Natural Resource Extraction on Growth”. Here, we describe the dataset and variables used in our paper, provide some robustness exercises and present extra tables. We also provide a more detailed discussion of (i) the principles and practices of oil extraction and production and of (ii) the distribution of oil royalties in Brazil. Finally, we present an analysis of treatment intensity.

A Appendix: Data and Extra Tables

A.1 Historical Data

Figure A.1 shows the boundaries of municipalities in 1997 and the corresponding MCAs in 1940. All variables used in the paper are aggregated at the MCA level when provided at the municipal level.

One of our main outcome variables is municipal GDP. Reis et al. (2004) used the sectoral value-added from Economic Censuses to calculate the sectoral municipal GDP as follows:

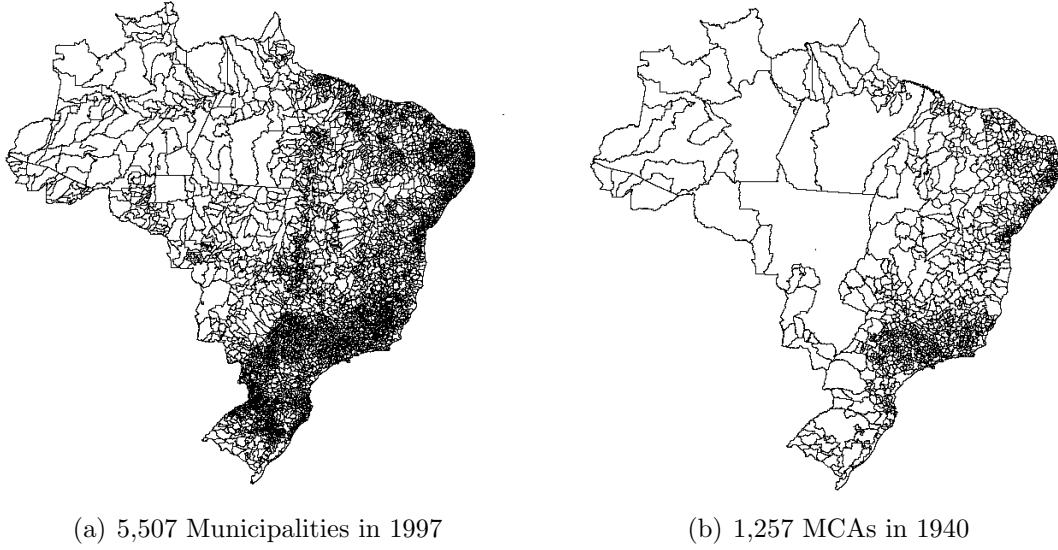
$$GDP_{ims} = \frac{VA_{ims}}{\sum_m VA_{ims}} GDP_{is}$$

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Fig. A.1: Municipalities and Minimum Comparable Areas (MCAs)



Notes. Figure A.1(a) shows the administrative boundaries of the 5,507 municipalities that existed in 1997 in Brazil. Figure A.1(b) shows the aggregation to the 1,275 Minimum Comparable Areas (MCAs) in 1940.

where VA_{ims} is the value added of sector i of municipality m in state s , GDP_{is} is the sectoral state-level GDP, and GDP_{ims} is the sectoral municipal-level GDP.

Sectoral GDPs (GDP_{ims}) were then added so as to calculate the total municipal GDP (GDP_{ms}). Data for agriculture, manufacturing, and the bulk of services exist in each historical Economic Census. For few year, the Censuses have data for virtually every economic sector, including detailed data on transportation, warehousing, public administration, retail, and wholesale. Oil and Mining were included in the manufacturing GDP. The GDP is deflated using the national implicit price deflator.

One should bear in mind at least three caveats when interpreting the GDP data. Firstly, in some Economic Censuses one cannot find output and input data for all economic sectors, so total municipal GDP was not feasible to be constructed. In order to obtain municipal-level GDPs through time, Reis et al. (2004) imputed the missing sectors by using shares of state-level sector GDP.¹ Secondly, as we are using a long time series, items which are considered output and input differ for distinct Economic Censuses. Lastly, 1996 and 2000 GDP data were constructed using different sources, so one needs to be cautious comparing different years (however, reliability increases over time).

We combine data from historical Population Censuses and Economic Censuses to construct our outcome variables from 1940 to 2000. The panel data are balanced, and we do not observe any attrition. However, the time dimension is unequally spaced for

¹The imputation of the Economic Censuses was done using wage data from the Population Censuses. Notice that Economic and Population Censuses were carried out in different years.

GDP *per capita*. Because Population Censuses were historically only conducted every 10 years and there are no data on GDP for 1990 or 1991, we end up with GDP *per capita* data for the years 1949, 1959, 1970, 1980, 1996, and 2000. In 1996, we use the Brazilian Institute for Statistics' official count as the population number. By contrast, our panel is virtually equally spaced in time for two dependent variables (urbanization rate and population density): 1940, 1950, 1960, 1970, 1980, 1991, 1996, and 2000. Employment data is for 1940, 1950, 1970, 1980, 1991, and 2000. The 1960 Census sample does not allow us to construct employment measures at the local level.

A.2 Comparison of Treatment and Control Groups

We used the normalized difference (ND) to study the overlap between our treatment and control groups. The 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

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

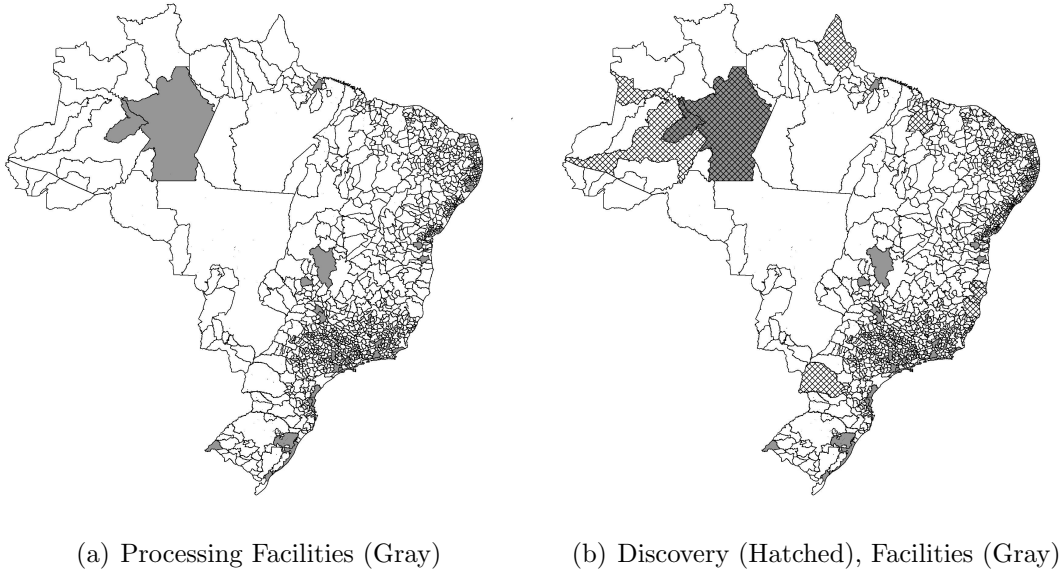
where p_t and p_c are the proportions (prevalences) for the treated and control groups, respectively.

The pre-treatment characteristics used in the propensity score model include: population density in 1940, urbanization rate in 1940, GDP *per capita* in 1949, share of manufacturing out of the total GDP in 1949, share of services in 1949, share of agriculture in 1949, geographical indicators (whether the MCA is located on the coast, in the semiarid region, or in the Amazon region), historical average rainfall and temperature, and latitude and longitude. Since the very large share of relevant discoveries took place after the creation of Petrobras in 1953 (oil was discovered in only 9 wells during the 1940s), the GDP variable for 1949 can be considered pre-treatment.

A.3 Downstream Production Data

We collected data on the location and date of construction of all refineries, directly oil-related factories (such as petrochemical plants) and oil terminals. We also collected data on thermoelectric power plants, which are associated with the oil and gas industry. Information on the construction date of each refinery, and of each onshore or offshore terminal, is from Petrobras and Transpetro. Information on the construction dates of

Fig. A.2: Processing Facilities



Notes. The figures show 1,275 Minimum Comparable Areas (MCAs) in 1940. The discovery dummy is the “All Discoveries” dummy (which is equal to one when at least one field, subfield, or field extension discovery was made in the MCA).

petrochemical plants and thermoelectric power plants is from Petrobras and various online sources. By the year 2000 there were 15 refineries or directly oil-related factories, 18 onshore oil terminals, 22 offshore terminals, and 2 thermoelectric power plants in Brazil. Using these data we constructed an indicator which we set equal to 1 if an MCA has at least one of those oil-related processing or transportation facilities.

To evaluate the link between the upstream and downstream oil sectors, we regress the production facilities dummy on the indicator for “True Discoveries”. As in the baseline regressions, a full set of controls is included. We include MCA and year fixed effects and clustered standard errors at the MCA level. Regardless of the control group, the coefficient for the true discoveries dummy is positive and significant. We observe that discoveries increase the probability of hosting a downstream facility by roughly 10%, which is not negligible but not overwhelming either (see Table A.1). This rises to 15% when we use an ad-hoc measure for large discoveries (top 20 in the year 2000 in terms of number of discovery wells).

We also collected data provided by ANP (2001) detailing which municipalities they classify as the main production and main production support sites, respectively. The idea is to perform an additional test of the hypothesis that production facilities are more likely to be located in MCAs in which large reserves of oil were discovered. Main production sites are defined as locations with facilities for processing, treating, storing, and transporting oil. Support sites are those with ports, airports, heliports, offices, or similar facilities used to support the extraction, production, and processing of oil. We

Table A.1: Discoveries and Processing Facilities

VARIABLES	Matched Dry Drilling	
	(1)	(2)
	Production Facilities Dummy	Production Facilities Dummy
Discovery Dummy	0.102** (0.0486)	
Large Discovery Dummy		0.147** (0.0709)
MCA FE	Yes	Yes
Year FE	Yes	Yes
Observations	896	896
Number of MCAs	128	128
Geographical Controls	Yes	Yes
Initial Conditions	Yes	Yes
Estimation	FE	FE

Notes. Standard errors clustered at the MCA level. Geographical controls and initial conditions have time-varying coefficients. The initial conditions with time-varying coefficients are GDP *per capita* in 1949, urbanization rate in 1940, and population density in 1940. The geographical controls with time-varying coefficients are latitude and longitude, the Amazon dummy, and the coastal dummy. Discovery is defined as “True Discovery”. “Large Discovery” is a discovery which makes the hosting municipality one of the top 20 in terms of number of wells.
*** p<0.01, ** p<0.05, * p<0.1

match these municipal data to the relevant MCAs and then construct a new indicator at the MCA level. Unfortunately, the data are available for only the year 2000, so we do not know the year in which the various municipalities first became main production or support sites. Therefore, we are unable to use these variables in a panel regression. Nevertheless, it is worth pointing out that the correlations between having had a discovery and being a main production or main production support site are 0.2466 and 0.2747, respectively.

A.4 Extra Tables

Table A.2: Summary Statistics: Minimum Comparable Areas

Category	Variable	Mean	Std. Dev.	Min.	Max.	N
Outcome Variables in 1940	Urbanization Rate	0.22	0.15	0.01	1.00	1,274
	Population Density	30.27	71.75	0.05	1,440.67	1,274
	Worker Density	10.23	22.94	0.00	492.33	1,275
	Share of Workers in Agriculture	0.77	0.18	0.03	0.97	1,268
	Share of Workers in Manufacturing and Extractive	0.07	0.07	0.00	0.68	1,268
	Share of Workers in Retail	0.03	0.03	0.00	0.26	1,268
	Share of Workers in Transport	0.02	0.03	0.00	0.30	1,268
	Share of Workers in Services	0.06	0.05	0.01	0.35	1,268
	Share of Workers in Public Sector	0.01	0.01	0.00	0.15	1,268
	GDP per capita	1.01	0.86	0.01	6.22	1,273
	Share of GDP: Agriculture	0.53	0.23	0.00	1.00	1,273
Outcome Variables in 2000	Share of GDP: Manufacturing and Extractive	0.13	0.14	0.00	0.84	1,257
	Share of GDP: Services	0.35	0.18	0.01	0.94	1,261
	Urbanization Rate	0.67	0.20	0.16	1.00	1,275
	Population Density	116.83	483.80	0.20	9,764.94	1,275
	Worker Density	43.81	178.11	0.05	3,201.31	1,275
	Share of Workers in Agriculture	0.35	0.20	0.00	0.79	1,275
	Share of Workers in Manufacturing and Extractive	0.11	0.08	0.00	0.50	1,275
	Share of Workers in Retail	0.13	0.05	0.02	0.30	1,275
	Share of Workers in Transport	0.04	0.02	0.00	0.12	1,275
	Share of Workers in Services	0.31	0.10	0.10	0.69	1,275
	Share of Workers in Public Sector	0.05	0.03	0.01	0.27	1,275
Oil Variables in 2000	GDP per capita	4.55	5.99	0.77	123.70	1,275
	Share of GDP: Agriculture	0.18	0.13	0.00	0.70	1,275
	Share of GDP: Manufacturing and Extractive	0.18	0.12	0.03	0.83	1,275
	Share of GDP: Services	0.58	0.13	0.10	0.85	1,275
	All Discoveries Dummy	0.05	0.22	0	1	1,275
	Oil Production Dummy	0.04	0.191	0	1	1,275
Geography	True Discoveries Dummy	0.04	0.18	0	1	1,275
	Stock of Producer Wells	8.22	80.68	0	1,814	1,275
	Stock of Discovery Wells	1.12	10.06	0	218	1,275
	Stock of Injection Wells	0.77	7.89	0	131	1,275
	Average Altitude	439.15	303.15	0	1,278	1,275
	Average Temperature	22.67	2.84	14.97	27.88	1,275
Geography	Average Rainfall	109.92	34.30	34.63	258.36	1,275
	Indicator: Amazon Region	0.07	0.26	0	1	1,275
	Indicator: Semiarid Region	0.23	0.42	0	1	1,275
	Indicator: Coastal MCA	0.11	0.31	0	1	1,275
	Latitude	-16.05	7.59	-33.19	2.16	1,275
	Longitude	-44.16	5.61	-73.01	-32.43	1,275

Notes. Data from ANP (Brazilian oil and gas industry regulator), Population Censuses, Economic Censuses, and Ipeadata. Data aggregated and treated for 1,275 Minimum Comparable Areas (MCAs). Densities are specified as population per square kilometer. The urbanization rate is the proportion of the population living in urban areas. Temperature is measured in degrees Celsius, precipitation in millimeters per month, and altitude in meters. GDP numbers are deflated using the national implicit price deflator and are in thousand Reais of 2000. For the “Outcome Variables in 1940”, GDP numbers are for the year 1949.

Table A.3: Drilling, Conditional on a Field Discovery

	(1)	(2)
Dependent variable:	Wells drilled per year	
Estimation:	OLS	Poisson
Field Discovery Dummy	4.900** (2.091)	5.449*** (0.334)
Field Discovery Dummy * log Population Density	-0.476 (0.976)	-0.0610 (0.103)
Field Discovery Dummy * log GDP/capita	0.877 (0.897)	0.107 (0.106)
Field Discovery Dummy * Urbanization	9.325 (8.167)	1.157 (0.870)
Field Discovery Dummy * log Worker Density	4.706 (5.925)	0.690 (0.829)
Constant	0.023*** (0.005)	-3.793*** (0.206)
Observations	3,821	3,821

Notes. Robust standard errors in parentheses. The regressions are for 1,275 Minimum Comparable Areas (MCAs). The dependent variable is the count of drills per year. The explanatory variables are a dummy for a field discovery and the interactions between this dummy and GDP/capita, urbanization, and population density.
*** p<0.01, ** p<0.05, * p<0.1

Table A.4: Spillovers to Neighbors

	SUTVA			
	(1)	(2)	(3)	(4)
VARIABLES	ln GDP <i>per capita</i>	ln Population Density	ln Workers Density	Urbanization Rate
“Discovery” in Neighboring MCA	-0.0227 (0.0305)	0.0415 (0.0369)	0.0199 (0.0390)	0.00397 (0.0107)
MCA FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Observations	7,252	9,672	7,248	9,672
Number of MCAs	1,209	1,209	1,209	1,209
Geographical Controls	Yes	Yes	Yes	Yes
Initial Conditions	Yes	Yes	Yes	Yes
Estimation	FE	FE	FE	FE

Notes. Standard errors clustered at the MCA level. Geographical controls and initial conditions have time-varying coefficients. The initial conditions with time-varying coefficients are: GDP *per capita* in 1949, Urbanization rate in 1940, Worker Density in 1940, and Population Density in 1940. The geographical controls with time-varying coefficients are: Latitude and Longitude coordinates, dummy for Amazon, and dummy for coastal location.

*** p<0.01, ** p<0.05, * p<0.1

Table A.5: Growth Rates

VARIABLES	Growth Rates			
	(1)	(2)	(3)	(4)
	Annual growth rate of GDP <i>per capita</i>	Annual growth rate of pop- ulation density	Annual growth rate of workers density	Annual change in urbaniz- ation rate
Discovery (past decade)	0.0310* (0.0157)	0.00380 (0.00423)	0.000548 (0.00412)	0.00380* (0.00203)
Discovery (current decade)	0.0102 (0.00941)	0.00170 (0.00337)	0.00475 (0.00373)	-0.00111 (0.00144)
MCA FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Observations	640	896	639	896
Number of MCAs	128	128	128	128
Geographical Controls	Yes	Yes	Yes	Yes
Initial Conditions	Yes	Yes	Yes	Yes
Estimation	FE	FE	FE	FE

Notes. Standard errors clustered at the MCA level. Geographical controls and initial conditions have time-varying coefficients. The initial conditions with time-varying coefficients are: GDP *per capita* in 1949, Urbanization rate in 1940, Worker Density in 1940, and Population Density in 1940. The geographical controls with time-varying coefficients are: Latitude and Longitude coordinates, dummy for Amazon, and dummy for coastal location.

*** p<0.01, ** p<0.05, * p<0.1

Table A.6: Intention-to-Treat Effect of True Oil Discoveries: Education

VARIABLES	Matched Dry Drilling					
	(1)	(2)	(3)	(4)	(5)	(6)
	Average Schooling	% Adults with more than 11 years of schooling	% Adults with less than 4 years of schooling	Average Schooling	% Adults with more than 11 years of schooling	% Adults with less than 4 years of schooling
Discovery Dummy	0.165 (0.122)	0.304 (0.308)	-2.593** (1.294)	0.201 (0.168)	-0.491 (0.424)	-3.193 (1.990)
MCA FE	Yes	Yes	Yes	No	No	No
Year FE	Yes	Yes	Yes	No	No	No
Observations	512	512	512	128	128	128
Number of MCAs	128	128	128	128	128	128
Period	1970–2000	1970–2000	1970–2000	2000	2000	2000
Geographical Controls	Yes	Yes	Yes	Yes	Yes	Yes
Initial Conditions	Yes	Yes	Yes	Yes	Yes	Yes
Estimation	FE	FE	FE	OLS	OLS	OLS

Notes. This table shows the results of estimating Equation 2 in Columns (1)-(3) and Equation 4 in Columns (4)-(6). Discovery is defined as “True Discovery”. In Columns (1)-(3), standard errors clustered at the MCA level, and geographical controls and initial conditions have time-varying coefficients. The initial conditions with time-varying coefficients are: GDP *per capita* in 1949, Urbanization rate in 1940, Worker Density in 1940, and Population Density in 1940. The geographical controls with time-varying coefficients are: Latitude and Longitude coordinates, dummy for Amazon, and dummy for coastal location. In Columns (4)-(6), robust standard errors in parentheses and the initial conditions are the following pre-treatment variables: urbanization rate in 1940, population density in 1940, worker density in 1940 and *per capita* GDP in 1949. In Columns (4)-(6), the geographical controls are: Latitude and Longitude coordinates and indicator variables showing whether the MCA is located in the semiarid region, in the Amazon region, or on the coast.

*** p<0.01, ** p<0.05, * p<0.1

Table A.7: Correlation between Institutions and Oil Discovery

	Institutional Quality Index (1)
Discovery Dummy	0.0229 (0.0763)
MCA FE	Yes
Observations	128
Number of MCAs	128
Geographical Controls	Yes
Initials Conditions	Yes
Estimation	OLS

Notes. This table shows the results of estimating Equation 4. It shows the correlation between oil discoveries and an index of institutional quality in Brazil (Ministry of Planning (2017)) . Robust standard errors in parentheses. 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.

*** p<0.01, ** p<0.05, *p<0.1

Table A.8: Intention-to-Treat Effect of True Oil Discoveries: Adding a Dummy for Democratic Periods

VARIABLES	Matched Dry Drilling			
	(1)	(2)	(3)	(4)
	ln GDP <i>per capita</i>	ln Population Density	ln Workers Density	Urbaniz- ation Rate
Discovery Dummy	0.295*** (0.110)	-0.0300 (0.0647)	-0.0602 (0.0760)	0.0493** (0.0233)
Discovery Dummy * Democracy Dummy	-0 .0514 (0.122)	0.0230 (0.0471)	0.0311 (0.0587)	-0.00843 (0.0217)
Democracy Dummy	Yes	Yes	Yes	Yes
MCA FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Observations	768	1,024	767	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

Notes. This table shows the results of estimating Equation 2. Standard errors clustered at the MCA level. Geographical controls and initial conditions have time-varying coefficients. The initial conditions with time-varying coefficients are: GDP *per capita* in 1949, Urbanization rate in 1940, Worker Density in 1940, and Population Density in 1940. The geographical controls with time-varying coefficients are: Latitude and Longitude coordinates, dummy for Amazon, and dummy for coastal location. Discovery is defined as “True Discovery”. The dummy for democracy which is set to 1 for years 1946-1963 and from 1986 onwards.

*** p<0.01, ** p<0.05, * p<0.1

**Table A.9: Intention-to-Treat Effect of All Oil Discoveries: Robustness to
Adding more Geographic Controls, with 1996 as Final Year of Analysis, and Excluding Locations with Downstream
Production**

VARIABLES	Control Group: Matched Dry Drilling											
	Adding more Geographic Controls				1996 as Final Year of Analysis				Excluding Locations with Downstream Production			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
	ln GDP <i>per capita</i>	ln Population Density	ln Workers Density	Urbanization Rate	ln GDP <i>per capita</i>	ln Population Density	ln Workers Density	Urbanization Rate	ln GDP <i>per capita</i>	ln Population Density	ln Workers Density	Urbanization Rate
Discovery Dummy	0.211** (0.0939)	-0.0208 (0.0827)	-0.0464 (0.0905)	0.0447* (0.0231)	0.225** (0.0969)	-0.0242 (0.0698)	-0.0573 (0.0808)	0.0449** (0.0210)	0.211*** (0.0738)	-0.00430 (0.0730)	-0.0250 (0.0800)	0.0424* (0.0238)
MCA FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	768	1,024	767	1,024	640	896	639	896	678	904	677	904
Number of MCAs	128	128	128	128	128	128	128	128	113	113	113	113
Geographical Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Initial Conditions	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Estimation	FE	FE	FE	FE	FE	FE	FE	FE	FE	FE	FE	FE

Notes. Standard errors clustered at the MCA level. Additional geographical controls are average temperature, average rainfall, average altitude and the semiarid dummy. Discovery is defined as "True Discovery". The initial conditions with time-varying coefficients are: GDP *per capita* in 1949, Urbanization rate in 1940, Worker Density in 1940, and Population Density in 1940. The geographical controls with time-varying coefficients are: Latitude and Longitude coordinates, dummy for Amazon, dummy for coastal location, average temperature, average rainfall, average altitude and the semiarid dummy.

*** p<0.01, ** p<0.05, * p<0.1

Table A.10: Intention-to-Treat Effect of All Oil Discoveries: Robustness to Alternative Clustering of Standard Errors

VARIABLES	Two-Way Clustering				Spatial Clustering			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	ln GDP <i>per capita</i>	ln Population Density	ln Workers Density	Urbaniz- ation Rate	ln GDP <i>per capita</i>	ln Population Density	ln Workers Density	Urbaniz- ation Rate
Discovery Dummy	0.259** (0.0795)	-0.0127 (0.0728)	-0.0394 (0.0819)	0.0430* (0.0213)	0.259*** (0.0546)	-0.0127 (0.0477)	-0.0394 (0.0580)	0.0430*** (0.0137)
MCA FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	768	1,024	767	1,024	768	1,024	767	1,024
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	FE	FE	FE	FE	FE	FE	FE	FE

Notes. In Columns (1)–(4) standard errors are clustered at the year and MCA level. In Columns (5)–(8) standard errors are clustered using Conley (1999)’s approach. Geographical controls and initial conditions have time-varying coefficients. The initial conditions with time-varying coefficients are: GDP *per capita* in 1949, Urbanization rate in 1940, Worker Density in 1940, and Population Density in 1940. The geographical controls with time-varying coefficients are: Latitude and Longitude coordinates, dummy for Amazon, and dummy for coastal location.

*** p<0.01, ** p<0.05, * p<0.1

Table A.11: 2SLS Estimation of the Mechanisms: Oil Discoveries, Wages, Worker Density, and Firm Density in 2000

VARIABLES		Control Group: Matched Dry Drilling																					
		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	
Baseline Results		ln GDP <i>per capita</i>	ln Populat- ion Density	ln Worker Density	Urbaniz- ation Rate	ln Worker Density Formal Sector	% Workers in the Formal Sector	ln Firm Density	ln Average Wage	Firm Manufact- uring	Services	Agricult- ure	Worker Density	Manufact- uring	Services	Agricult- ure	ln Firm Size	ln Skilled Worker Density	ln Unskilled Worker Density	Skilled Worker Fraction	Avg. Skilled Wage	ln Avg. Unskilled Wage	Fraction Total Workers
Production Dummy		0.615*** (0.191)	-0.0417 (0.199)	-0.0964 (0.210)	0.0854* (0.0480)	0.785* (0.467)	6.753** (2.804)	0.597 (0.462)	0.287*** (0.115)	0.473 (0.532)	0.661 (0.488)	0.429 (0.460)	0.519 (0.705)	1.234** (0.582)	0.854 (0.593)	0.573*** (0.186)	1.103* (0.587)	1.072* (0.576)	-0.0292 (0.0409)	0.261** (0.120)	0.135 (0.0933)	-0.0874* (0.0450)	
Observations		128	128	128	128	128	128	128	128	121	128	122	121	128	122	128	128	127	128	128	127	128	
Number of MCAs		128	128	128	128	128	128	128	128	121	128	122	121	128	122	128	128	127	128	128	127	128	
Geographical Controls		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
Initial Conditions		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
First-stage F-statistics		20.56	20.56	20.56	20.56	20.56	20.56	20.56	20.56	20.12	20.56	20.36	20.12	20.56	20.36	20.56	20.56	20.39	20.56	20.39	20.56	20.56	
Estimation		IV	IV	IV	IV	IV	IV	IV	IV	IV	IV	IV	IV	IV	IV	IV	IV	IV	IV	IV	IV	IV	

Notes. 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. The pre-treatment variables are urbanization rate in 1940, population density in 1940, worker density in 1940 and *per capita* GDP in 1949. The geographical controls are Latitude and Longitude coordinates and indicator variables showing whether the MCA is located in the semiarid region, in the Amazon region, or on the coast.

*** p<0.01, ** p<0.05, * p<0.1

Table A.12: Correlation between Drilling Attempts and Pre-Treatment Characteristics

	(1)	(2)	(3)	(4)
Dependent variable:	Drilling Dummy		Drilling Count	
	Linear Probability	Logit	Linear Probability	Poisson
Urbanization in 1940	0.0575 (0.0939)	0.481 (0.837)	28.32 (22.22)	1.284 (0.888)
Pop. Density in 1940	-0.000343 (0.000249)	-0.00171 (0.00161)	-2.722 (3.354)	-0.177 (0.167)
GDP <i>per capita</i> in 1949	-0.00712 (0.0144)	-0.0787 (0.156)	3.413 (8.567)	0.129 (0.404)
Semiarid Indicator	0.00742 (0.0220)	0.0938 (0.232)	20.63 (19.95)	1.292* (0.782)
Amazon Indicator	0.395*** (0.0530)	2.292*** (0.276)	-7.137 (7.567)	-0.809* (0.470)
Coastal Indicator	0.518*** (0.0443)	2.776*** (0.243)	90.65*** (34.54)	3.001*** (0.651)
Constant	0.0934*** (0.018)	-2.314*** (0.184)	3.725 (8.538)	1.572*** (0.374)
Observations	1,275	1,275	1,273	1,273
R-squared	0.255	-	0.053	-

Notes. This table shows the correlation between well drilling and a set of pre-drilling MCA characteristics. Robust standard errors in parentheses. The regressions are for 1,275 Minimum Comparable Areas (MCAs). There are two dependent variables: a dummy variable that is equal to 1 if any drilling attempt was made during the years 1940 to 2000 (columns (1) and (2) of the table) and the number of drilling attempts made during that period (columns (3) and (4) of the table). The pre-drilling 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.

*** p<0.01, ** p<0.05, * p<0.1

B Appendix: More Details on Oil Extraction and the Institutional Background

B.1 On Oil Drilling and Production

There is an extensive literature on the principles and practices of oil drilling and production (e.g., from petroleum geology and petroleum engineering). In this appendix, we aim to clarify selected aspects of drilling and production that are relevant to our research design, without detailing every single aspect of oil (and gas) exploration and production.

Oil exploration and production are associated with risk. Although there are several technical methods for appraising hydrocarbon resources, the industry always works with limited information on the existence of hydrocarbon deposits. The uncertainty is related to the location, volume, and quality of hydrocarbon deposits. Even with enough geological information, there is always the risk of drilling a dry exploratory hole or not discovering commercial quantities of oil. There are also risks during the production phase, such as the price of oil, costs and taxes, institutional uncertainty, regulation, natural disasters, and accidents. Offshore drilling in deep water presents even greater challenges. According to Harbaugh et al. (1995), luck is a major factor in oil exploration. The name for an exploratory well (called a “wildcat”) speaks for itself regarding the inherent risk of the oil business.

The petroleum industry is loosely divided into two segments: upstream and downstream. The upstream industry comprises exploration and production activities, where production activities means the process of recovering petroleum from the subsurface. Upstream activities occur both onshore and offshore. The downstream industry entails processing, retailing, and transporting of petroleum.

Oil exploration involves several steps and uses a compilation of knowledge from geology, geophysics, and geochemistry. The oil company aims to find an oil field — a contiguous geographic area with oil. First, petroleum professionals collect useful geological information on a “prospect” (a delimited area that possesses certain geological features that may induce drilling). By “useful information,” they mean a source rock, a reservoir, and a trap.² A *source rock* is a rock within which oil or gas is generated from organic material (Petroleum Extension Service (2005)). A source rock is usually a shale rock. Nevertheless, not every shale has enough biogenic material to be classified as a source rock. A *reservoir* accumulates hydrocarbons and is made from porous rocks.

²There are three types of rock according to how they are formed: igneous (from magma), sedimentary (from erosion), and metamorphic (a heated sedimentary or igneous rock). Sedimentary rocks are of great interest in regard to oil production, because they are the ones in which petroleum accumulation chiefly occurs. An example of a sedimentary rock is shale, which originates as clay and is compacted by subsurface pressure and weight. Other examples of sedimentary rock are sandstone (from sand) and limestone (from shells).

Porosity is needed for the accumulation of hydrocarbons, and basically only sedimentary rocks are porous enough. Typical sedimentary rocks that form a reservoir include sandstone and limestone. The “quality” of the oil inside the reservoir can vary, depending on its properties and impurities (e.g., the presence of sulfur and metals). The company also looks for areas with specific geological features called *traps*. A hydrocarbon trap is composed of two elements: a structure (subsurface contortion) and a seal. Hydrocarbon molecules are lighter than water, and there are subsurface contortions that induce the hydrocarbons to move upward towards the surface (e.g., anticlines and faults). Therefore, there is a need for a “seal” to prevent the hydrocarbons from spilling out onto the surface. A seal is a rock with low permeability. (Just as porosity is important for the accumulation of hydrocarbons in a reservoir, the degree of connections between pores in a rock formation determines whether a rock can serve as a seal.) Although shale has high porosity, it also has very low permeability, and typically makes for a good seal.

In sum, the area should possess certain characteristics, such as abundant sandstone for reservoir rocks, shale for hydrocarbon source rocks, and numerous geological structures for potential trapping of hydrocarbons. Each oil field has its own “fingerprint” and its unique characteristics lead to a case-by-case analysis of drilling attempts. Wells are very expensive to drill, so studies in advance of a decision to drill must be as accurate and precise as possible.

If there are strong indications of potentially oil-bearing formations, the oil company may drill an exploratory well. Even with all positive indications of oil, only by *making a hole* can the company be sure of the presence (or absence) of oil. During the drilling process, data acquisition is key. There are several “logging-while-drilling” (information-recording) procedures that are performed during the drilling phase, for example, to differentiate between permeable and impermeable rock formations.³ Depending on the outcome of the exploratory drilling, the company evaluates the well’s hydrocarbon potential. Not even evidence of hydrocarbon deposits as indicated in the logs is a guarantee that oil production is feasible. One can assign *a priori* probabilities before drilling, and then revise the probability of success given the result of the drilling attempt. Updated probabilities can be used as a source of knowledge to be applied to future drilling attempts. Depending on the preliminary information accumulated during drilling, the well can be abandoned or not. In the end, using all information available the company decides whether the drilling generated a discovery or a *dry hole*.

After a discovery, the appraisal continues: Additional drilling is required to delineate the size and extension of the oil field.⁴ “Step-out” wells (delineation or appraising wells) are the wells used to evaluate the extent of the field. The more that is known about the

³One example is the logging of information on the cuttings of rock brought to the surface by the circulating drilling fluid.

⁴“Play” is the name used to describe the extent of a hydrocarbon-bearing formation.

oil field, the easier and less expensive to drill additional wells. Generally, the number of step-out wells is positively correlated with the magnitude of the field that was discovered. Once the oil company has delineated the oil field and is confident about the viability of production, it undertakes to *complete* the existing wells and drill additional production wells (producer wells). To complete a well means to perform the necessary operations to bring fluids to the surface (Petroleum Extension Service (1997)). After completion and the drilling of producer wells, the oil and gas production cycle begins. Production cycle occurs after exploration has proven successful. An economic assessment of the production cycle should entail reserve and risk calculations (Hyne (2001)).

The production cycle involves a natural phase and an enhanced phase. Initially, natural pressure in the reservoir brings oil from the reservoir to the surface. Normally, the reservoir pressure falls as production proceeds, and the oil company needs to (artificially) increase the pressure in the well. The addition of artificial pressure to optimize production is broadly called “enhanced oil recovery” and is divided into primary, secondary, and tertiary recovery. *Primary recovery* (or primary production) means to use an artificial method of lifting. The most common artificial lift system is a *beam pump* to pump up the oil. During primary recovery, only a small percentage of the hydrocarbon deposits are extracted. *Secondary recovery* aims to restore the reservoir pressure by injecting water (waterflooding) or gas. Secondary recovery is costly, because it requires huge amounts of water or gas. To boost the pressure once it begins to fall, new wells are drilled (injection wells) for injection of water and gas, usually at the edges of the oil field. This injection aims either to slow a decline in production or to increase production. Finally, *tertiary recovery* is done by injection of steam or special chemicals (chemical flooding) into the reservoir. In practice, all three recovery phases can occur concurrently.⁵

Enhanced recovery is so important in the petroleum industry that the location of the producer well is chosen with the secondary well (injection well) in mind. As mentioned before, efforts to enhance recovery are costly and are dependent upon the state of the economy and the potential oil recovery volume. Consequently, repeated monitoring of a reservoir is essential to choose the best locations for the injection wells. The idea is to design an optimal distribution of injection wells so as to optimize long-term production.

There are several types of wells: wildcat well, rank wildcat well, step-out well, producer well, injection well, etc. Since there are different steps in the process of obtaining oil, wells are classified broadly as exploratory wells and development wells. Examples of *exploratory wells* are wildcat wells (drilled a mile or more from an area of existing oil production) and rank wildcat wells (drilled in an area where there is no existing production). If the exploratory drilling proves successful, the company starts to drill step-out wells (also included in the exploratory well category). After the oil field has been delineated, the company starts to drill production wells within the known extent of the field.

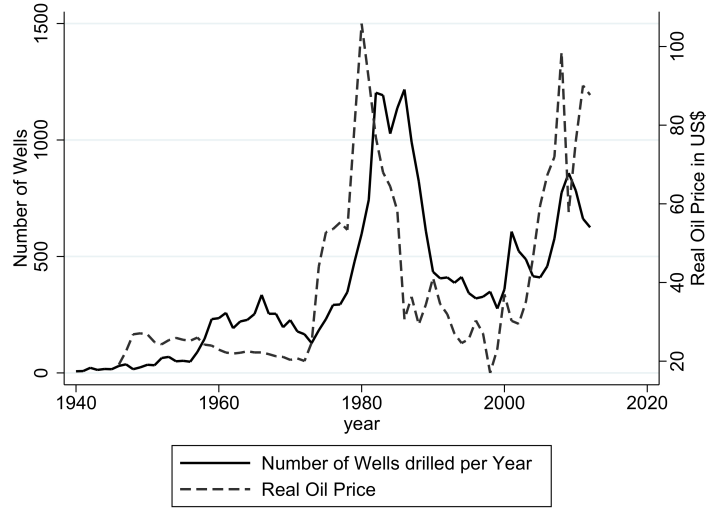
⁵There are other forms of well stimulation such as hydraulic fracturing.

Every well drilled inside the known extent of the field is called a *development well* (Hyne (2001)). The development well category includes producer wells and injection wells (recall that injection wells are drilled to enhance oil recovery). Different categories of wells have different probabilities of finding oil. On average, rank wildcat exploratory wells have lower success ratio than step-out wells. An oil company can rank wells in terms of probability, even in the face of uncertainty. The American Petroleum Institute reported that in 2000 the success rate for wildcat wells was 39% (Hyne (2001)). Note that an unsuccessful drilling is classified as a dry hole in both exploratory and development well categories.

The evolution of knowledge of how to identify potentially oil-bearing formations comprises both advances in the theory of petroleum-bearing formations and ever-improving technology. In the early days of oil exploration, conspicuous targets were searched for oil, either without applying geology theory (e.g., surface pools in the form of natural oil seeps) or by using knowledge of geology (e.g., anticlines and salt domes). Investigation of the surface (topography) of a region could point to conspicuous areas of oil-bearing formations. In the 1920s and 1930s, aerial photography expanded the possibilities for mapping areas suitable for drilling. In the mid 1900s, seismic technology improved subsurface mapping for the location of potential petroleum-bearing formations. By and large, seismic activity produces sound waves that can be used to characterize subsurface formations, that is, sound waves are generated and recorded by receivers, and that information could be used to infer rock formations. The idea is to map the subsurface rock layers by using sound waves as different rock layers have different acoustical properties. The recorded sounds are processed and assembled for interpretation. Existing seismic and well information highlights the potential for exploration of large hydrocarbon resources. Computerization of seismic data provided a great leap forward for the extraction industry: A large body of data can be processed at high speed and precision. Another revolution in the oil industry was the 3D visualization that made possible a more reliable selection of the best targets to be drilled. Moreover, 4D visualization (repeated 3D through time) helped in the planning of well life-time operation. In the past decade, automated drilling (the evolution of automation in drilling) has been an ongoing topic of discussion. Modern technology helps in making decisions regarding the best drill sites. Computers and satellite images have improved the assessment of deposits. Nevertheless, ultimately it is only by drilling that a company can be certain that hydrocarbon deposits really exist. In other words, even with the use of modern technology, it is only by drilling that the existence of oil can be confirmed.

One important factor in the identification strategy employed in this paper is the relationship between drilling effort and international oil prices. Figure B.1 shows a striking correlation between wells drilled and international oil prices, in agreement with the literature on the role of oil prices (e.g., Mohn and Osmundsen (2008)).

Fig. B.1: Drilling in Brazil and International Oil Prices



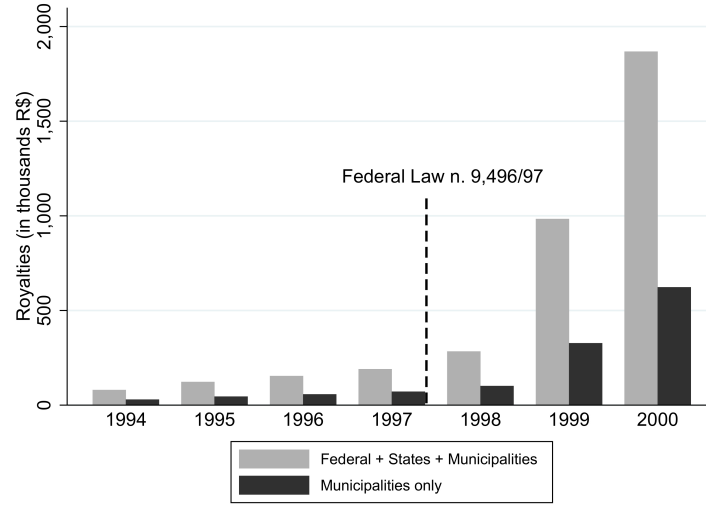
Notes. The figure shows the evolution of approximately 28,000 wells drilled (the universe of wells drilled in Brazil during the period from 1940 to 2013) and the evolution of the international price of crude oil during that period, defined as the monthly WTI (West Texas Intermediate) oil price in real US dollars per barrel.

Up to this point, we have described some general aspects of the upstream industry. The downstream industry includes the refineries, petrochemical plants, and distribution facilities (e.g., ports and terminals). Crude oil and natural gas are of little use in their raw state (Petroleum Extension Service (1997)). Refining and processing for the selection of certain groups of components (called “fractions”) is what creates value. Refining means applying chemical processes to convert fractions into commercial products. Oil and gas vary in their hydrocarbon compounds and impurities (such as sulfur and metals). For instance, there are light crude oils as well as heavy and thick crude oils. The complexity of the composition of petroleum fractions leads to more than 2,000 individual refinery products (Fahim et al. (2009)). Examples of refined oil products are gasoline, jet fuel, kerosene, diesel fuel, and feedstocks for the petrochemical industry.

B.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% of the revenue from onshore oil production was to be distributed to states (80%) and municipalities (20%) 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.

Fig. B.2: Distribution of Royalties: 1994–2000



Notes. In 1997, Federal Law n. 9,496/97 changed the rules for distribution of royalties.

The 1997 law requires an oil company to allocate between 5% and 10% 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.

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).

B.3 More Details on the Institutional Setting

Under certain circumstances, other oil companies could explore for oil in Brazil during that period, but only in partnership with Petrobras. Following the oil crisis in 1973, Petrobras and other oil companies could sign a so-called risk contract to explore specific areas between 1975 and 1987. The terms of the contracts varied, but usual stipulated that the oil found under this type of contract could not be exported and that Petrobras could

simultaneously explore an adjacent area by itself.⁶ There is a sharp contrast in terms of ownership of resources between the United States and Brazil. There are thousands of oil companies, with various business models in the U.S.,⁷ while oil production in Brazil has historically been linked with Petrobras’s monopoly.

Even though Petrobras’s choice of where to drill is likely endogenous, local governments had little space to influence Petrobras (or CNP) on where to search for oil or the speed of drilling. Petrobras (as a national oil company) followed a long-term national goal, namely, to achieve self-sufficiency for Brazil in oil production, which were not necessarily correlated with local-level objectives. In addition, several factors which influence exploration activity, such as the international price of oil (e.g., Mohn and Osmundsen (2008)), are determined exogenously.⁸ Furthermore, Petrobras knew it could drill only in locations with selected geological characteristics.⁹ One concern might be that Petrobras’s “risk contract” partners were local companies with a local agenda. However, the vast majority of those contracts were signed with profit-maximizing multinational oil companies.¹⁰

C Appendix: Treatment Intensity

We endeavor to measure the effect of treatment intensity. We ask how the outcome is related to the “dose” of the treatment. The literature on treatment intensity emphasizes the estimation of a weighting function to capture which group or observation is contributing the most to the results (e.g., Angrist and Imbens (1995), Frölich and Lechner (2010)). In the spirit of Angrist and Imbens (1995), our goal is to estimate a coefficient that can be interpreted as a weighted average of per-unit treatment effect. We thus estimate the following equation:

$$Y_{it} = \alpha + \tau prod_{it} + \beta'_t X_i + \gamma_i + \rho_t + \epsilon_{it}, \quad (1)$$

⁶The first contracts were signed in 1976 through a public bidding. Nine of the ten bidding areas were offshore, the remaining one being in the Amazon basin. More than 100 risk contracts were signed over a period of 12 years. According to the contracts, all the oil that was found was required to be sold internally until the country reached self-sufficiency in oil production. This did not occur until three decades later, in 2006.

⁷Institutions such as the U.S. Energy Information Administration and the Independent Petroleum Association of America report the existence of several thousand oil operators in the U.S. economy.

⁸Figure B.1 in Appendix B.1 shows the very high correlation between drilling activity in Brazil and international oil prices.

⁹Recall that Figure 1(b) shows that all oil wells in Brazil are located within sedimentary basins.

¹⁰Three smaller Brazilian companies also signed exploration contracts with Petrobras. One of these three companies was government owned Paulipetro, which was founded in 1979 by São Paulo state. Between 1980 and 1983, Paulipetro drilled 33 wells in one specific area; these attempts led to only one discovery well — one that was non-economical (Bosco (2003)).

where we instrument the number of production wells ($prod_{it}$) with the number of discovery wells (field, subfield, and field extension wells) ($(disc_{it})$).¹¹ As an alternative measure of treatment intensity, we use the number of injection wells. The pressure in the reservoir is a key element in oil production, because that is the mechanism that drives oil and gas out of the reservoir. Normally, after some time, the pressure decreases and the oil company needs to (artificially) increase the pressure in the well. At that point, the oil company starts to drill “injection wells” to inject water, gas, chemicals, or steam to adjust for the falling pressure. Injection wells give us indirect information on the producing life of an oil field, because injection wells are used only to enhance production. Efforts to enhance production are costly and are dependent upon the potential oil recovery volume. In other words, it is viable to design injection wells to enhance production, but only if production is expected to be above a certain level. Therefore, we use injection wells as a measure of treatment intensity.¹² Note that while the t-statistic for the number of discovery wells in the first stage is always very high, the F-statistic for the GDP regressions are not particularly strong, indicating a potential weak instrument problem.

Table C.1: Treatment Intensity

VARIABLES	Matched Dry Drilling			
	(1)	(2)	(3)	(4)
	ln GDP <i>per capita</i>	Urbanization Rate	ln GDP <i>per capita</i>	Urbanization Rate
Number of Production Wells	0.000664** (0.000317)	0.0000755** (0.0000370)		
Number of Injection Wells			0.0123** (0.00573)	0.00146* (0.000871)
First Stage F-Stat.	6.98	15.92	6.29	31.21
MCA FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Observations	768	1,024	768	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

Notes. Standard errors clustered at the MCA level. The main explanatory variable is the number of injection wells. The numbers of injection and production wells are instrumented with the number of discovery wells. Geographical controls and initial conditions have time-varying coefficients.

*** p<0.01, ** p<0.05, * p<0.1

The signs of the various regressions are as in the baseline regressions, and so we focus on quantifying the average per-unit effect on GDP *per capita* and urbanization. The results are reported in Table C.1. GDP *per capita* increases by 0.066% per production well and by roughly 1% per injection well. The urbanization rate increases by 0.007% per production well and by 0.15% per injection well. The coefficients for production wells

¹¹We obtained production data by oil field from ANP for the year 2000 to construct production volume by MCA and compare it to the number of production wells. While the correlation between the two is high, it is higher for onshore than offshore production.

¹²Tabulations from Brazil support this choice. In the year 2000, for onshore fields, the MCAs with discovery wells and injection wells had much higher production volumes of both oil and gas than those that had discovery wells but no injection wells. In other words, the MCAs with injection wells were the ones with a lot of production.

are quite small. With the average producer MCA having 160 production wells, this gives an average impact of oil production of $160 \times 0.0007 = 11.2\% < 20\%$. On the other hand, the coefficients for injection wells seem very large. This is a consequence of their ability to isolate the large production fields very well. In fact, only a handful of large fields onshore in the northeast or off the coast of Rio de Janeiro have any significant number of them. Our interpretation of these results is that large discoveries have a disproportionately large impact.

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