Intensive and Extensive Margins of Mining and Development: Evidence from Sub-Saharan Africa

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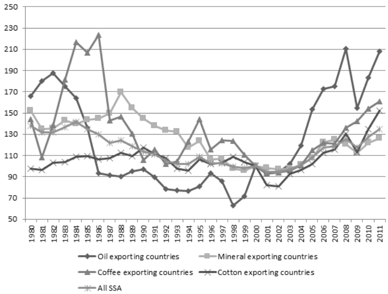
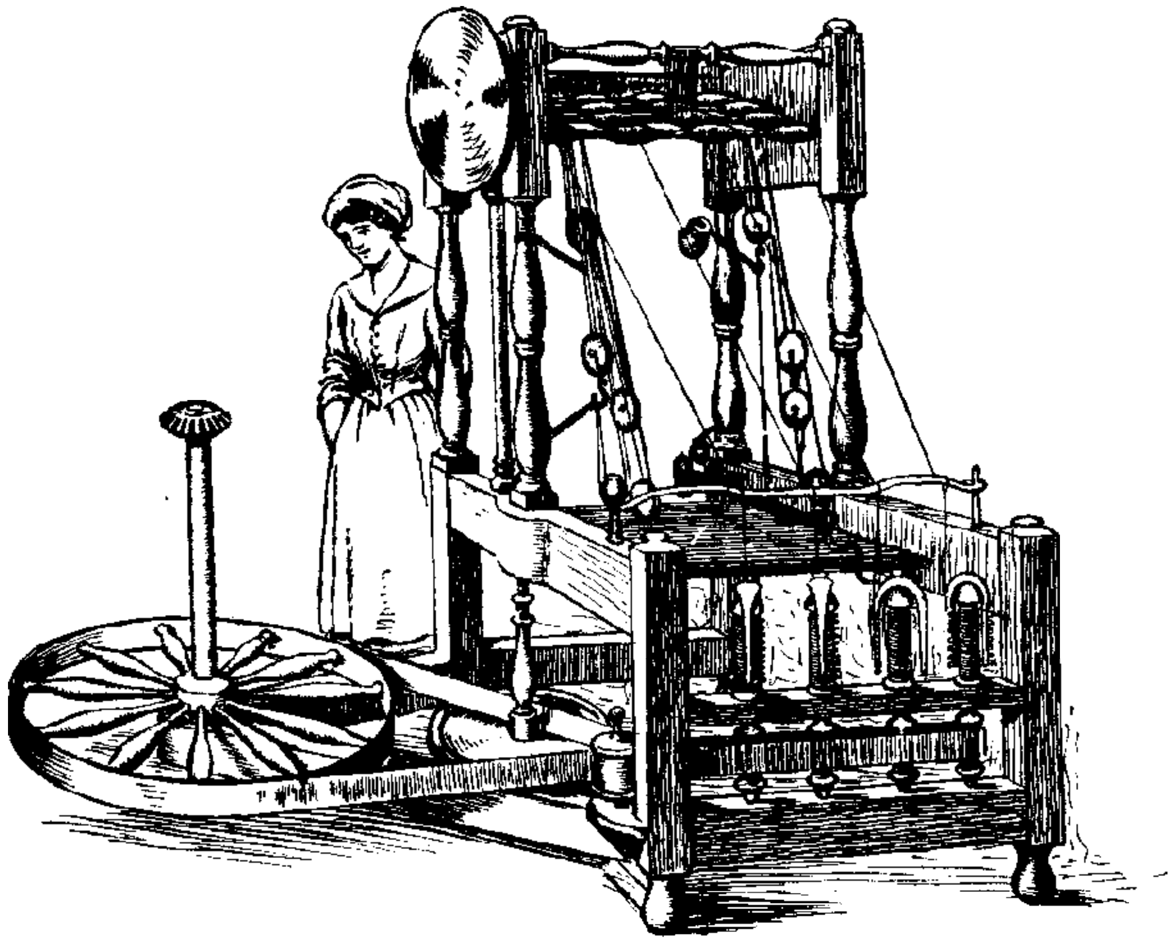
Motivation

- Robust growth in sub-Saharan Africa, fueled by commodity exports
  - Mineral exports ballooned from $38 billion to $300 billion
  - Growth has shifted sectoral shares, resource sector gaining
- ToT turned to the advantage of commodity exporters:



Motivation



Resource Curse

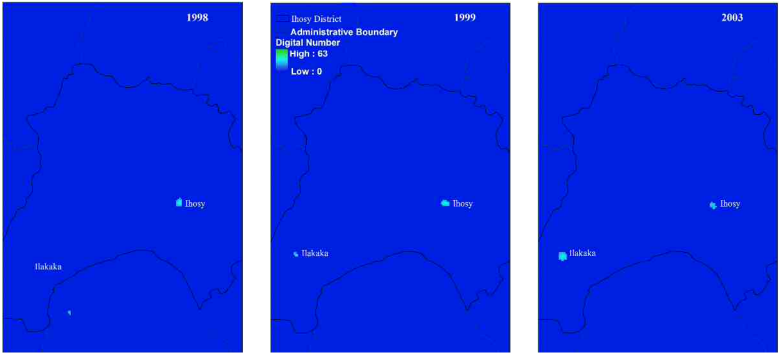
- Several causes
  - Dutch Disease (Corden & Neary 1982, Krugman 1987)
  - Macroeconomic stability (Deaton 1999)
  - Rent-seeking (Torvik 2002, Vicente 2010, Collier & Hoeffler 2004, Lei & Michaels 2014)
- Resource curse conditional on the quality of institutions (Mehlum et al., 2006; Robinson et al., 2006; Collier & Hoeffler, 2009; Bhattacharyya & Hodler, 2010, 2014; Bhattacharyya & Collier, 2014)
- Mining sector highly productive (McMillan & Rodrik 2014), but very limited forward and backward linkages (Singer 1950) been actively discussed by many scholars, thorough empirical analyses of the extent of spillovers are non-existent

Motivation

- Literature moved to local level analysis
  - Off-shore oil induced windfall & public goods provision in Brazilian municipalities: "missing money" (Caselli & Michaels 2013, *AEJ: AE*)
  - Oil and gas booms and busts in resource-abundant U.S. counties: No evidence of "Domestic Dutch disease" (Allcott & Keniston 2015, *REStud*)
  - Peruvian gold mine (Aragón & Rud 2013, *AEJ: AE*)
  - Female employment in sub-Saharan Africa (Kotsadam & Tolonen, 2016, *WD*)

- **This paper: Did mineral extraction and discovery raise local living standards in sub-Saharan Africa?**

Ihosy finds Sapphire in 1999



Innovations

- Focus on minerals as opposed to oil/gas; local level but covering an entire continent
- Distinction between intensive and extensive margin
- Tackling causality
  - Discoveries of mineral deposits as exogenous news shock
  - Proposing a plausible control group
  - Placebo tests
- Explicit modeling of General Equilibrium effects
  - Exclude lights emitted from mine itself
  - Spatial Spillovers, Aggregation
  - Directional (capital city)

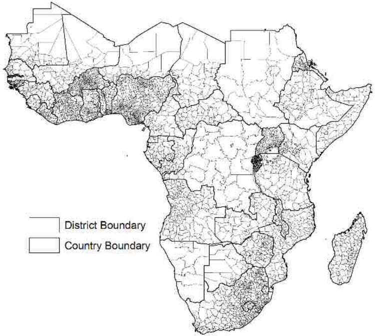
Preview of Findings

- Night-lights increase with expansion in mineral production **(intensive margin)**:
  - 2%-4% increase in night-lights for a 1% increase in production
- Large effects are mainly associated with new discoveries and new production **(extensive margin)**
  - 2 years prior to production start, 6 year post-discovery
  - An average mine increases district GDP by ca. 16%
- **General equilibrium effects**: Little evidence of large spillovers across districts boundaries, within the same administrative region, to capital cities, or major cities
- Little **persistence**: When districts lose all their mines, night-lights drop to pre-mining levels

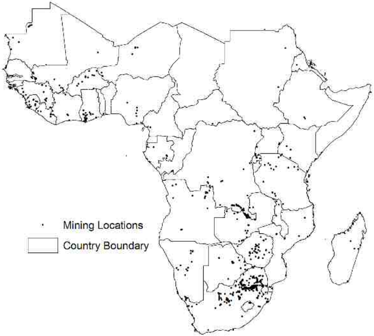
Data

- District (2nd level administrative unit) as unit of observation
- Mineral production quantity of 21 commodities for 548 industrial size mines from Intierra RMG database
  - Diamonds, iron, gold, silver, copper, nickel, aluminum, cobalt, zinc, lead, manganese, bauxite, tantalum, zircon, tin, chromite, antimony, platinum-group metals (PGE), vanadium, vermiculite and graphite
- Precise discovery dates and locations for 263 giant and major mineral discoveries 1950-2012 from MinEx consultancies
- 3,635 districts, 519 regions and 42 countries over 1992-2012

Data

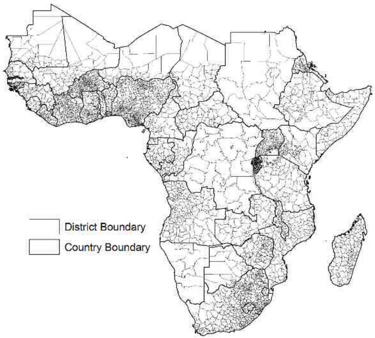


District Level Boundary Map

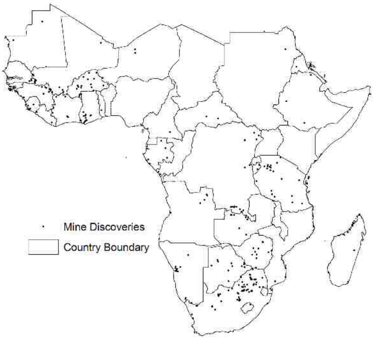


Mining Industry Locations

Data



District Level Boundary Map



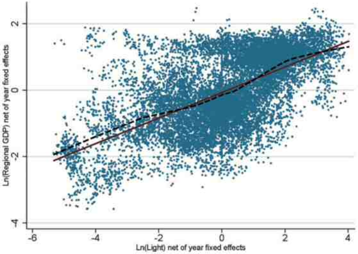
Mineral Deposit Locations

Data

- Measuring local economic activity from outer space: satellite data on **night-time lights** ("luminosity") from NOAA (2013)
- Available at a high spatial resolution (30-second grids - equivalent to 1 square kilometer)
- We construct **lights density** - lights adjusted for area controlling for population
  - Henderson, Storeygard and Weil (2012) in *AER*
  - Chen & Nordhaus (2010) as *NBER Working Paper*
  - Michalopoulos and Papaioannou (2013) in *Econometrica*
  - Hodler & Raschky (2014) in *QJE*

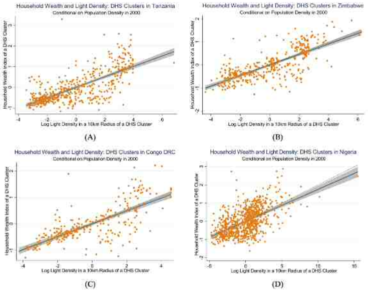
Luminosity and Measures of Income and Wealth

Regional GDP & luminosity



Source: Hodler & Raschky (2014)

Household wealth & luminosity



Source: Michalopoulos & Papaioannou (2013)

Summary Statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
Main Variables					
Ln(0.01+Lights density per sq. km)	76335	-2.36	2.38	-4.61	4.51
Ln(Mineral production)	1802	16.86	3.47	-0.23	27.63
Ln(Min. prod. 1992 commodity prices)	1802	16.96	3.06	1.66	27.57
Mineral production (1=yes)	76335	0.04	0.20	0	1
Mineral discovery	76335	0.00	0.03	0	1
Mineral discovery (permanent switch)	76335	0.01	0.10	0	1
Controls: Population and Geography Variables					
Ln(Population density per sq. km)	76335	3.98	1.61	0.02	10.04
Ln(Altitude in m)	76335	5.88	1.38	0.62	7.91
Ln(Ruggedness)	76335	4.05	1.14	0	6.93
Share of district with fertile soil	76335	18.60	29.45	0	100
Ln(Distance to the coast in km)	76335	5.55	1.39	-4.23	7.45
Ln(Land surface area in sq. km)	76335	7.41	1.72	-0.73	12.79
Controls: Climate Variables					
Ln(Annual average rainfall in mm)	76335	5.12	0.76	0.13	6.38
Share of district with tropical climate	76335	60.19	47.12	0	100
Share of district with temperate climate	76335	14.32	32.64	0	100
Share of district with dry/arid climate	76335	25.28	42.14	0	100
Controls: Urbanization and Political Economy Variables					
Capital city (1=yes)	76335	0.01	0.11	0	1
Ln (Distance to the capital city in km)	76335	5.47	0.97	0.66	7.54
Ethnic Fractionalization	76335	0.21	0.24	0	0.93
Controls: Infrastructure Variables					
Ln(Paved road density per sq. km (2000))	76335	0.02	0.04	0	0.52
Ln(Railway density per sq. km (2000))	76335	1.01	1.72	0	6.79
Ln(Electric-grid density per sq. km (2000)	76335	0.07	0.17	0	2.25

Intensive Margin and Local Development

We start with exploring the effect of mineral production in mineral producing districts **(intensive margin)**:

$$LD_{dt} = \alpha_d + \beta_t + \gamma MP_{dt} + X_{dt}\Phi + \epsilon_{dt}$$

where LD_{dt} is the natural log of night-lights density; MP_{dt} is the natural log of mineral production value summed up over 21 commodities; X_{dt} is a vector of district level control variables; α_d are district fixed effects; β_t are year fixed effects

- We distinguish between **value** and **quantity** by expressing MP_{dt}
  - in 1992 constant dollars
  - in 1992 constant commodity prices

Extensive Margin and Local Development

- To study the **extensive margin**, we replace MP_{dt} with a dummy variable equal to one if the district has a producing mine
- Identification comes from temporal variation within districts
- Validity of this strategy rests on the assumption that fluctuations in mineral production are driven by factors external to the district

Identification strategies - Extensive margin

- Identifying a suitable **control group** (that matches the treatment group in every respect except the treatment)
  - Districts that never had any mining activity (control 1)
  - Districts with mining potential as examined in a feasibility study, but where no mining has taken place yet (control 2).
- We define the **treatment group** as those districts that started mineral production for the first time between 2003 and 2012
- We have a symmetric pre- and post-treatment period of 1992-2002 and 2003-2012, respectively
- We rely on the same pre-treatment trends to lend confidence to the parallel trend assumption

Identification strategies - Extensive margin

Identification using discoveries of mineral deposits: exogenous news shocks:

$$LD_{dt} = \tilde{\alpha}_d + \tilde{\beta}_t + \sum_{j=0}^{10} \tilde{\gamma}_j MD_{dt-j} + X'_{dt}\tilde{\Lambda} + \tilde{\epsilon}_{dt}$$

where MD_{dt-j} is a dummy variable equal to 1 if a mineral discovery has been made in year $t-j$, 0 if no discovery has been made (comparison group)

- We restrict MD_{dt-j} to **first discoveries** in districts that never had any mining activity before. This restriction serves two purposes:
  - Existing mining may affect local development and it is difficult to disentangle this effect from the effect of a new discovery
  - Anticipation due to past knowledge of discoveries. First discovery and its exact timing are much harder to predict
- Placebo: MD_{dt+j} Effects before discovery?

Spatial Patterns of Spillovers

Identify spillover effects using techniques from spatial econometrics:

$$LD_{dt} = \alpha_d + \mu_t + \rho WLD_{dt} + \gamma MA_{dt} + \theta WMA_{dt} + X_{dt}\beta + WX_{dt}\delta + \epsilon_{dt}$$

where: W represents spatial weights matrix that defines potential interaction, and interaction is defined if districts share a common border (0/1 weights); WLD - spatially lagged dependent variable; WMA - spatially lagged explanatory variables

- Thus, **spillovers can originate from two sources**:
  1. Mining activities in neighboring districts WMA may affect a district's night-lights LD
  2. Mining activities MA directly affect district's night-lights LD, and this represents a change in WLD to district's neighbors

Main result

Table 2: Associations between Mineral Production and Night-Lights at District Level

	Intensive margin			Extensive margin
	(1)	(2)	(3)	(4)
Ln(Mineral production)	0.024*		-0.061	
	(0.014)		(0.047)	
Ln(Mineral production in 1992 commodity prices)		0.038**	0.102*	
		(0.018)	(0.057)	
Mineral production (1=yes)				0.554***
				(0.117)
Population density & Rainfall	Yes	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes	Yes
District Fixed Effects	Yes	Yes	Yes	Yes
N	1,802	1,802	1,802	76,335
N(Districts/Regions/Countries)	137/80/28	137/80/28	137/80/28	3,635/519/42
R-squared adj.	0.979	0.979	0.979	0.945

Notes: This table shows the association between night-lights and various measures of mining activity in a panel of district-year observations for the period 1992-2012. Dependent variable is Ln(0.01+Nighttime Lights Density per sq. km). Column (1) expresses the mineral production value in 1992 constant USD. Column 2 expresses the mineral production value in 1992 constant commodity prices. Column 3 includes both those indicators. Column 4 uses a dummy variable equal to one if the district had a producing mine thereby using the full sample. For a detailed variable description, see Data Appendix. Robust standard errors clustered by region are in parentheses. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% level, respectively.

Where do mining investments go?

Table 3: Where Do Mining Investments Go?

	Grassroots in 2012 (1)	Exploration in 2012 (2)	Adv. Expl. in 2012 (3)	Pre-Feasibility in 2012 (4)	Feasibility in 2012 (5)	Construction in 2012 (6)
Number of districts at each stage	353	290	203	86	82	19
Ln(Nightlights density in 2000)	0.003	-0.001	-0.002	-0.001	0.002	0.001
	(0.005)	(0.004)	(0.004)	(0.002)	(0.003)	(0.001)
Ln (Population density in 2000)	-0.007	-0.001	0.007	-0.002	0.007	0.003*
	(0.008)	(0.006)	(0.006)	(0.003)	(0.004)	(0.002)
Ln(Paved road density in 2000)	0.083	0.093	-0.054	-0.061	0.077	-0.023
	(0.096)	(0.082)	(0.084)	(0.053)	(0.055)	(0.041)
Ln(Railway density in 2000)	-0.005	0.002	-0.007*	-0.001	-0.002	0.001
	(0.005)	(0.005)	(0.004)	(0.003)	(0.003)	(0.001)
Ln(Electric grid density in 2000)	0.012	-0.048*	0.025	-0.011	-0.026	0.001
	(0.024)	(0.026)	(0.033)	(0.016)	(0.016)	(0.005)
Geographic Controls	Yes	Yes	Yes	Yes	Yes	Yes
Climatic Controls	Yes	Yes	Yes	Yes	Yes	Yes
Political Economy Controls	Yes	Yes	Yes	Yes	Yes	Yes
Region Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
N	3,635	3,635	3,635	3,635	3,635	3,635
N(Districts/Regions/Countries)	3,635/519/42	3,635/519/42	3,635/519/42	3,635/519/42	3,635/519/42	3,635/519/42
R-squared adj.	0.291	0.294	0.233	0.251	0.205	0.171

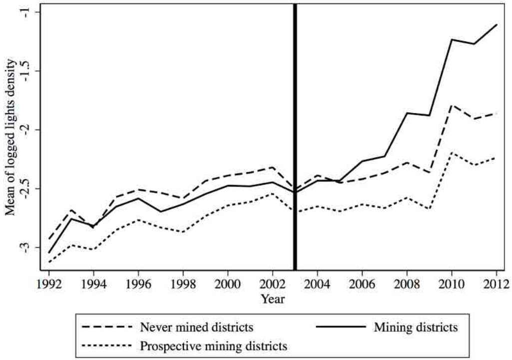
Notes: This table reports the correlation between district characteristics in 2000 and different stages of mining exploration in 2012 in a cross-section of district observations. The stages of mining exploration data is derived from IntierraRMG. We test for six stages that mining projects typically undergo, from grassroots explorations to construction. With the passing of each stage mineral production becomes more likely. In columns (1) - (6), the dependent variable is a dummy equal to one if a district experiences grassroots exploration, exploration, advanced exploration, pre-feasibility study, feasibility study and actual construction of a mine, respectively. Linear Probability Model is used for the estimation. Robust standard errors in parentheses are clustered by region. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% level, respectively.

Control-Treatment comparison, Dif-and-Dif

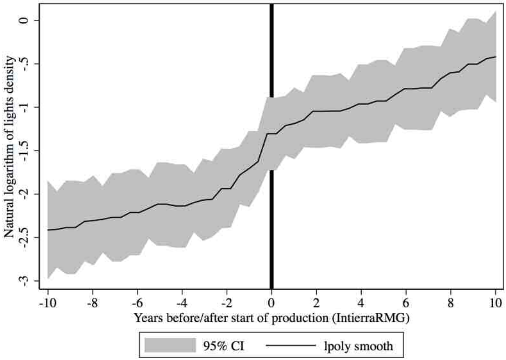
Table 4: Comparison of Treated and Control Districts (Mineral Production Treatment)

	Treated	Normalized Difference Treated-Control 1 Never mined	 Treated-Control 2 Feasibility
	(1)	(2)	(3)
Number of Districts	53	3284	156
Panel A: Time-Invariant Cross-Sectional Variables			
Ln(Altitude in m)	6.18	0.14*	-0.00
Ln(Ruggedness)	4.31	0.14*	-0.04
Share of district with fertile soil	16.09	-0.04	-0.09
Ln(Distance to the Coast in km)	5.76	0.09	0.05
Ln(Land surface area in sq. km)	8.40	0.36***	-0.03
Ln(Average annual rainfall in mm)	4.73	-0.15**	0.03
Share of district with tropical climate	50.88	-0.11*	-0.09
Share of district with dry/arid climate	27.17	0.03	0.00
Share of district with temperate climate	21.94	0.12**	0.11
Capital city (1=yes)	0	-0.11	-0.08
Ln (Distance to the capital city in km)	5.56	0.05	-0.03
Ethnic Fractionalization	0.31	0.24***	0.02
Ln(Paved road density per sq. km in 2000)	0.02	-0.05	0.10
Ln(Railway density per sq. km in 2000)	1.66	0.21***	0.03
Ln(Electric-grid density per sq. km in 2000)	0.06	-0.05	0.16**
Panel B: Trend Comparison			
Ln (0.01+Nighttime Lights Density)			
Pre-treatment growth 1992-2002	0.60	-0.00	0.00
Post-treatment growth 2003-2012	1.33	0.41***	0.53***
Ln (0.01+Nighttime Lights Per Capita)			
Pre-treatment growth 1992-2002	0.40	0.01	0.02
Post-treatment growth 2003-2012	1.17	0.44***	0.55***

Districts that started mining post 2002: Parallel Trends



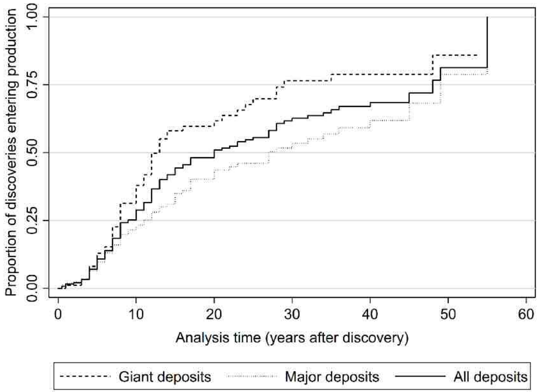
Districts that started mining post 2002: Parallel Trends



Mineral Discovery

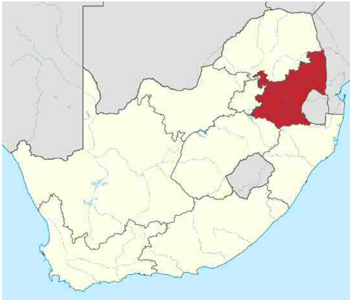
MD_{dt-j}: Mineral discovery made in year $t-j$	First Discoveries (1)	Single, First Discoveries (2)	Giant Discoveries (3)	Major Discoveries (4)
$j=0$	-0.029	-0.028	-0.032	-0.024
	(0.061)	(0.063)	(0.098)	(0.081)
$j=1$	0.023	0.024	0.100	-0.005
	(0.073)	(0.075)	(0.111)	(0.091)
$j=2$	-0.011	-0.008	0.075	-0.043
	(0.079)	(0.081)	(0.106)	(0.098)
$j=3$	0.019	0.006	-0.015	0.039
	(0.086)	(0.087)	(0.131)	(0.094)
$j=4$	0.071	0.068	0.085	0.070
	(0.100)	(0.104)	(0.167)	(0.111)
$j=5$	0.126	0.114	0.146	0.122
	(0.104)	(0.109)	(0.174)	(0.114)
$j=6$	0.194*	0.190*	0.314	0.134
	(0.112)	(0.118)	(0.220)	(0.118)
$j=7$	0.242**	0.218*	0.342	0.190
	(0.121)	(0.126)	(0.235)	(0.123)
$j=8$	0.387***	0.391***	0.484**	0.331**
	(0.137)	(0.147)	(0.235)	(0.161)
$j=9$	0.401***	0.402***	0.477**	0.355**
	(0.149)	(0.155)	(0.247)	(0.171)
$j=10$	0.438***	0.431***	0.538**	0.373**
	(0.149)	(0.156)	(0.253)	(0.166)
Pop. density & Rainfall	Yes	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes	Yes
District Fixed Effects	Yes	Yes	Yes	Yes
N	74,234	74,178	73,150	73,828
N(Discoveries)	[66, 79]	[57, 77]	[21, 28]	[38, 55]
N(Districts/Regions/Countries)	3,560/516/42	3,557/516/42	3,493/515/42	3,530/515/42
R-squared adj.	0.944	0.944	0.944	0.944

From Discovery to Production



Spillovers, Linkages, or an 'Enclave'?

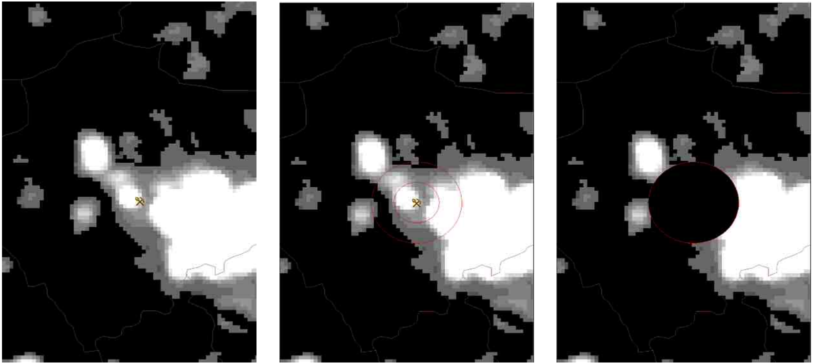
- Extreme form: Just the light emitted from the mine itself



South Deep gold mine in Mpumalanga, South Africa

Extreme form: Just the light emitted from mine itself?

- Drop lights emitted within a 2 km radius of the mine



- Coefficients decrease slightly, but remain significant

Spatial Spillovers

	Start-up of Mineral Production OLS (1)	SDM (2)	First Mineral Discovery OLS (3)	SDM (4)
Panel A: Estimated Coefficients				
District has a producing mine	0.554***	0.559***		
	(0.117)	(0.115)		
W(District has a producing mine)		-0.153		
		(0.182)		
Discovery in the past 5 years			0.009	0.011
			(0.072)	(0.067)
Discovery in the past 6-10 years			0.257**	0.247**
			(0.113)	(0.108)
Discovery more than 10 years ago			0.593***	0.572***
			(0.150)	(0.145)
W(Discovery in the past 5 years)				-0.121
				(0.176)
W(Discovery in the past 6-10 years)				-0.128
				(0.211)
W(Discovery more than 10 years ago)				0.056
				(0.286)
Population density & Rainfall	Yes	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes	Yes
District Fixed Effects	Yes	Yes	Yes	Yes
ρ		0.232***		0.232***
		(0.016)		(0.016)
$\delta = 0$ (χ^2-Test, p-val)				0.66
$\theta = \delta = 0$ (χ^2-Test, p-val)		0.38		0.45
$\theta = -\rho\beta$ and $\delta = -\rho\gamma$ (χ^2-Test, p-val)		0.19		0.43
N	76,335	76,335	76,335	76,335
N(Districts/Regions/Countries)	3,635/519/42	3,635/519/42	3,635/519/42	3,635/519/42
R-squared	0.947	0.173	0.947	0.145
Panel B: Direct & Indirect Effects of Mining from SDM				
	Direct	Indirect	Direct	Indirect
District has a producing mine	0.573***	0.004		
	(0.115)	(0.264)		
Discovery in the past 5 years			0.013	-0.172
			(0.064)	(0.276)
Discovery in the past 6-10 years			0.230**	-0.139
			(0.104)	(0.242)
Discovery more than 10 years ago			0.518***	0.172
			(0.129)	(0.296)

Spillovers to non-mining districts of the same region

Table 7: Associations between Mineral Production, Discovery and Night-Lights at Region Level

	Intensive margin				Extensive margin			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Region excluding districts with mineral activities	No	Yes	No	Yes	No	Yes	No	Yes
Ln(Mineral production)	0.018	-0.006						
	(0.018)	(0.019)						
ln(Mineral production in 1992 commodity prices)			0.032*	0.005				
			(0.018)	(0.019)				
Mineral production (1=yes)					0.295***	0.101		
					(0.082)	(0.069)		
Discovery in the past 5 years							0.003	0.016
							(0.047)	(0.065)
Discovery in the past 6-10 years							0.052	0.032
							(0.056)	(0.085)
Discovery more than 10 years ago							0.166**	0.056
							(0.084)	(0.104)
Population density & Rainfall	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Region Fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	1,057	948	1,057	948	10,899	10,710	10,805	10,710
N (Regions/Countries)	80/28	72/27	80/28	72/27	519/42	510/42	516/42	510/42
R-squared adj.	0.984	0.983	0.984	0.983	0.957	0.957	0.957	0.956

Notes: This table shows associations between mining activities and night-lights in a panel of region-year observations for the period 1992-2012. Dependent variable is Ln(0.01+Nighttime Lights Density per sq. km). Column (1) & (2) expresses the mineral production value in 1992 constant USD. Column (3) & (4) expresses the mineral production value in 1992 constant commodity prices. Column (5) & (6) uses a dummy variable equal to one if the region had a producing mine thereby using the full sample. Column (7) & (8) expresses mining activity as a dummy equal to one if the region had at leaset one discovery in the last 5, 6-10, and more than 10 years ago. In every odd column, the unit of observation is a region aggregated over all districts, whereas in every even column region aggregate excludes districts with any recorded mining activity. Robust standard errors clustered by region are in parentheses. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% level, respectively.

Spillovers to Cities

- Rents may be consumed in cities (Gollin et al. 2016)
- Lights of capital city & two largest cities in 1992 NOT correlated with mineral exports value or mineral rents as a percentage of GDP

Persistence after mines shut down

Table 8: Mine Closure and Development

	(1)	(2)	(3)
District has been mined	0.722***	0.725***	0.722***
	(0.162)	(0.161)	(0.162)
Shutdown	-0.491*	-0.224	-0.224
	(0.264)	(0.137)	(0.137)
Shutdown and not reopened by 2012		-0.837	-0.531
		(0.700)	(0.787)
Population density & Rainfall	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes
District Fixed Effects	Yes	Yes	Yes
N	76,335	76,335	76,314
N(Districts/Regions/Countries)	3,635/519/42	3,635/519/42	3,634/519/42
R-squared adj.	0.947	0.947	0.947

Notes: This table shows association between a stop in mining activities and night-lights in a panel of district-year observations for the period 1992-2012. Dependent variable is Ln(0.01+Nighttime Lights Density per sq. km). "District has been mined" is a dummy variable equal to 1, once a district had at least one producing mine. "Shutdown" is a dummy variable equal to 1, if all mines in a district shut down (it may be temporary or persistent). "Shutdown and not reopened by 2012" is a dummy variable equal to 1 if all mines in a district shut down and none has reopened by 2012. Column (1) and (2) include all districts. Column (3) excludes Bonthe District in Sierra Leone, where the closure was reportedly caused by rebels during the civil war. Data from MinEx. Robust standard errors clustered by region are in parentheses. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% level, respectively.

Robustness

- Missing production data
  - Drop district-year observations if quantity of a single commodity is missing
- Light intensity in sparsely populated areas (Min 2008; Cogneau & Dupraz, 2015)
  - Drop sparsely populated districts (< 4 people per km^2)
  - Drop zero luminosity districts
- Implicit weighting using districts as unit of observation
  - Weight districts by population size
  - Weight districts by the inverse of the total number of districts in a country
- Districts possibly endogenous
  - Use 0.5 x 0.5 degree grid cells (ca 55 x 55 km at the equator)

Findings

- Night-lights increase with expansion in mineral production **(intensive margin)**:
  - 2%-4% increase in night-lights for a 1% increase in production
- Large effects are mainly associated with new discoveries and new production **(extensive margin)**
  - 2 years prior to production start, 6 year post-discovery
  - An average mine increases district GDP by ca. 16%
- **General equilibrium effects**: Little evidence of large spill-overs across districts boundaries, within the same administrative region, to capital cities, or major cities
- Little **persistence**: When districts lose all their mines, night-lights drop to pre-mining levels