Landmines and Spatial Development*

Giorgio Chiovelli[†]
Universidad de Montevideo

Stelios Michalopoulos[‡]
Brown University, CEPR and NBER

Elias Papaioannou[§]
London Business School, CEPR

December 11, 2019

*We thank the four anonymous referees of this journal for insightful comments and useful suggestions. We thank UK's Department of Foreign International Development (DFID) and the Centre for Economic Policy Research (CEPR) for generous funding via the PEDL programme. We are grateful to London Business School Institute for Innovation and Entrepreneurship for supporting this research, as well as the UK's EPSRC. A special thanks to Sebastian Hohmann for help in various phases and aspects of this project. We would like to thank Suzana Moreira and the MoWoza team for helping us collect and organize some of the data. We would like to thank all demining operators involved in the Mine Action program in Mozambique and, in particular, APOPO, HALO Trust, Handicap International (Humanity and Inclusion), and Norwegian's People Aid for kindly sharing the original data on their interventions and generously sharing their expert knowledge and on-the-ground experience. This project could not have been completed without the generous support of many dedicated individuals. We are thankful to Olivier Cottray, Anne-Li Naucler, and Wendi Pedersen from the Geneva International Center for Humanitarian Demining (GICHD) for assisting us in various stages of this project. Our gratitude goes to Paul Heslop (UNMAS) and Martin Barber for sharing their time, knowledge and expertise about Mine Action. We are truly grateful to Alberto Maverengue Augusto from Mozambique's National Institute of Demining; Mica Bevington, Jean-Baptiste Richardier, and Gilles Delecourt, Alma Al Osta, and Emanuel Sauvage from Humanity and Inclusion; Camille Wallen and Rachel Boddy from HALO Trust; Afedra Robert Iga and Hans Peter Risser from NPA; Ashley S. Fitzpatrick and Tess Tewelde from APOPO; Chris Pearce and Richard Holmes from Dynasafe; Manuel Sitoe from UNADP. A special thanks goes to Peter Ainsworth, Richard Boulter, Johan Coetzee, Aderito Ismael, David Hewitson, and Ulrich Weyl for helping us understanding the history and technical aspects of demining in Mozambique. We are also thankful to to Greek-Orthodox Diocese Archbishop of Zambia, Malawi, and Mozambique Ioannis, Stergios Varvaroussis from the EU mission in Maputo, and Maro Spanoudi. We thank Alberto Marden da Cruz, Novella Maugeri and Jorrit Oppewal from the International Growth Center. We thank Antonio Francisco from the Instituto de Estudos Sociais e Economicos (IESE). Panos Kosmas and Jamie Barras kindly shared their technical expertise on landmine detection and removal technology. We also thank Patrick Domingues for kindly sharing his data on the civil war incidents. We thank for comments and valuable feedback Francesco Amodio, Costas Arkolakis, Lorenzo Casaburi, Alejandro Cunat, Francesco Caselli, Ruben Enikolopov, Remi Jedwab, Nuno Limao, Ted Paterson, Thorsten Persson, Yannick Pengl, Ricardo Reis, Thodoris Rapanos, Sandra Sequeira, Ina Simonovska, Silvana Tenreyro, Jaume Ventura, Joachim Voth, and Austin L. Wright. We also thak Chris Woodruff for his support. We also thank seminar participants at the 15th Meeting of State Parties to the Mine Ban Treaty, Brown, UPF-CREI, CSAE Conference at Oxford University, EIEF, Harvard, IIES, Maryland, George Washington, John Hopkins, Zurich, Vienna, Macedonia, Glasgow, King's College, McGill, Mondlane, LBS, LSE (macro), the 20th National Directors' Meeting at UN Mine Action, NBER's Economics of National Security Meeting, Queen Mary, Sussex, Universidad Catolica del Uruguay, Universidad de Montevideo, and "Geodata in Economics" workshop at the University of Brunswick – Institute of Technology, and the IGC-PEDL-LSE conference. All errors are our responsibility. Additional material can be found at www.land-mines.com

†Giorgio Chiovelli. Universidad de Montevideo, Department of Economics, Prudencio de Pena 2440, Montevideo, 11600, Uruguay; gchiovelli@um.edu.uy. Web: https://sites.google.com/site/gchiovelli/

‡Stelios Michalopoulos. Brown University, Department of Economics, 64 Waterman Street, Robinson Hall, Providence RI, 02912, United States; smichalo@brown.edu. Web: https://sites.google.com/site/steliosecon/

§Elias Papaioannou. London Business School, Economics Department, Regent's Park. London NW1 4SA. United Kingdom; eliasp@london.edu. Web: https://sites.google.com/site/papaioannouelias/home

Abstract

Landmine contamination affects the lives of millions in many conflict-ridden communities long after the cessation of hostilities. Yet, little research exists on the role of demining in post-conflict recovery. We examine the economic consequences of landmine clearance in Mozambique, the only country that has moved from heavily contaminated in 1992 to mine-free status in 2015. First, we construct a detailed catalogue tracing the universe of clearance operations collecting thousands of reports from the numerous demining actors across the country. Second, we establish a robust positive association between demining and local economic activity, as reflected in satellite images of light density at night. Third, to alleviate concerns related to the strategic coordination and prioritization, we exploit mistakes in the three countrywide surveys that guided clearance over time. The demining-development association remains strong when we focus on hazardous areas the nationwide surveys missed (type-II error). Moreover, luminosity does not respond to instances of operators visiting areas for clearance only to find out that the locals were already using the suspected land (type-I error). Fourth, we investigate heterogeneity to shed light on mechanisms. Economic activity responds strongly to clearance of the transportation network and of rural localities hosting agricultural markets. Recognizing that landmine removal reconfigured the accessibility to the transportation infrastructure motivates the use of "the market-access" approach. Fifth, the market access estimates reveal that demining conferred substantial improvements in aggregate economic activity. Counterfactual policy simulations project considerable gains had the fragmented process of clearance been centrally coordinated, prioritizing the colonial transportation routes.

Keywords: Africa, Development, History, Land Mines.
JEL classification Numbers: N47, N77, O10, O55

1 Introduction

The millions of refugees escaping conflict-ridden parts of the world in recent years, has added urgency in understanding (the absence of) economic growth in the aftermath of violence. Shedding light on the factors that enable a swift post-conflict recovery is vital, since sluggish growth may push a war-torn region back to the vicious circle of violence, poverty, and refugees flows (IGC (2018)). The consequences of conflict are multifaceted, permeating all aspects of the societal fabric; loss of lives, injuries, the destruction of infrastructure, distrust, and the deterioration of institutional capacity, among others. Nevertheless, one conspicuous legacy of conflict -that economics research has not examined- is that of landmine and other unexploded ordnance (UXOs) contamination.[1] "*Peace agreements may be signed and hostilities may cease, but landmines and explosive remnants of war are an enduring legacy of conflict*" states in its introduction the 2017 Landmine Monitor. In spite of landmines' extensive use in civil wars after WWII and the salience of this topic for the international community,[2] there has been little research quantifying their role in post-conflict recovery. This paper aims to start filling this gap focusing on Mozambique, the only country so far that has moved from "heavily contaminated by landmines" in 1992 to "landmine-free" status in 2015.

Landmines have been coined "*the weapon of the poor*", as they cost as little as one dollar to build. Pol Pot, Cambodia's Khmer Rouge infamous leader reportedly argued that "*a landmine is a perfect soldier, it doesn't need food or water, it doesn't take any salary or rest, and it will lie in wait for its victim.*" Hence, it is not surprising that landmines have been extensively used, among others, in Cambodia, Congo, Afghanistan, the Caucasus, and during the breakup of Yugoslavia. Human Rights Watch estimated in 1993 that in the previous 25 years, 5 million mines were manufactured. Today mine contamination remains a threat in around 50 countries, most importantly in Angola, Afghanistan, Cambodia, Somalia, Sudan, but also in frontier/developing economies, Colombia, El Salvador, Nicaragua, Ukraine, and Myanmar (Landmine Monitor, 2017). Media reports suggest ongoing use in Syria, Iraq, Libya, Yemen, and Myanmar.[3]

Landmines are a particularly damaging legacy of wars, as they remain active, hidden on the ground long after the cessation of hostilities posing an incessant threat to the population. Graca Machel, an expert of the UN Secretary-General on the "Impact of Armed Conflict on Children" and former minister of education of Mozambique, argued that "*landmines are uniquely savage in the history of modern conventional warfare not only because of their appalling individual impact, but also*

[1]Landmines are containers of explosive material with detonating systems that are triggered by contact. They are designed to incapacitate that person or vehicle through damage caused by an explosive blast, fragments, or, in the case of some antitank mines, a jet of molten metal.

[2]Its importance can be glimpsed by the NGOs, government agencies, donors and commercial partners that engage in mine-related activities. For example, there are 14 agencies under the auspices of the UN mine-action program, which as of 2008 was active in 43 countries. Conservative estimates put the annual budget of landmine and UXO clearance to an average of 700 million USD (Landmine Monitor, 2016).

[3]The use of landmines has been quite extensive in international wars, including WWI and WWII. Nevertheless, conventional armies, unlike warring parties in civil wars, keep records of minefields that greatly facilitate their clearance.

their long-term social and economic destruction" (UN General Assembly Resolution 48/157, 1996). The Landmine Monitor has recorded more than 110,000 mine/UXO fatalities, since its partial global tracking in 1999; these are underestimates, as landmine casualties go often unrecorded due to states' weak capacity, misgovernance, and under-reporting by hospitals and clinics (Landmine Monitor (2017), Ascherio *et al.* (1995)). The attention of the international community and media has naturally been on the victims; yet, contamination affects the lives of millions of people, who live, work, and play in landmine-affected areas. For example, the 2001 Mozambique Landmine Impact Survey estimated that around 3 million people were living in communities significantly affected by landmines. Once people bitterly learn of contamination, they adjust their living avoiding suspected areas. But, even when contamination does not result in injuries or fatalities, the economic and social ramifications are ongoing. Our study is a first step to quantify the economic consequences of demining.

1.1 Results Preview

We examine the economic impact of landmine and UXO clearance on Mozambique that emerged in 1992 from 25 years of warfare severely damaged with hundreds of thousands of landmines across roughly 7,000 minefields scattered across its vast territory. In September 2015, with support from international agencies, foreign governments, and the strength of the its people, Mozambique was officially declared "landmine free".[4]

Our analysis proceeds in six steps. First, we present the self-collected, cross-validated data on thousands of clearance operations, conducted by dozens demining actors. We are able to provide for the first time an almost complete documentation of landmine and UXO clearance for any country, a non-negligible contribution as such data are not available from governments or the United Nations.

Second, we trace how local economic activity reacts to landmine clearance across localities over time. To bypass data unavailability, especially in the 1990s when Mozambique was among the poorest nations in the world, we use satellite images of light density at night that are available at a fine spatial resolution since 1992. After showing that luminosity correlates strongly with measures of wealth and education across the overwhelmingly rural regions of Mozambique (as well as regions in other Sub-Saharan African countries), we compare luminosity in localities, where demining took place in a given year/period, to localities that were either not contaminated or were mined but not cleared yet. The analysis shows that local economic activity picks up following the removal of landmines and UXOs. This pattern is robust to numerous sensitivity checks that -among other- account for measurement error and the return of refugees and internally displaced people at the end of the war.

Third, to advance on causation we develop an identification strategy that exploits the numerous

[4] HALO Trust (2007) provides the definition of an area being landmine free, "*That is not to say that there are no more mines remaining. Unfortunately, the manner in which the war was conducted means that mines may remain in isolation which nobody alive knows anything about, and their presence will go undetected until such time that they explode or are uncovered. But, nevertheless, there are no more areas left to demine, nobody in the north of the country can point at an area and say 'I think there are mines there*".

Type I and II errors in the Mozambique-wide surveys that guided demining at different points in time. There is a strong positive correlation between demining and development, even when we solely examine clearance of hazardous areas that were not identified as suspected of contamination in any preceding nationwide surveys (false negatives) and could thus not have been part of any centralized prioritization scheme. Moreover, luminosity does not change when operators visit areas that were erroneously recorded in the surveys as contaminated (false positives), demonstrating that -in line with the anecdotes- demining did not target localities with high potential.

Fourth, we explore heterogeneity to shed light on mechanisms. Demining remote, disconnected from the transportation network and without agricultural points of exchange localities leaves no visible imprint on development. In contrast, clearance of localities hosting local agricultural markets (*cantinas*) and those along the at-independence transportation network translates into substantial improvements in economic activity. These patterns are also present across exclusively rural localities.

Fifth, recognizing that clearing landmines in one area may impact economic activity elsewhere via transportation network linkages, we examine the economy-wide consequences of clearance, employing recently-developed techniques in quantitative trade (e.g., Eaton and Kortum (2002), Donaldson and Hornbeck (2016), Donaldson (2018)). The "market-access" analysis that approximates both the direct and indirect effects of clearance reveals considerable effects of landmine removal. The estimates ["beta" coefficients of $0.2 - 0.3$] are in line with the estimates of the effect of large infrastructure projects, such as the extensions of railways in the United States in the late 19th century (Donaldson and Hornbeck (2016)). These results are similar when we look at changes in market access stemming from the clearance of hazardous areas not identified as suspected of contamination by the nationwide surveys.

Sixth, we conduct counterfactual policy simulations to assess the aggregate consequences of clearance. As a starting point, we assess how luminosity would have evolved in absence of any clearance, finding that in this extreme scenario aggregate light density in 2015 would have been roughly 67% lower. Given a lights-GDP elasticity of around 0.25 (Henderson, *et al.* 2012), this implies an output boost of around 16% from clearance. We then approximate the costs of the fragmented and non-coordinated nature of clearance estimating a counterfactual removal path that prioritizes the three "corridors" connecting the main ports (Maputo, Beira, and Nacala) with the mainland, followed by the clearance of the only highway connecting the south to the central regions. The comparison of actual demining with this counterfactual reveals substantial losses from the absence of central prioritization.

1.2 Related Literature

There is little academic research assessing the role of landmine clearance and none on its aggregate economic consequences. Nonetheless, our study connects to several research strands that have developed largely in parallel.

First, our findings contribute to our understanding of the economic legacy of civil wars (see Blattman and Miguel (2010) for a thorough overview). Works based on cross-country comparisons and case studies (e.g., Collier and Hoeffler (2007), Collier and Sambanis (2005)) show that, while typically growth resumes at the end of conflict, the strength and timing of the recovery varies considerably. Landmine contamination may partially account for the observed heterogeneity, yet there is not much work. Exceptions are Merrouche (2008), who presents cross-sectional correlations across 126 Mozambican districts between contamination and poverty rates and Arcand, Rodella-Boitreaud, and Rieger (2014), who using survey data from Angola, document cross-district associations between contamination and malnutrition.[5] Besides focusing on the consequences of landmine clearance, an important, but unexplored consequence of warfare, we bring into this body of research a theoretically-grounded approach that is well-suited to quantify spatial spillovers in agriculture-based economies. In our context, we find that landmine clearance generates sizeable spatial externalities.

Second, from a methodological standpoint, our paper relates to recent works in spatial economics that apply insights from general equilibrium trade theory to study the aggregate, direct and indirect, effects of transportation infrastructure on economic activity (see Donaldson (2015) for an overview). In an important paper, Donaldson and Hornbeck (2016) adopt the Ricardian model of Eaton and Kortum (2002) to derive a reduced-form expression linking changes in regional welfare (income) to changes of a region's market access, that reflects its proximity via the transportation system to all other markets, scaled by population and income. A similar approach has been applied in other contexts, including the building of colonial railroads in India (Donaldson (2018)), the construction of Indian highways (Alder (2017)), and road construction in Sub-Saharan Africa (Jedwab and Storeygard (2018)). The market access framework appears useful in addressing some policy-relevant questions in this understudied topic. What are the aggregate, as opposed to local, effects of removing landmines? How shall NGOs, international organizations, and governmental agencies design clearance, a critical issue nowadays in Cambodia, Colombia, and other countries?

Third, our focus on the legacy of a devastating civil war that left Mozambique contaminated with hundreds of thousands of landmines connects our work to the broader agenda on the origins of African (under)-development (see Bates (2007) and Collier and Gunning (1999) for overviews of the role of post-independence policies). Since landmine clearance is often funded by foreign donors and development agencies (as in Mozambique), our paper relates to the large literature on foreign aid (see Easterly and Pfutze (2008) for a review), showing that such assistance may be quite beneficial.

Fourth, our paper contributes to practitioner/applied works on the topic (e.g., Cameron, Gibson, Helmers, Lim, Tressler, and Vaddanak (2010), Keeley (2006), Elliot and Harris (2001), often summarized in the annual editions of the Landmine Monitor). Most impact assessment reports, which are qualitative focusing on a single (few) community(ies), do not uncover significant effects of clearance

[5]There is some connection between our paper and studies on bombardment. Miguel and Roland (2011) and Dell and Querubin (2017) quantify the long-run effects of the bombing of Vietnam on the economy, local governance, and insurgency. Lin (2016) shows that the bombing of Cambodia entailed small on average effects, that are however considerable in soil-rich areas. Davis and Weinstein (2002) look at the economic geography after the WWII bombing of Japan. Trebbi, Weese, Wright, and Shaver (2018) examine how insurgents in Afganistan adapt quickly to improvements by coalition forces in the detection and detonation of landmines and other improvised explosive devices.

(see DFID (2014)). Medical research, in contrast, points to significant adverse effects, but given the lack of data and considerable under-reporting of fatalities and amputations, it is based on tiny samples (see Frost et al. (2017) for a review).[6] We bring into this body of work a methodology to study the impact of contamination and clearance and show that spatial spillovers are likely sizable, an angle that the practitioner community seems to have underestimated.

Paper Structure The paper is structured as follows. In the next section, we provide an overview of the use of landmines in Mozambique and the 23 year-long process of clearance. In Section 3, we present and describe the self-collected data on demining operations. Section 4 reports specifications examining the within-locality correlation between landmine clearance and development. In Section 5, we exploit mistakes in the Mozambique-wide surveys to alleviate concerns of prioritization. Section 6 explores the heterogeneous response of luminosity. Section 7 reports the market-access estimates that quantify the aggregate effects of landmine clearance. Section 8 presents counterfactual policy experiments assessing the losses from the absence of coordinated prioritization. In section 9, we discuss implications of our findings and offer some thoughts on future research.

2 Historical Background

This section provides a brief account of the use of landmines ($1964-1992$) and the subsequent clearing efforts ($1992-2015$). Appendix *I* provides an overview of the Mozambican war of independence and the ensuing civil war, focusing on landmine use. Appendix *II* provides a detailed description of the landmine clearance process.

2.1 Conflict and Landmine Use

Mozambique's experience with landmines starts with the war of independence ($1964-1974$). The Portuguese planted large minefields along the border with Tanzania to prevent the fighters of the Front for Liberation of Mozambique (FRELIMO), the main independence movement, to enter the country. The colonial administration also planted mines along infrastructure to protect them from the insurgents, including a ring of $80,000$ mines along the Cahora-Bassa dam, the largest in Africa. In turn, FRELIMO used landmines for military purposes, to demoralize the colonial army, destabilize the countryside, and cut road communications. Although Mozambique becomes independent in 1975, conditions deteriorate, as the country soon enters one of the most disruptive civil wars since WWII. The main warring parties, FRELIMO now in government, backed by socialist countries, and the Mozambique Resistance Movement (RENAMO), supported initially ($1977-1980$) by Rhodesia and

[6] Ascherio *et al.* (1995) conducted surveys in two Mozambican provinces shortly after the war and estimated ratios of fatal and non-fatal landmine injuries of $8.1-8.2$ per $1,000$ (roughly $3.8^{0}/_{00}$ deaths, $3.2^{0}/_{00}$ amputations, and $1.1^{0}/_{00}$ other injuries). These estimates are ten-times higher than the ones based on hospital or amputee-assistance-programmes. Roughly 75% of fatalities happen before the victim reaches a health center.

subsequently by South Africa's apartheid regime, used extensively landmines; for military purposes, to protect infrastructure (e.g., electricity pylons and roads), to terrorize civilians, to block rearmament, and to ring-fence towns, villages, and farms. Militias and other groups also used landmines.

2.2 Mozambique in 1992. The Problem of Landmines

According to the Penn World Table statistics, Mozambique was at the end of the civil war the third poorest country in the world; a Human Rights Watch (HRW) (1992) report suggested that "*parts of the country had returned to the stone age.*" Landmines and unexploded ordnance posed massive problems and interacted with other devastating consequences of the civil war. Refugees in neighboring countries (approximately 1.5 million) and internally displaced (roughly 3 million out of a total population of around 15 million) could not return to their homes. Contamination was widespread along the main transportation routes. Mines had been planted around schools, police stations, and government buildings, often used as local rebel or government headquarters. The General Peace Accord signed in Rome in September 1992 required in Protocol VI that FRELIMO and RENAMO "*organize and implement mine-clearing operations*" and provide assurances that they will not "*prevent them.*"

HALO Trust 1994 survey (SHAMAN), conducted for the United Nations Office for Humanitarian Assistance Coordination, provides an early, though noisy, account of contamination. First, the problem was mostly on the extensive -rather than the intensive- margin, as the "*use of landmines in Mozambique is characterized by a highly dispersed pattern*". A handful of mines can have adverse effects. For example, eight mines cleared in 1996 were preventing $20,000$ people in Mahniça valley from returning to their villages. HRW (1997) makes a similar point. "*During a Norwegian Peoples Aid mine clearance operation in Maputo province, a team was sent in 1994 to clear the village of Mapulenge, which had been the center of a community of about 10,000 people. It had been deserted for some four years because it was locally believed to be heavily mined. After three months of work, the clearance team reported finding four mines; these, and the rumor of many more, were sufficient to depopulate the entire area.*" Second, infrastructure was heavily mined; the report stated that in the southern and central provinces "*all dams, railway lines, electricity substations and pylon lines should be assumed to be mined*" and a similar though somewhat better assessment applied to the northern districts. Third, UXOs posed also a challenge, as due to rainfall and landslides, they would move around, blend with mud, and become hard to detect.

2.3 Landmine Clearance

The process of freeing Mozambique from landmine contamination spanned three periods. Each phase started with a nationwide survey that set the stage for subsequent demining.[7] Mozambique is the first

[7]Specifically, mine action tenders, financed by the UN and foreign donors, dictated the deminer's payment as a function of the area cleared (and not by the number of UXOs and landmines found). A demining contract usually specifies the clearance of a GPS location or of a target in square meters cleared. As recognized by GICHD (2012), "*the*

country where NGOs and commercial firms led demining; in the past, professional armies conducted clearance. Best practices had not been developed, deminers had to be trained, there was minimal (if any) co-ordination among operators, and the clearance process was fragmented. Effectively, humanitarian demining starts in Mozambique and the lessons learned from the many challenges and mistakes served as the basis for the more standardized practices that emerge after the mid-2000s.

2.3.1 Phase 1. (1992 – 1999)

The 1992 Peace Accord specified that the UN had to work with national authorities to coordinate and conduct clearance. However, UN initiatives were delayed by FRELIMO and RENAMO, as well as internal frictions. Up until the 1994 elections, there were just a handful of interventions targeting war camps and some border passages, as priority was given to the return of refugees.

Aided by the 1994 countrywide SHAMAN survey of suspected hazardous areas (SHA) clearance gets organized along three humanitarian programmes. First, The HALO Trust (HT), a British-American NGO, started operating in the northern provinces. Mozambique was effectively the first country of HT's operations at large scale; by 1999, HT was employing close to 200 deminers. Second, the Norwegian People's Aid (NPA) started demining in the central provinces in 1993; though NPA initially was not focused on landmines, by 1999 it was employing close to 500 deminers. Since 1998 Handicap International (HI, renamed Humanity and Inclusion), an international humanitarian network focusing on victim assistance, decided to experiment with clearance in Inhambane and later in Sofala. Third, with the help of the UN, the government established the Accelerated Demining Program (ADP) in 1995 that contracted with commercial operators and NGOs operating in the southern provinces of Maputo, Gaza, and later Inhambane. ADP was slow in clearing and in the initial stage, its focus was on training. By the end of 1998, ADP employed 10 platoons of 50 deminers each.

The first phase can be characterized as preparatory; the 1994 survey provided some estimates of contamination, the country established centers for training, and a few organizations proceeded with demining (North). There was minimal progress on actual clearance, as there were many challenges and because humanitarian demining was at its infancy. Moreover, given the flaws of the SHAMAN survey (discussed in detail below), the government, the UN, and NGOs had an incomplete picture of the problem. Osório Mateus Severino, director of Mozambique's mine clearance operations describes the situation in 1997: "*We are in the dark about that [landmines], and without a sound knowledge of the situation, it is impossible to define a strategy, let alone determine the cost and resources needed for clearance operations*", Human Rights Watch (1997).

contractor is rewarded only for "clearing" square meters and there is no incentive to use survey to release land".

2.3.2 Phase 2. (1999 – 2006)

The establishment of the National Demining Institute (IND) in 1999 marks the beginning of the second phase of demining. Donor funding increased from approximately $5 - 8$ millions per year in $1993 - 1996$ to around 15 millions during $1999 - 2004$. The IND soon commissioned a countrywide survey. Mozambique's Landmine Impact Survey (MLIS) found that landmines affected 123 out of 128 districts, with 3 million people living in communities with at least modest contamination. The survey was a key input for Mozambique's five-year $(2002 - 2006)$ mine-action plan.[8]

Sadly, when clearance gained momentum, Mozambique experienced devastating floods in 2000 in the Southern provinces killing about 600 people, displacing more than $200,000$ and affecting the lives of millions. A major flood hit the central provinces the next year. These events stretched the government's capacity and delayed clearance by complicating the detection of landmines and UXOs. Allegations for corruption erupted in 2003 that led to donor fatigue. Some NGOs suspended their operations and funding declined from about 20 millions in 2002 to 5 millions in 2007. The UN's collaboration with the IND ended in 2005, leaving the best-trained staff unpaid, delaying demining in the southern and central provinces.

2.3.3 Phase 3. (2007 – 2015)

The third phase commences with the government's Mine Action Plan $2008 - 2014$, which was based on (i) the 2007 Halo Trust Mine Impact Free (MIFD) survey that declared the three northern provinces and Zambezia "landmine free" and (ii) a baseline assessment of conditions in Southern provinces, based on other operators' records. The surveys revealed that there were three times as many mines than previously thought; more than 600 new mine-contaminated areas were listed.

This time around clearance proceeded at a brisk pace. HALO Trust moved to Maputo, Manica and Tete in the center. APOPO, a Belgian-Tanzanian NGO experimenting with the use of rats for detection, got involved in Gaza and in Manica. HI moved beyond Inhambane assisting also in Sofala and Manica. Donors returned as the problem was still acute and because local capacity improved. Foreign aid for clearance increased fourfold. The last phase is characterized by increased efficiency; the government and NGOs had learned from past mistakes and precise technical surveys aided demining. International standardization of processes also helped. The last plan's timeframe was (roughly) respected and in September 2015, Mozambique was declared landmine free.

[8] The official request of the Government of Mozambique for the third 5-year extension (2008) summarizes the challenges during Phase 2: "*The large size of Mozambique and the absence of a functional road network in much of it, extensive flooding in parts of the country in* 2001*, the widespread distribution of mine-affected communities, the absence of comprehensive and accurate national gazetteer (i.e., official listing of communities and their geographic coordinates), the lack of accurate maps at an appropriate scale, the impossibility of applying in its entirety the SAC protocol for false-negative sampling, and, the nature, availability and quality of expert opinion.*"

3 Data

This Section presents the newly-compiled data on landmine clearance, as well as data on the transportation network and development. Mozambique is divided into 10 provinces and the city of Maputo, the capital. We conduct our analysis across $1,187$ admin-4 units (localities),[9] the lowest administrative division. In terms of land area, Mozambican localities are between municipalities ("cantons") and arrondissements in France and had a median population of $11,515$ $(8,629)$ in 2007 (1997). Regarding Mozambique's economic structure, the share of employment in agriculture exceeds 75% throughout 1990-2015. Tobacco, sugar, cotton, cashews, maize and tea are the main agricultural goods. Most agriculture, especially in the 1990s and early 2000s, consists of subsistence farming with smallholder agriculture occupying about 90% of cultivated land. Farms are small and their productivity is below Sub-Saharan averages. Manufacturing is effectively non-existent, even today.

3.1 Landmine Clearance

We went over around $7,000$ completion, clearance and progress reports, and technical surveys compiling a dataset that records interventions from 1992 till 2015. This is a non-negligible component of our contribution to the international community that lacks a complete coding of operations for any country. Below, we briefly go over the data collection, depict contamination at the end of the war, and plot the evolution of clearance. Appendix III offers details on the catalogue's construction, provides examples, reports summary statistics, and gives visualizations. Our dataset stores $7,423$ interventions in $6,712$ confirmed hazardous areas.[10] The vast majority of the CHA (91%) had exactly one intervention, whereas the remaining 611 CHA (9%) had on average 2.16 interventions (and associated reports). We will be using interchangeably the two.

3.1.1 Clearance Data

First, we accessed the Information Management System for Mine Action (IMSMA) database stored at the National Institute of Demining (IND) in Maputo.[11] This database lists suspected and confirmed hazardous areas along with clearance activities at the intervention level. Coverage is uneven across time. Entries' quality, accuracy, and detail are rather imprecise during the early phase $(1993-1999)$, improve after 2001, and become precise after 2007, when according to IND officials and practitioners the database is (almost) complete. We corrected inconsistencies, deleted duplicates, and going over hand-written reports, we cleaned the IMSMA data. Our dataset includes $6,231$ interventions from the IND database.

[9] We aggregate the respective localities for Maputo, Matola, Beira, Chimoio, Nampula, and Nacala (population exceeding $200,000$). There are 140 districts (admin-2 units) and 417 postos administrativos (admin-3 units).

[10] Updating the status of a SHA to that of a confirmed hazardous area (CHA) is an essential task, done via non-technical surveys. When the latter delivers sufficient evidence of contamination, a technical survey follows that concludes with the clearance of the hazard(s) and the issuance of a completion report.

[11] IND started using this system in the mid-2000s.

Second, we collected, processed, and digitized reports of the main humanitarian demining operators (Halo Trust, HI, NPA, and APOPO), using these organizations' internal records. We validated (and improved the detail of) the IMSMA entries post 2001 and expanded coverage in the pre-2001 period. We added 827 interventions from HALO Trust's inventory and 39 interventions from the NPA after visiting their (now closed) warehouse in Tete.

Third, we retrieved information from smaller operators in the 1990s from various sources. For example, we added 68 operations conducted by the German Agency for Technical Operations with MineTech in Manica in the mid-late 1990s. We reached out to former deminers, both to verify data entries and expand the database in the early period. For example, we reconstructed 35 not-recorded interventions from the Accelerated Demining Program.

Fourth, as the UN led clearance between the 1992 peace treaty and the 1994 elections, we digitized maps of early interventions from its mission archives and from USAID that funded most of them (e.g., Project Caminho, the main demining operation).

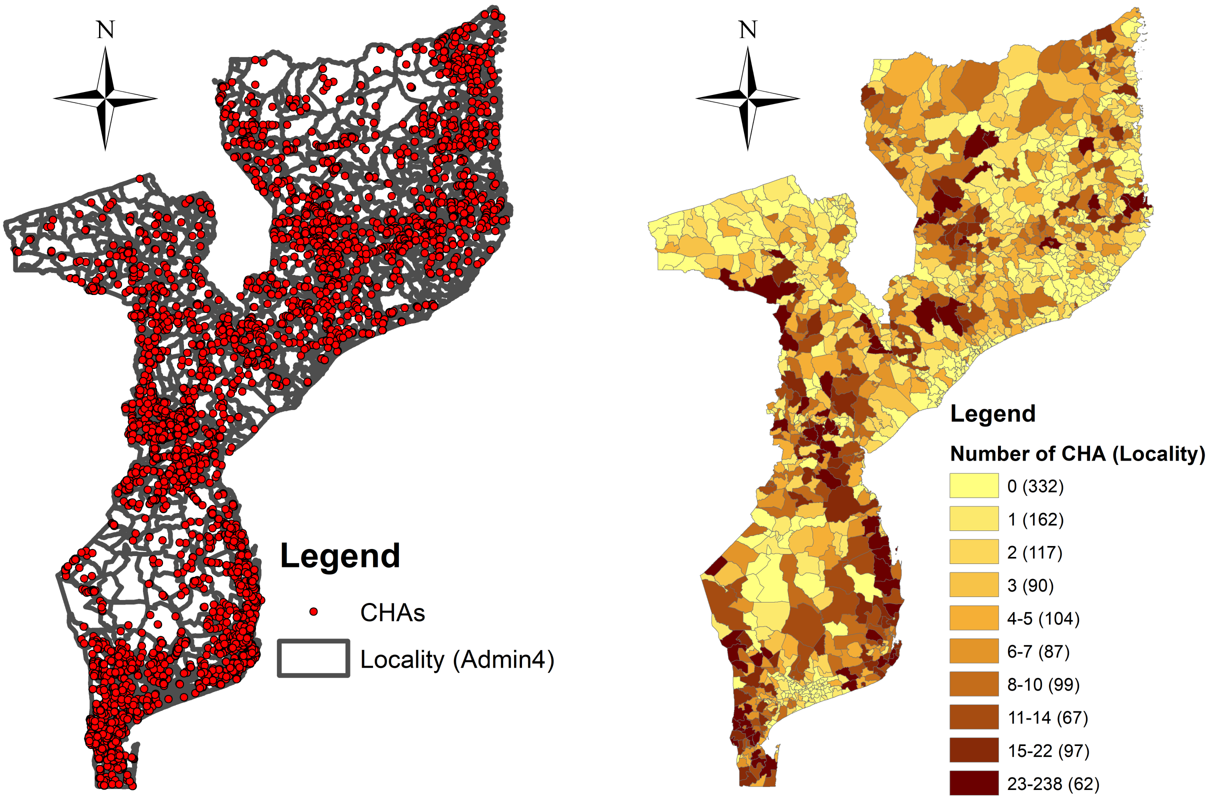
We digitized the three Mozambique-wide surveys (1994 SHAMAN, $2000-2001$ LIS, and $2007-2008$) that mapped suspected for contamination hazardous areas (SHAs). This allowed us to uncover additional clearance operations, recorded in the 2001 (38 operations) and 2007-2008 surveys (251 operations). Most importantly, the many mistakes in the surveys allowed us to develop an identification strategy that exploits false positives and false negatives to alleviate concerns of strategic prioritization and targeting of areas with growth potential (see Section 5).

3.1.2 Report Quality and Characteristics

Hazardous areas differ considerably. Some interventions regard large in terms of area and contamination minefields, as for example, the ones extending the Tanzanian border. Others target road segments that could be as long as 208 kilometers (Macata-Malema road cleared in 2006). Some CHAs entail a handful of mines blocking access to wells or streams. Others cover small areas outside schools, townhouses, etc. The details of clearance reports differ. At the minimum, they include the demining operator, coordinates, and the date. Around half (56%) mention the size of the contaminated area (in square meters), while most post-2008 reports also delineate polygons of contamination. The average operation cleared $64,949\ m^2$ (a square with a side of 250 meters); while the median is $2,500\ m^2$. The largest minefield is $45,870,000\ m^2$ (a square with a side of 2.2 km). The most complete reports give information on the number of landmines (manufacture, type, origin), along with maps, the demining team, equipment, and a brief description. A typical entry reads, "*a minefield covering an area of* 18,893 *square meters was cleared by Halo Trust on a civil war battle trench nearby Matsinho village in Manica province in* 2015".

3.1.3 Landmine Contamination and Clearance

Figure 1 - Panel A illustrates the spatial distribution of CHAs. The map, thus, provides an ex-post visualization of contamination. $3,092$ clearance operations took place in the third phase of demining (post-2008), $3,418$ in the second phase $(2000-2007)$ and 913 in the first phase $(1992-1999)$. All provinces are affected, though intensity differs. The most contaminated provinces are in the South: Maputo $(1,211)$, Manica $(1,053)$, Inhambane (992), and Sofala (936), areas that RENAMO targeted in the brutal phases of the civil war. Appendix VI tabulates the statistics by province and period. In



Panel A: Location of CHAs **Panel B: CHAs across Localities**

Figure 1: **Spatial Distribution of Confirmed Hazardous Areas (CHAs)** Panel A portrays the spatial distribution of $7,424$ CHAs across Mozambique. Panel B portrays the distribution of CHAs across $1,187$ localities (admin-4 units)

Figure 1 - Panel B we aggregate the interventions across localities. Table 1 gives summary statistics. 72.03% of localities (855 out of the $1,187$) had at least one contaminated site. On average, a locality has 6.25 CHA (standard deviation of 14.16). Across the 855 mined localities, the mean (median) is 8.68 (4) with a standard deviation of 16.04.

There is considerable variation within provinces. Figures $2a-c$ portray interventions in Manica Province, North of Maputo (see Appendix III for mappings of the other provinces). Contamination is intense along the railway connecting Harare, Zimbabwe, to the port city of Beira along the Indian

Ocean, and along the paved road connecting Chimoio, close to the border with Zimbabwe, to the North. In the initial phase, the few interventions were scattered. After 1999 clearance accelerates. The large minefields bordering Zimbabwe in the South-East are cleared in the last phase when also the main cities and the railroad are fully cleared.

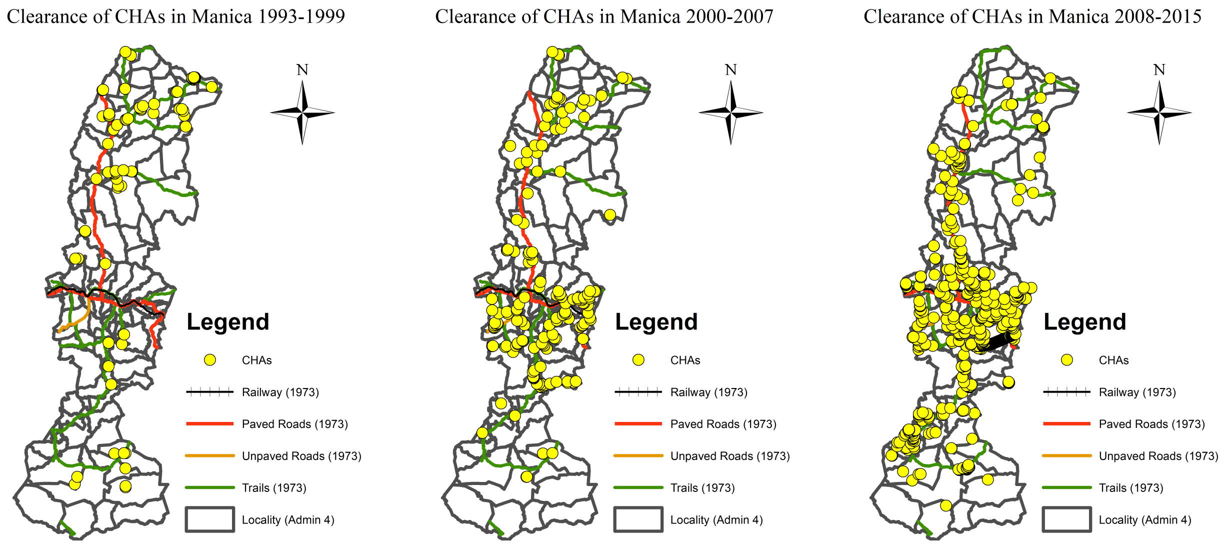


Figure 2: **Interventions in Manica.** The figure portrays clearance of confirmed hazardous areas (CHA) in the Province of Manica during the first (Panel A), the second (Panel B), and the third phase (Panel C) of demining.

3.2 Transportation Network

We collected information on the length and quality of railways, primary and secondary roads, and trails in 2011, 2003, and 1998. We also digitized maps on the conditions of the transportation network in 1973 that we merged with information on railroad conditions and status (functioning or destroyed) at the end of the civil war. There were (and still are) three main rail-lines, connecting the coastal areas along the Indian Ocean to inland: the Northern line links Nacala to Malawi; the central line connects Beira to Harare; and the Southern route goes from Maputo to South Africa (and also to Zimbabwe and Swaziland). A peculiar feature of the rail network, a colonial legacy, is the absence of connection among the main railroads. With the exception of the Zambezi, that effectively cuts the country in the middle, the other rivers do not accommodate large or medium-sized boats. As colonial investments in transportation were minimal, at independence primary roads crossed just 17% and railroads just 13% of Mozambican localities (Table 1).

3.3 Population and Development

We digitized the pre-clearance population census of 1980, and the post-war censuses of 1997 and 2007. [The national statistical agency has not processed the 2017 − 2018 Census, yet.]

Obtaining a reliable, time-varying, fine-resolution proxy of economic activity for one of the poorest countries in the world that emerged ruined from years of violence with nominal state capacity, and vast swaths of land virtually inaccessible, is a challenge. Following Henderson, Storeygard, and Weil (2012) and subsequent works (summarized in Michalopoulos and Papaioannou (2018) and Donaldson and Storeygard (2016)), we proxy regional development using satellite imagery on light density.[12] As of 1992, only 11% of the localities had some detectable luminosity. It increases to 17.7% in 1999 and 22.7% in 2007. It jumps to 42% in 2015 (Table 1).

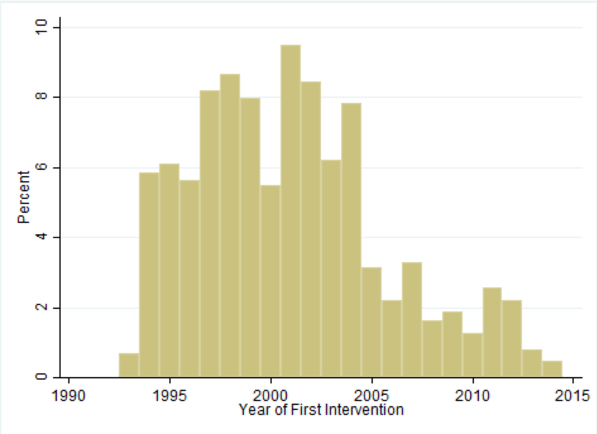
3.4 Correlates of Contamination

To better understand the spatial distribution of landmine placement during the war of independence and the civil war, we examined its correlates. We run linear probability, probit, and negative binomial ML models associating the likelihood (and number) of CHAs with geographic and location-specific characteristics (e.g., proximity to roads, railroads, and borders), early development (e.g., population density in 1980) and civil war proxies. For brevity, we report and discuss the results in Appendix V. The analysis yields the following. First, in accordance with the narrative, contamination is intense along the borders with Zimbabwe, Swaziland, and Tanzania. Second, the transportation network was heavily mined. Third, landmine placement was, on average, higher in larger and more populous localities. Fourth, contamination was higher in places that experienced more conflict (though the conflict data are quite noisy). However, the explanatory power of the empirical models is weak, in line with the anecdotes and surveys on the idiosyncrasies of landmine use.

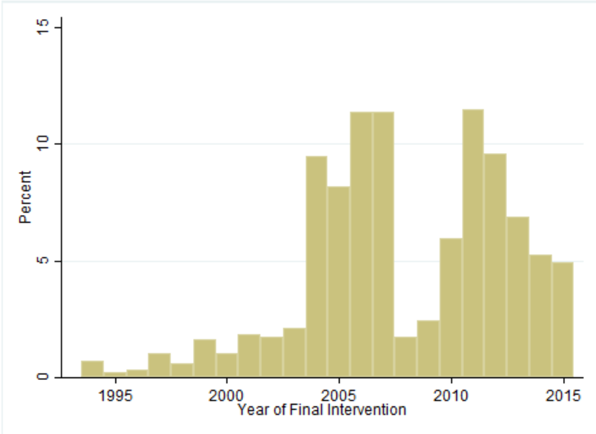
3.5 Correlates of Timing of Clearance

We then examined the evolution of clearance, looking separately at the first and last intervention. Panel A Figure 3 plots the share of localities that had their first demining operation in each year. By the end of 1994, when the elections took place, clearance operations had taken place in just 56 localities. By 2000, the cumulative percentage (number) of localities where some clearing had taken place was 48.53% (415 of 855). It jumps to 89.12% in 2007. Panel B - Figure 3 depicts the yearly evolution of the share of fully cleared localities. At the end of 1994, just 1% (6) localities were fully cleared. The share increases to 5.61% in 2000 and roughly 50% in 2007. The average (median) years to clear a locality is 6.99 (6) with a standard deviation of 5.93. The difference between the timing of the first and last clearance is not because operations take years to complete (on average a CHA is cleared in four months), but because there were several interventions in a locality (for example, one targeting a road segment, another one along the border, and another in a school yard). Due to the

[12] In Appendix V we show that luminosity correlates strongly with (i) mean years of schooling across localities using data from the 1997 and the 2007 Mozambique censuses and (ii) wealth proxies from the Demographic and Health Surveys (DHS) across many Sub-Saharan African admin-3 units, incl. Mozambique. These associations apply to rural and urban areas. Appendix VI provides visualizations of the spatial evolution of luminosity.



Panel A: First Intervention across Localities



Panel B : Last Intervention across Localities

Figure 3: **Distribution of the Timing of Intervention across Localities.** Panel A plots the share of contaminated localities (admin-4 units) that experience for the first time some clearance operations per year. Figure 3, Panel B plots the share of cleared from all confirmed hazardous areas localities per year. Overall, there are 855 contaminated localities (with at least one Confirmed Hazardous Area (CHA)).

fragmented nature of demining and the errors of the initial surveys, operators had to go back and forth, visiting contaminated localities multiple times (see Appendix III).

We associated the years elapsed between 1992 and the year of the first and the last intervention with locality features to understand the timing of clearance. The analysis -reported in Appendix IV- yields the following: First, the timing of the initial intervention is related to just a few observable characteristics. Early interventions took place in areas close to the border with Malawi, as a key objective was to bring back refugees. Clearance started earlier in localities that had experienced warfare and in more densely populated ones. Those with railroads or primary roads do not seem to be targeted earlier. The economic significance of these variables is rather weak and the explanatory power of the model poor. Second, when we examine the correlates of years elapsed till full clearance, we also find that the model fit is poor and the economic magnitudes small. Localities alongside the main transportation network or more populous ones are not cleared earlier. These findings suggest that by and large the process of clearance did not follow a systematic pattern, reflecting among other constraints the lack-of-coordination, IND's limited capacity, the ad-hoc and short-term nature of contractors (as financially constrained NGOs were doing fund-raising for specific CHA), the flaws of the 1994 and 2001 surveys, the big floods of $2000-2001$, and the ebb and flow of foreign aid.

4 Landmine Clearance and Local Development

In this section, we explore the within-locality association between clearance and development. Before presenting the results, it is important to notice that the correlations do not necessarily identify causal effects. Although the timing of landmine clearance does not seem to follow a systematic pattern, demining was not an outcome of some strict randomization. Moreover, spatial interdependencies are likely, as clearing a particular area from landmines may have positive or even negative (via population relocation) spillovers.

4.1 Panel Estimates

The estimation explores the coevolution of luminosity and CHA clearance, netting out locality, time-invariant characteristics μ_i and allowing for province-specific time effects $\mu_{t,p}$. The specification reads:

$$y_{i,t} = \mu_i + \mu_{t,p} + \beta CLEAR_{i,t} + \eta_{i,t}, \tag{1}$$

$y_{i,t}$ is economic activity in locality i, as reflected in nighttime luminosity, in year t. We conduct the analysis at the yearly level and at the end of each of the three demining periods (1999, 2007, 2015) beginning in 1992. To account for the non-linear nature of the dependent variable, we apply two transformations. First, we focus on the extensive margin of luminosity using an indicator that equals one if the locality is lit. Second, we use the log of light density augmented by a small number.[13] We use two proxies of demining, $CLEAR_{i,t}$, and $Cleared\ Threats_{i,t}$. The latter denotes the logarithm of one plus the cumulative number of cleared CHA.[14] The $Cleared_{i.t}$ indicator takes on the value of 0 while a locality is contaminated and becomes 1 the year/period it becomes landmine free and remains 1 thereafter; the variable equals zero for non-contaminated localities. The locality constants, μ_i, capture time-invariant, local characteristics that may affect development and clearance. The province-time constants, $\mu_{t,p}$, account for the idiosyncratic process of demining across provinces, unobserved trends in regional development, and allows us to compare localities with broadly "similar" histories and geographies.

Table 2 reports the estimates. Standard errors are clustered at the admin-2 (district) level, as this accounts both for serial correlation and spatial (within-district) interdependencies.[15] The table also reports [in brackets] standardized "beta" coefficients that reflect the change in the outcome variable to a one-standard-deviation increase of the explanatory variable. In columns (1)-(4) we exploit annual variation, while columns (5)-(8) report demining-end-of-period estimates. Across all yearly specifications, the clearance proxy ($Cleared\ Threats_{i,t}$ and $Cleared_{i.t}$) enters with a significantly positive estimate. Economic activity increases significantly in localities that become partially or fully cleared compared to localities that have not been (fully) cleared and localities without any contamination. In columns (3) and (4) we examine how the extensive margin of luminosity reacts to a decline or the elimination of CHAs. Clearing a locality from all contaminated hazardous areas

[13] We add half the minimum positive value in the data; $\ln(0.0001 + light/km^2)$.

[14] We use the cumulative number, so positive coefficients imply an increase in luminosity after clearance.

[15] Clustering at the coarser province level (admin 1) or at the finer posto level (admin 3) or applying Conley's correction with a cut-off of 900 km to account for spatial interdependencies yield smaller standard errors. We also experimented with double clustering at the time (year/period) and the province/district/posto level. Standard errors are similar to the ones in Table 2. In Appendix VI we reproduce some of the basic results with alternative standard errors.

increases the likelihood of lit by roughly 4%; this estimate should be compared with the 17.7% (11%) likelihood of a locality being lit in 1999 (1992). Figure 4 provides a visualization of the evolution of the lit indicator in the five years before and the five years after full clearance, netting out province-year and locality fixed-effects.

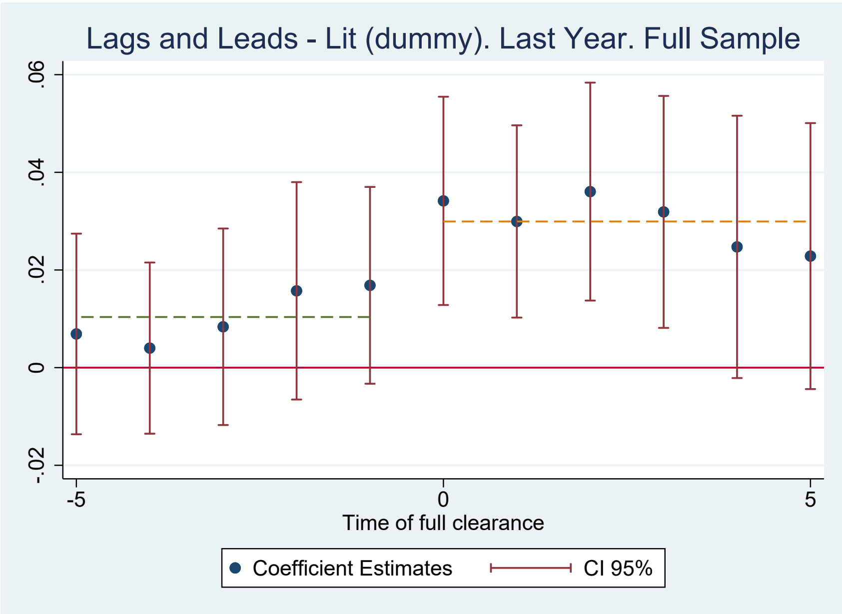


Figure 4: **Evolution of Luminosity around Full Clearance (t=0).** The figure plots the estimated coefficient of year indicator variables before, during, and after the year of full clearance (t=0). The dependent variable is an indicator that takes the value of one if the locality is lit and zero otherwise. The coefficients are estimated with the following model:

$$\mathrm{y}_{i,t} = \mu_i + \mu_{t,p} + \beta \text{Full Clearance}_{i,t} + \sum_{j=1}^{5} \gamma_j \text{Full Clearance}_{i,t-j} + \sum_{j=1}^{5} \rho_j \text{Full Clearance}_{i,t+j} + \eta_{i,t}$$

Full Clearance is an indicator taking the value of one if t is the year of full clearance for locality i and zero otherwise. The graph also reports 95% confidence intervals based on clustered at the district-level (admin-2) standard errors.

In columns (5)-(8) we examine the association between light density and clearance over the medium run ($7-$ year periods). A benefit of these specifications is the reduction in measurement error in the exact timing of operations. Moreover, it is conceivable that it may take some time for economic activity to pick up following demining. The magnitudes are uniformly larger suggesting that demining's payoffs materialize over time. The likelihood of a locality being lit increases by around 8 percentage points when fully cleared. To gauge the economic significance of the coefficients, we estimated the elasticity between light density and development proxies across Mozambican localities using the 2009 and 2011 Demographic and Health Surveys as well as the 1997 and 2007 censuses [see Appendix *V*]. The difference in education between lit and unlit localities is around 1 year (in both DHS and Censuses) and DHS tabulations suggest that lit compared to unlit localities are on average 18% percentage points wealthier (in terms of the composite wealth index).

4.2 Further Evidence and Sensitivity Analysis

We perturbed the specifications across various dimensions to examine robustness and better understand the correlations. We discuss them briefly below and in detail in Appendix VI.

4.2.1 Alternative Outcomes

We examined the association between CHA clearance and population over the 1992 – 2007 period (as the 2017 Census is unavailable). The specifications reveal a positive but in general small and not always significant association.

We then explored the relationship between landmine clearance and (i) building of new roads and (ii) improvements of the colonial transportation network. Demining is unrelated to new road construction. But, it correlates significantly with improvements in the colonial-era network, revealing a plausible mechanism at play.

4.2.2 Measurement Error

We commence the sensitivity analysis accounting for error in clearance data. First, we augmented the specification with interactions between period-specific constants and operator-specific fixed effects to account for potential differences in (mis)reporting across demining operators over time. Second, in a more restrictive specification, we zoom in the Northern provinces, where measurement error is presumably lower. HALO Trust, that carried almost all operations (90%) since its arrival in 1994, was recording interventions in a consistent manner using IT systems. Reports' quality is higher with more details, a more standardized structure, and richer information. Third, we dropped the initial period (1992 – 1999), when neither local authorities nor donors gathered data systematically. Across all these permutations, we obtain a significantly positive within-locality correlation between luminosity and clearance. Fourth, we focus exclusively on rural localities[16] to assuage concerns that the luminosity-development correlation reflects hard-to-account-for differences between rural and urban locations. The correlation retains statistical and economic significance.

4.2.3 Further Sensitivity Checks

We conducted a plethora of sensitivity checks. First, we drop Maputo, Beira and Nacala, where luminosity is much higher, compared to the rest of the country, and contamination was relatively low. Second, we dropped all localities in the Maputo province, as there are sizable differences in urbanization and development between the capital province and other parts. Third, we stopped in 2013 (rather than 2015), as in this year there is a change in the satellite recording. Fourth, to mitigate concerns that the relationship between clearance of landmines and economic activity, is

[16] We use the 1997 census classification to distinguish between rural and urban households. We define as rural localities where 100% of the inhabitants are classified as such.

driven by refugees returning to their home towns, we excluded localities receiving the largest migration inflows and localities suffering the largest war-related outflows, as recorded in the 1997 Census. The results across all these permutations remain intact. Fifth, we added interactions between a third-order latitude-longitude polynomial and period-specific constants to account for spatially correlated unobserved time trends. Sixth, we added interactions of period constants and time-invariant location-geography features. Seventh, in a quite restrictive test, we replaced the province-period constants with district-period ones, to account at a fine level for local trends and time-varying factors related to operations and economic performance. Eighth, we estimated dynamic panel specifications with the annual data (though the data are noisier). Due to inertia in luminosity, the "long-run" association between clearance and local development is larger than the yearly estimates and quite close to the end-of-period estimates (our preferred ones). Ninth, we focused only within contaminated localities. Standard errors increase -as we lose roughly 30% of the sample- but the estimates retain significance. Tenth, instead of deriving the locality estimates of landmine contamination based on the number of demining interventions we used the number of CHA. Eleventh, we examined whether luminosity increases as early as the first demining operation or when the locality is completely cleared from contamination. Economic activity picks up when a locality is fully cleared, rather in-between the initial and the final intervention. This finding further suggests that development projects concurrent to demining an/or the mere presence of deminers are unlikely to be driving the uncovered associations. Twelfth, we controlled for new road construction and improvements of the pre-existing transportation network. The estimates remain intact.

5 Landmines and Local Development. An "Errors-in-Surveys" Approach

To minimize concerns regarding prioritization, in this Section we develop an identification strategy that exploits variation in clearance driven by the inaccuracies in the three countrywide surveys that guided demining in each period.[17] We first discuss survey errors. Second, we lay down the empirical specification. Third, we report the panel estimates.

5.1 Surveys. Challenges and Errors

5.1.1 Initial Phase. 1994 Report

The 1994 SHAMAN was conducted under extremely demanding conditions, including a debilitated transportation infrastructure, the return of millions of internally displaced and refugees, and insecurity.

[17] This approach relates to the one of Chodorow-Reich, Coglianese and Karabarbounis (2018). They exploit errors on real-time unemployment rates, and their ex-post corrections, to quantify the role of unemployment benefits on employment.

Resources were scarce and the survey was done in a rush.[18] Many parts of the country were inaccessible and thus the surveying teams did not visit several localities.

Unsurprisingly, the survey contained many errors. Out of the $1,746$ demining interventions conducted between $1994-2000$, less than half (831) took place in areas identified by the survey as SHA. Strikingly, only 258 were actual clearance operations, with the remaining 573 indicating "cancelled" SHA (false positives). Hence, 804 clearance operations took place in areas that the Survey did not identify as potentially contaminated. Often locals were using the suspected land as the initial classification of SHA (573) turned out to be erroneous based on inaccurate information.

5.1.2 Second Phase. 2000-2001 Report

The Mozambique Landmine Impact Survey (LIS) of $2000-2001$ provided guidance during the second phase. Although security was restored and the displaced had returned, LIS faced many difficulties (see the independent evaluation of *Scanteam* for the United Nations). An initial defect was its dual objective, measuring contamination and assessing impact. Then was the lack of expertise. The survey was done mostly by sociologists interested in qualitative assessments rather than demining experts who were desperate to obtain a concise mapping of contamination. Demining operators did not collaborate much, an issue that was magnified by distrust towards the newly established National Institute of Demining that was replacing its inefficient and allegedly corrupt predecessor.

LIS contained both types of error. Only 945 of the $3,789$ interventions in the second phase regard clearance of areas identified as suspected of contamination by the LIS. An additional 293 clearance operations took place in sites identified by the 1994 survey. Type-I error was considerable: 793 of the total of $1,738$ SHA recorded in the 2001 LIS were in fact not contaminated and demining organizations had to reclassify them as "canceled" after visiting the area. Type-II error was also sizable, as $1,730$ clearance interventions in the second phase took place in areas neither identified as suspected of contamination by the 2001 LIS nor by the 1994 SHAMAN.

5.1.3 Third Phase. 2007-2008 Report

The 2008 Baseline Survey that collected information on the remaining threats as of 2007 from various operators, guided clearance during the final period. The survey was done in a peaceful environment. It was significantly more accurate than the previous ones. But, some of the aforementioned challenges, though attenuated, were present. Connectivity was low, as for example, the two Zambezi river bridges linking the North with the South were still not operating. Funding was limited, as the corruption scandals of $2004-2006$ had made donors sceptical. HALO Trust did not visit suspected areas and simply gathered scattered information from the various demining operators across the country.

[18] To fix ideas the survey in the four Northern provinces, whose size is approximately that of Italy, was conducted by just two teams of 4 people in less than 6 months. The surveys in the Southern provinces and Tete, whose total size is approximately that of Spain, was carried out by three teams of 4 people in five months.

Clearance proceeded fast in the final phase. Our dataset stores $3,883$ operations. Type-I error was moderate 10% (377 operations involved the reclassification of SHA as cancelled). Type-II error was considerable, as $1,147$ clearance interventions took place in areas not identified as SHA in any of the previous surveys.

5.2 Specification

Having distinguished operations between expected (reported in previous surveys) and unexpected (not reported in earlier surveys) as well as cancelled ones, we explore their association with local development (luminosity) modifying the baseline empirical specification as follows.

$$y_{i,t} = \mu_i + \mu_{t,p} + \beta_1 H_{i,t}^{S,A} + \beta_2 H_{i,t}^{NS,A} + \beta_3 H_{i,t}^{S,F} + \eta_{i,t}, \tag{2}$$

- $H_{i,t}^{S,A}$ indicates actual clearance (superscript A) of areas identified (correctly) as suspected of contamination by the preceding surveys (superscript S). For example, ADP cleared $3,189$ Anti-Personnel mines on the "protective ring" of Moamba between 1994 and 1998, an area that the 1994 SHAMAN identified as potentially contaminated. The survey writes "*perimeter minefield around entire village approx 12 km long...minefield is clearly visible from road*". Overall, $3,743$ (40%) interventions reflect those that surveys had rightly identified as hazardous areas.

- $H_{i,t}^{NS,A}$ denotes actual clearance of hazards not been identified as SHA by the preceding surveys (superscript NS). These reflect type II survey errors. For example, "*HALO Trust cleared 8 AP mines and 1 UXO on Djuba bridge located in Matola Rio (Maputo Province)*" in 2010, an area that was not identified as suspected by any of the three earlier surveys. Overall, $3,681$ (39%) interventions fall into this category. [The sum of $H_{i,t}^{S,A}$ and $H_{i,t}^{NS,A}$ is the universe of $7,424$ CHAs]

- $H_{i,t}^{S,F}$ denotes the reclassification of areas from suspected of contamination (superscript S) to cancelled. In these cases, no clearance took place (superscript F), as upon visiting the area demining teams realized that the information surveyors had gathered was inaccurate. These reflect type I error in the surveys. For example, the 1994 SHAMAN listed Muambica village in Niassa as suspected of contamination, though the surveying team never visited the area and got the tip from a local 46 km away. When HALO Trust visited Maumbica to clear the minefield, it realized that the area was "free and safe from mines". Overall, there are $1,743$ (18.5%) cancelled SHA. [19]

Appendix VII reports examples and descriptive statistics on type I and type II error. The Appendix further shows that while there are some small geographic-locational differences between cancelled SHA, expected-surveyed CHA, and not-in-surveys-CHA, these disappear when we exploit

[19] There are also a few cases of "cancelled" SHA that were not included in the earlier survey(s). As there are just 251 we blend them together with the "false positives" of the surveys.

within-locality over time variation (as we do in the regression analysis). Likewise, the mean-median year of clearance is similar for the three categories in each period.

5.3 Panel Estimates

5.3.1 Surveyed and Non-Surveyed CHA

In odd-numbered columns of Table 3 we distinguish between SHA that were contaminated and eventually cleared [$H_{i,t}^{S,A}$] and the clearance of SHA that were not identified as contaminated by the preceding surveys [$H_{i,t}^{NS,A}$]. We obtain a significantly positive estimate with clearance of SHA, recorded in the three countrywide surveys. This applies both when we use the continuous variable, the log of cumulative SHA (in (1) and (5)) and the binary variable (in (3) and (7)). A concern with these estimates is that of central prioritization, as these hazardous areas were known to the demining community in the beginning of each demining phase. However, clearance of SHA that were not recorded by any nationwide surveys -and hence where unknown ex-ante to the demining operators- is also associated with a significant boost in economic activity. The linear probability model estimate on the cleared indicator suggests that the likelihood of a lit locality increases by approximately 5% when it is cleared from SHA that could not have been part of any strategic consideration.

5.3.2 Cancelled SHA

In the even-numbered columns of Table 3 we examine whether luminosity changes when demining teams visit a suspected hazardous area, already in use by the locals. The coefficient on cancelled SHA [$H_{i,t}^{S,F}$] is small, changes sign, and is statistically indistinguishable from zero. Local development does not respond to instances of demining operators realizing once on the ground that the classification of SHA was erroneous. This non-significance assuages concerns that demining operators were targeting localities with better growth (opportunities), as if that was the case, luminosity would have increased even in absence of clearance. Moreover, it suggests that demining activities were not concurrent to other development projects (as our interviews also suggest). Would the latter be true, then the mere reclassification of a SHA into a cancelled one might lead to changes in local economic activity.

6 Heterogeneity

The specifications reveal a significant boost in economic activity after clearance. But this does not necessarily imply that landmine clearance is equally beneficial. In this Section, we explore heterogeneity with respect to intervention and to locality features, as this may provide clues into the mechanisms.

6.1 Intervention Characteristics

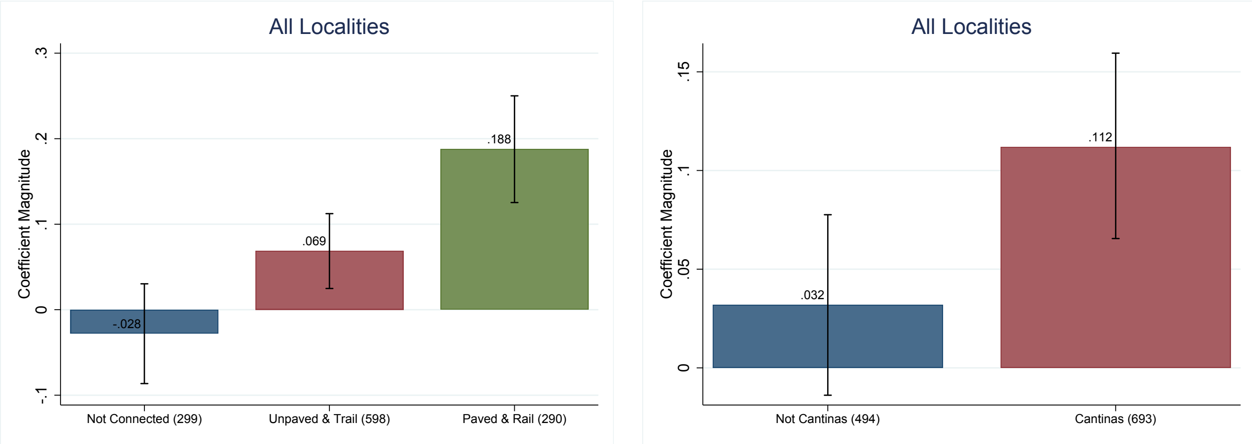
We start exploring heterogeneity with respect to *intervention* characteristics. We used the CHA coordinates to classify interventions into 7 non-mutually-exclusive categories based on proximity to roads and railroads (using a distance cutoff of 100 meters to the 1973 network), navigable rivers (cutoff of 100 meters), borders (cutoff 10 kilometers), villages and towns (radius of 1 kilometer), electricity pylons-grid (100 meters radius), cantinas (radius of 1 kilometer), and centroids of civil war violence (radius of 1 kilometer).[20] Table 4 reports estimates, where we interact the number of cumulative cleared hazardous areas (in (1) and (2)) and the cleared dummy (in (3) and (4)) with indicators reflecting the type of the contaminated area. On the one hand, reducing the number of contaminated areas along roads-railroads and clearing areas around villages and towns, especially the ones with cantinas, is associated with significant increases in luminosity. On the other hand, removal of landmines placed in remote areas (the residual category), close to national borders, and rivers does not seem to lead to increases in luminosity. Clearing border areas is negatively related to luminosity, though the estimate is statistically insignificant.

6.2 Locality Characteristics

Then, we explored heterogeneity with respect to *locality* characteristics. We start looking at localities' connectivity to the colonial transportation network. 290 localities host primary roads or railroads; 598 are connected to the transportation system only via unpaved roads or trails whereas 299 appear non-connected (see Table 1). Figure 5 plots the coefficients (and standard errors) when we allow the clearance indicator to differ across these groupings (Appendix VI reports the corresponding panel estimates). The likelihood that the satellite will detect light is 19 percentage points higher when operators clear localities connected via primary roads and railroads; the estimate for localities intersected by secondary and tertiary roads is around 7%. Clearance is not associated with significant increases in luminosity across localities non-connected to the transportation network.

We then investigated whether demining was more important for localities with agricultural markets before the civil war. Cantinas were small trading posts, initially owned and operated by Portuguese or Asian settlers, specializing in "*the acquisition and transport of various types of produce (peanuts, cashews, cotton, corn, etc.) harvested by the natives to procure for the town dwellers*" (Bastos (2006)). Cantinas "*performed an essential role in agricultural marketing, providing seeds, textiles, domestic utensils, and agricultural implements to locals*" (Darch (2018)). They were the most widely available (and often the only) means for Mozambican farmers to sell their goods to the cities and towns, whole-sellers or factories (in the case of cashews). Cantinas were scattered across all provinces; 693

[20] 16% of CHAs were found along the transportation network; 14% placed within a kilometer from villages' and towns' centroids; 8% are found along border areas and a similar percentage was traced close to cantinas; 10% of CHAs were found either in areas that experienced civil war violence and along the electricity grid. 61% of CHAs, which are not sufficiently close to any of the aforementioned features, are in the residual category.



Panel A: Connected vs Non Connected **Panel B: Cantinas vs Non Cantinas**

Figure 5: **Heterogeneity with respect to Locality Characteristics.** Panel A plots the estimates of clearance on localities connected by (at least) one i) roads or railways connected (290); ii) unpaved road or trail (598); iii) non-connected (299). Panel B shows the estimates of clearance on localities having (at least) one cantinas 693 and those (494) without one.

localities hosted at least one (average 1.43 [median 1]), whereas 494 did not have any.[21] Panel *B* of Figure 5 plots the coefficients when we allow the clearance indicator to differ across the two sets of localities. The linear probability model estimates suggest that after clearance the likelihood of a locality without cantinas to turn lit increases by 3%, which is statistically indistinguishable from zero. The corresponding likelihood for localities with cantinas is precisely estimated at 11 percentage points.

6.3 Sensitivity

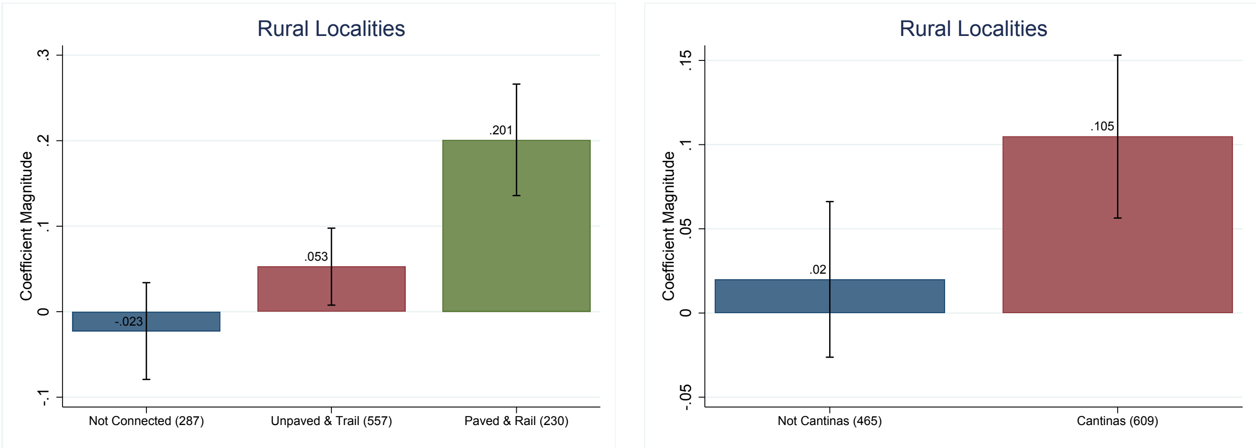
The uncovered heterogeneity appears robust to various perturbations (see Appendix VI). Three issues deserve a more detailed discussion.

6.3.1 Rural Area Analysis

One concern is that the uncovered heterogeneity reflects hard-to-account-for differences between rural and urban areas. Although the locality-specific constants account for these, we repeated the analysis restricting estimation to exclusively rural localities.[22] Figure 6 plots the estimates (and standard errors), when we allow the coefficient to differ across connected and non-connected rural localities (Panel *A*) and across rural localities with and without cantinas (Panel *B*). Clearance boosts economic

[21] The presence of cantinas is correlated with the colonial transportation network. Nevertheless, there is significant variation. Among 299 localities not connected to the colonial transportation network, 124 host a cantina, (40%). Across the remaining 888 connected localities, 569 (64%) have at least one, while 319 localities (36%) do not.

[22] There is sizable variation in transportation connectivity and the presence of cantinas in the latter sample. 230 rural localities have primary roads or railroads; 557 rural localities host unpaved roads or trails; and 289 localities are non-connected. 609 rural localities host (at least) one cantina, whereas 465 do not have any. For example, among the 287 rural localities without connectivity to the colonial transportation network, 121 host a cantina, (42%). Across the remaining 787 connected localities, 488 (62%) have at least one cantina while 299 localities (38%) do not.



Panel A: Connected vs Non Connected **Panel B: Cantinas vs Non Cantinas**

Figure 6: **Heterogeneity with respect to Locality Characteristics. Rural Localities.** Panel A plots the estimates of clearance on rural localities connected by (at least) one i) roads or railways (230); ii) unpaved road or trail (557); iii) non-connected (289). Panel B shows the estimates of clearance on rural localities having (at least) one cantinas 609 and those (287) without one.

performance in rural localities connected to the transportation network, especially the ones with railroads and primary roads, and in rural localities with agricultural markets. In contrast, the within-rural-locality association between luminosity and clearance is muted in rural localities non-connected to the transportation and without cantinas.

6.3.2 Luminosity-Development Nexus

Another concern is that the heterogeneous response of luminosity to clearance is not indicative of the latter facilitating exchange of goods across space, but it reflects differences in how well light density captures economic activity across the different sets of localities. In Appendix V we show, using data from the 1997 and 2007 censuses, that changes in luminosity are robust predictors of changes in schooling over this 10-year interval both across localities connected and non-connected to the transportation infrastructure as well those with and without cantinas.

6.3.3 Surveyed SHA, Unexpected CHA, and Cancelled SHA

Expanding on the "error-in-surveys" approach, detailed in Section 5, we distinguished between clearance of SHA, as recorded in the nationwide surveys, and clearance of SHA that surveyors missed and are therefore unlikely to be part of any central plan of coordination. The coefficient on the indicator that takes the value one, when a locality connected to the transportation infrastructure is cleared, is positive and highly significant both when we look at clearance of SHA recorded in earlier survey(s) and, most importantly, at CHA that were not part of the surveys. We find the same pattern when we explore heterogeneity w.r.t. the presence of cantinas. These findings assuage concerns of centrally planned and coordinated strategic prioritization. Moreover, "cancelled" SHA are uncorrelated with luminosity both when we look at connected (with cantinas) and non-connected localities (without cantinas). These non-results demonstrate that the estimates do not reflect deminers simply prioritizing areas with growth (potential).

6.4 Summary

The analysis uncovers meaningful heterogeneity. Clearing hazardous areas along the transportation network and rural areas of commercial importance maps into larger economic payoffs than interventions elsewhere. These findings suggest that clearing the transportation infrastructure and agricultural trading hubs is likely to not only benefit the locality where the contaminated segment lies, but also generate externalities across connected regions. We explore this issue below employing a framework designed to assess spillovers across interconnected regional economies.

7 Landmines and Development. A Market-Access Approach

In this Section, we examine the economy-wide effects of clearance. We start discussing the theoretical underpinnings of the empirical approach and proceed with the construction of the "market-access" measures that require calculating locality-pair transportation costs factoring in landmine contamination and road-railroad quality. We then report the baseline results and summarize the sensitivity analysis. Appendix $VIII$ provides an in-depth discussion of the underlying theoretical framework, details on the construction of the market access measures, and various sensitivity checks.

7.1 Theoretical Foundations[23]

The conceptual framework of our empirical analysis follows Donaldson and Hornbeck (2016) that, building on Eaton and Kortum (2002), develop Ricardian general equilibrium models of inter-district trade and spatial development. This setup approximates well commerce in agricultural economies, like Mozambique, where the share of employment in agriculture exceeded 80% in the 1990s, while nowadays hovers around 70%. For example, Donaldson (2018) employs this framework to study the role of colonial railroads in India where agriculture's share in GDP was around 66% and the majority of Indian farmers were engaged in subsistence farming. Alder (2017) uses this framework to quantify the effects of India's large highway system in the 2000s on welfare, as reflected in luminosity. Barjamovic, Chaney, Cosar, and Hortacsu (2019) use a modified Eaton and Kortum (2002) setup to study trade during Assyrian times in 19th BC and predict the location of "lost" cities. Donaldson and Hornbeck (2016) quantify local and aggregate effects of US railroads in the mid/late 19th century on the value

[23]Donaldson (2015) provides a review. Costinot and Rodriguez-Clare (2014) give an overview of quantitative works on trade across and within countries.

of agricultural land.[24]

Donaldson and Hornbeck (2016) derive a "reduced-form" log-linear relationship from this set of models linking aggregate welfare (income) to a locality's "market access".[25]

$$\ln(Y_o) = \kappa + \alpha_o + \lambda \ln(MA_o), \tag{3}$$

where a locality's o "market access" $[MA_o]$ is:

$$MA_o \approx \sum_{d=1}^{D} \tau_{o,d}^{-\theta} N_d(Y_d). \tag{4}$$

N_d and Y_d reflect population and output of all but-the-origin localities. α_o are locality fixed effects, capturing technology, endowments, and other local features. Market access (MA_o) for locality o is the sum of the income (population) of all other (destination) localities, d, discounted by transportation costs ($\tau_{o,d} > 1$), scaled by a "trade elasticity" parameter (θ). The latter theoretically approximates localities' comparative advantage, with lower (higher) values pointing to stronger (weaker) comparative advantage.

7.2 Market Access across Mozambican Localities

7.2.1 Bilateral Transportation Costs

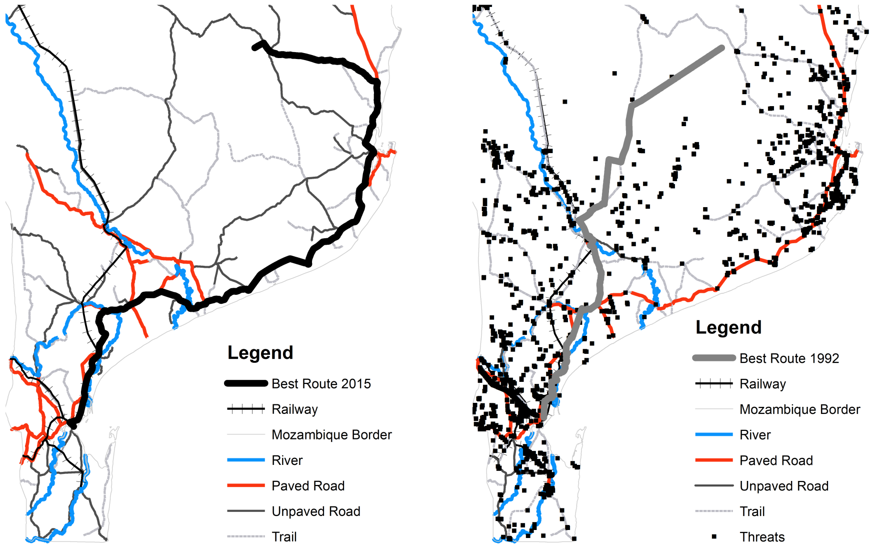
The construction of bilateral transportation costs entails four steps ($\tau_{o,d}$). First, we create the transportation network that consists of railroads, paved and unpaved roads, trails, and navigable rivers. We also allow for straight-line connection on foot among localities' centroids.

Second, we parameterize the (relative) cost of the network's elements trying to tie our hands to earlier and parallel works focusing on similar settings (Donaldson (2018), Donaldson and Hornbeck (2016), Alder (2017), and Jedwab and Storeygard (2018)). The most efficient (trade) technology is the railway, whose cost is normalized to 1. Following studies on road quality and transportation cost in Africa (Kim, Molini, and Monchuk (2012)) and Mozambique (Alemu and Van Schalkwyk (2008)), we set the relative cost of paved roads to 2 and of unpaved roads to 4. The relative costs of trails - that typically connect roads to villages and small towns - is 10, as they are in poor conditions. The relative cost for walking is 20. Given the tiny, if any, role of navigable rivers for trade, we assign a relative cost of 15. The precise values of the cost parameters are not particularly important; what matters are relative costs. In Appendix $VIII$ we show that the results are robust to alternative parameterization.

Third, regarding landmines, we impose that the presence of a CHA within 100 meters of a road/railroad/trail/river is blocking usage. This accords with clearance reports, the Mozambique-

[24]See also Nagy (2018) on trade in Hungary during World War I and Atkin and Donaldson (2015) on inter-district trade in Ethiopia and Nigeria.

[25]Alder (2017) shows that the log-linear association between income and market access obtains both when one assumes labor mobility (as Donaldson and Hornbeck (2016)) and when labor is immobile.



Panel A: Optimal Route 2015 **Panel B: Optimal Route 1992**

Figure 7: **Least-Cost Route according to Dijkstra's Algorithm**

wide surveys, the reports of various organizations (Landmine Monitor (2015), ICRC (2002)), and our interviews.

Fourth, we approximate the travel time using Dijkstra's algorithm that solves for the lowest-cost path between any two localities' centroids.

Figure 7 illustrates the shortest route between Maputo and Funhalouro, approximately 600 km north of the capital. Panel A shows the optimal path in 2015. As all hazards have been cleared, the algorithm employs the most efficient network elements, yielding an almost identical to the "google maps application" path for a 9-hour journey. The route for 1992, illustrated in Panel B, is rather different. As the main primary road (highway $N1$, connecting Maputo to the Centre alongside the Indian Ocean) and the secondary road linking it to Funhalouro are blocked by dozens of minefields, the algorithm uses the non-contaminated parts of the transportation network relying often on unpaved roads and trails; this results in a 3.5-fold cost increase.

7.2.2 Trade Elasticity

The literature has produced estimates of the trade elasticity (θ) ranging from 2.5 to 10. As a benchmark, we follow Donaldson (2018) and Donaldson and Hornbeck (2016) using a value of 3.88. This is at the midpoint ($2.79 - 4.46$) of the estimates that Simonovska and Waugh (2014a,b) produce in their careful estimation of the trade elasticity in comparative advantage settings.

7.3 Market Access Measures

We construct market access measures using contemporaneous values for population-development and transportation costs [$MA^c_{o,t}$] and fixing population-development to pre-clearance levels and imposing the transportation network at independence [$MA^f_{o,t}$]. For both the contemporaneous and the initial conditions based measures, we compile two statistics. First, we proxy aggregate demand (total output) in the destination locality with the sum of lights, $Y_{d,t}$. This approach is similar to Alder (2017), who also uses night time light density to proxy output in Indian localities. Second, we use population ($N_{d,t}$), an approach that is similar to Donaldson and Hornbeck (2016) and Jedwab and Storeygard (2018).[26] We construct the market access measures in the beginning of each of the main periods of demining (1992, 1999, and 2007) and in 2015 when the country was declared landmine free.[27]

Figures 8$a-b$ map the long-run changes of the "market access" measures that are net of any swings in population/luminosity and new road-railroad. The correlation of changes between the two market-access measures is 0.77. There is considerable variation in changes in market access, even within provinces as province constants explain 25%-30% of the variance. Even when we add admin-2 constants, there is substantial residual variation, as the R^2 is far from one, 0.66 and 0.53 with the luminosity and the population-based market access, respectively.[28]

7.4 Baseline Results

7.4.1 Specification

We estimate the relationship between a locality's development, as reflected in luminosity ($y_{i,t}$), and its market access ($MA_{i,t}$), running variants of the following regression:

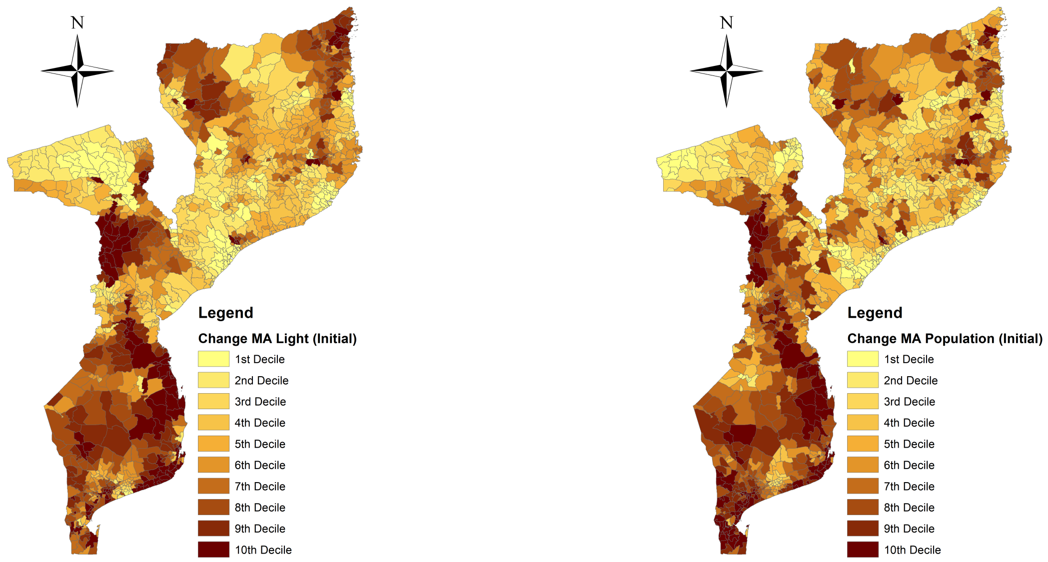
$$y_{i,t} = \mu_i + \mu_{t,p} + \lambda \ln[MA^{c,f}_{i,t}] + \zeta_{i,t}. \tag{5}$$

μ_i and $\mu_{t,p}$ are locality constants and province-specific time effects, respectively. The coefficient on the contemporaneous market access ($MA^c_{i,t}$) reflects both the direct and indirect effects on local economic activity of improved accessibility, due to landmine clearance, road-railroad improvements and extensions, as well as changes in population-development. When we impose the 1973 transportation network and use the pre-clearance population or development ($MA^f_{i,t}$), λ isolates the direct and indirect

[26]We compile market-access measures with both lights and population, as we face a trade-off. Lights is conceptually a better proxy of development (market size); yet there are many zeros, especially in the initial period (1992). Population exhibits much higher variability; however, it is a less appealing proxy of consumer purchasing power and we lack data for 2015, as the latest census is unavailable. Given this we report results with both measures.

[27]For the initial market access we use the 1973 network and the census population of 1980 or luminosity in 1992. For the 1999 measures, we use the 1998 network and the population census of 1997. For the 2007, we use the infrastructure network in 2003 and the census of 2007. For the market access in 2015, we use the transportation infrastructure of 2011 with the population of 2007, as the 2015 Census is not available.

[28]The contemporaneous market access exhibit higher variability, as population-luminosity changes over time, there are improvements in the transportation network, and new road segments are added. Province-specific constants explain 19% and 5% of the overall variation of the contemporaneous market access measures.



Panel A: Change in Log MA (Luminosity) Pre-clearance Network-Population

Panel B: Change in Log MA (Population) Pre-clearance Network-Population

Figure 8: **Change in Market Access. Initial Conditions.** Panel A illustrates the spatial distribution of the change in the log market access fixing the network and luminosity at pre-clearance level. Panel B shows the same distribution for the equivalent population-based measure.

impact of landmine clearance.

7.4.2 Luminosity - Market Access Elasticity

Table 5, columns (1)-(4), reports the luminosity - contemporaneous "market-access" association. The elasticity with the luminosity-based (population-based) market access measure is 0.29 (0.25). The linear probability model estimates in (2) and (4) suggest that a one-standard deviation increase in contemporaneous market access (around 3 log points, see Table 1) increases the likelihood that the locality is lit by $7.5\% - 9.5\%$.

In columns (5)-(8) we use the market access measures imposing the pre-clearance transportation network (1973), population (1980 Census), and luminosity (1992). While this does not fully resolve endogeneity, it allows isolating the role of clearance from that of new road building and improvements over old roads. The elasticity ("beta" coefficient) on the luminosity-based market access measure in (5) is 0.32 (0.25). This is quite close to Donaldson and Hornbeck (2016) estimates of US railroads in 1890-1870 (beta 0.3); it is also comparable to Jedwab and Storeygard (2018) quantification (beta 0.28-0.88) of the market access of road construction on African urbanization post-independence. The linear probability model estimate (in (6)) implies that a one standard deviation increase in market access (around 3) is associated with a 9 percentage points rise in the likelihood that the locality will be lit. The estimates on the 1980-population-based market access proxy in (7) and (8) are also highly significant.

To compare the magnitude of the effects, we also run two-stage-least-squares (2SLS) specifications, "instrumenting" the contemporaneous market access measures with their analogues imposing the at-independence transportation network and the pre-clearance population-luminosity (see Alder (2019) for a similar approach). The first-stage fit is strong, as there is inertia in population-development and transportation network expansion-improvements.[29] The 2SLS estimates in (9)-(12) suggest that the component of "market access" stemming from clearance operations on the old network and taking population-development fixed is a robust correlate of regional development.

7.4.3 Direct Effects

Table 6 reports specifications that account for the local effects of clearance. Panel A reports estimates with the luminosity (in 1992)-based market access, while Panel B with the population (in 1980) market access measures, imposing the 1973 transportation network. While theoretically the coefficient on the market access measure captures both direct and indirect effects, controlling for landmine contamination is useful for several reasons. First, it allows us to gauge the relative importance of the direct and spillover effects. Second, unlike the buildup of transportation infrastructure, landmine clearance may increase land productivity, by releasing unused land. Third, a significant local estimate may reflect intra-locality commerce effects. Fourth, the coefficient on market access may be attenuated, as there is subjectivity on the exact parameterization (Donaldson and Hornbeck, 2016).

In (1)-(2) we augment the specification with the log number of cleared CHA. Two patterns emerge. First, the luminosity - market access elasticity continues to be highly significant. Compared to the analogous specifications in Table 5 (columns (5)-(8)), the estimates drop by around $10\%-20\%$. Second, the coefficient on landmine clearance also retains statistical significance, though it drops by around 20%, compared to the estimates in Table 2 that solely examined the "local" impact of demining. Local and spillover effects seem to be at play. The comparison of the standardized coefficients [in brackets] of the market access shows that spillovers are considerable.[30]

In columns (3)-(4) we add indicators for localities experiencing an improvement in the 1973 transportation network and for new road-railroad segments.[31] This does not affect the market access coefficient, as by fixing initial conditions, the market access measures only reflect the decline in transportation costs due to CHA clearance of the network at-independence.

[29] The first-stage relates contemporaneous market access, $\ln[MA^{c}_{i,t}]$, with fixing initial conditions "market access", $\ln[MA^{;f}_{i,t}]$, conditional on locality fixed-effects and province-specific time effects. The elasticity (clustered standard error) is around 0.9 (0.05); the within R^2 is 0.84%.

[30] Donaldson and Hornbeck (2016) also find that railroads entailed both a direct and a "market access" effect, with the later being considerably larger than the former.

[31] New road building is positively linked to luminosity, though not statistically significant. Improvements in the transportation network are associated with a significant increase in luminosity. The estimate on the clearance indicator is approximately 50% higher, as compared to the one for improvements in the old transportation network (0.083 vs 0.058 in the linear probability model estimates).

Another way to control for the local clearance and shocks is using a market access measure that does not reflect local conditions. We recalculate the market access measures setting adjacent localities' market size to zero; this allows focusing on changes in market access from more distant localities (see Donaldson and Hornbeck (2016) and Alder (2019) for similar approaches). Columns (5)-(6) report the results.[32] The luminosity-market access elasticity retains statistical and economic significance.

7.5 Isolating the "Unexpected" Component of Market Access

To minimize concerns that the market access estimates reflect strategic central prioritization, we identify the component of market access that is less likely to be prone to such considerations. We compile separate "market access" measures leveraging variation only from the clearance of CHA identified in a preceding survey. To isolate the impact of the "unexpected" component of market access, we run panel estimates that link luminosity to the overall market access (always fixing initial conditions) and the market access measure based only on surveyed-expected threats (assuming that non-surveyed CHA are never cleared). Table 7 reports the panel estimates. As the expected-surveyed SHA market access index captures potential central coordination and strategic prioritization, the estimate on the baseline market access isolates the residual component of market access.[33] The coefficient on the baseline market access is stable and highly significant. This suggests that the luminosity-market access association is strong even when we exploit variation only from the clearance of unexpected hazardous areas.[34]

7.6 Sensitivity Analysis

We performed many robustness checks that we report in detail in Appendix $VIII$.

Market Access Parameterization We experimented with alternative parameter values of the components of the market access. First, we used alternative values for the trade elasticity (θ) that quantifies the role of transportation costs. We used the low (2.7) and the high (5.23) estimates of Simonovska and Waugh (2014a,b) regarding agriculture-based Ricardian models of trade. Second, we experiment with Harris' (1954) "market potential" measure that effectively imposes a trade elasticity of 1. Third, we used a simple measure of locality's connectivity to all others leveraging only changes in average τ. Fourth, given the importance of Maputo, Beira, and Nampula-Nacala for trade with neighboring countries we inflated the population/luminosity of these cities adding the values of Johan-

[32]Omitting neighboring localities may also account for spatially correlated error-in-variables, though our interviews and reading of the historical narrative suggests that this is not very likely.

[33]This approach is akin to work on media economics, assessing for example the impact of radio or TV on various political economy outcomes (see, among others, Durante, Pinotti, and Tesei (2019) and Olken (2009)).

[34]Another way to isolate variation in market access stemming from clearance of non-surveyed SHA, is "instrumenting" overall market access with clearance of hazardous areas that were not identified as SHA by the preceding surveys. There is a strong positive association between overall market access and market access based only from clearing of unexpected at the time SHA; as such, the first-stage is strong. The IV estimates, reported in Appendix VII, show that the component of overall market access driven by clearance of (unexpected) hazardous areas correlates strongly with luminosity.

nesburg, Harare, and Lilongwe, respectively. Fifth, we altered the parameterization of transportation costs using, among others, the one of Jedwab and Storeygard (2018) who focus on Sub-Saharan Africa over $1960 - 2000$. Sixth, we dropped railways, as their role for intracountry commerce is limited. Seventh, we relaxed the assumption that mines block usage of affected transportation, assuming instead higher passage costs. The results are robust to these perturbations.

Measurement Error We then explored the role of measurement error on landmine clearance.[35] First, we looked only at the Northern provinces, as data quality is higher. Moreover, the North was disconnected from the center and the south till 2011 as the Zambezi bridges were destroyed. Second, we dropped the initial period ($1992 - 1999$) where there is under-reporting and records are of lower quality. Third, we added period-operator fixed effects to account for misreporting across humanitarian demining programs. The "luminosity-market access association" is highly significant.

Other We also examined the stability of the results to other perturbations. First, following Donaldson and Hornbeck (2016) we run population weighted least squares regressions. Second, we added interactions between period dummies and a third-order latitude-longitude polynomial to allow for time-varying influence of local geography. Third, we interacted geographic-location features with period dummies. Fourth, we replaced the province-specific time constants with district-time fixed effects. These are quite demanding specifications (as there are 120 districts); nonetheless, the coefficients on the market access measures (and local demining) drop only slightly, retaining significance.

8 Counterfactual Policy Simulations

8.1 Mozambique without Demining

What would have been Mozambique's aggregate economic activity in 2015 (2007), had the international community and the government left the problem of contamination entirely unresolved? We address this undoubtedly extreme scenario estimating a simple policy counterfactual that approximates the economywide impact of clearance. The counterfactual (that builds on Donaldson and Hornbeck (2016)) works as follows. First, we calculate locality to locality lowest cost path connections in presence of landmines (i.e., without any clearance) using the 1973 transportation network. Second, we estimate two counterfactual luminosity-based market access statistics. The first assumes that landmines' presence does not alter the distribution of luminosity; the second assigns to each locality its share in 1992 multiplied by the sum of luminosity in 2015 (2007). Third, we calculate the difference between actual market access in 2015 (2007) and the counterfactual measures. We then sum the (exponent of) differences in realized and counterfactual market access across all localities multiplied

[35]Error-in-variables in clearance is likely less a concern in the market access specifications, as the aggregation often reduces (spatial) noise.

by the luminosity-market access elasticity (0.25). This sum approximates the aggregate (integrated over all localities) effects of clearance.[36]

Table 8 compares realized market access with the two counterfactuals. The counterfactual that uses actual luminosity growth suggests that luminosity in 2015 would have been 52.7% (21.1%) lower in absence of clearance. The counterfactual that imposes the 1992 distribution of luminosity suggests that in the absence of any clearance luminosity in 2015 would have been 65.8% (31.7%) lower. Given a GDP - luminosity elasticity of around $0.25 - 0.35$ (Henderson, Storeygard, and Weil (2012), see also Appendix V) these exercises imply that Mozambique's GDP in 2015 (14.8 billion USD) would have been $16\% - 23\%$ lower.[37] As the landmine clearance process lasted 23 years, these tabulations suggest an impact of landmine clearance of around $0.7 - 1.0$ percentage points per year.

8.2 Coordination and Prioritization

We then ask how much market access would have changed if demining operators had followed a coordinated strategy (under perhaps the UN or the Government) that would prioritize clearance of localities along the transportation network, as clearing this type of contamination seems to have had larger local benefits (Table 4) and externalities (Table 5).

Using the spatial general equilibrium model of intra-country (across-locality) trade and the econometric estimates, we simulate demining process that follows heuristically by considering Mozambique's history and its economic geography. The counterfactual works as follows: in the first period ($1992 - 1999$), demining actors prioritize clearance along the three development corridors, where primary roads and railroads connect Maputo, Beira, and Nampula to the interior. During the second period ($2000 - 2007$), clearance continues across the three corridors and then targets the main highway ($N1$) connecting the South to the Central coastal areas and the North. In the third period ($2008 - 2015$) clearance focuses on other contaminated localities. To be consistent with the at-the-time constraints, we match the number of simulated localities to the cleared ones (e.g., the simulation clears 39 localities in the first-phase, matching the actual number of cleared localities).

Table 9 reports the average change of actual and simulated market access at the end of each phase (1999, 2007, and 2015) fixing luminosity and infrastructure to the pre-clearance levels so as to isolate the role of demining. Panel A focuses on the entire clearance period ($1992 - 2015$). Actual changes in market access are identical to the simulated changes, as by 2015 all contaminated localities are cleared both in reality and in the simulation. The mean (median) increase in market access is 1.21 (0.83). Panel B looks at the $1992 - 1999$ period. During the first phase of demining only 39 localities were fully cleared. The average increase in log market access is thus small, 0.11. The increase in market

[36]Following Donaldson and Hornbeck (2016), we compute the percentage decline in luminosity as $\sum(((exp(\hat{\beta} * (\log \text{MA cf}_t - \log \text{MA act}_t)) - 1) * Light_t) * 100/\text{Total Light}_t)$

[37]Unfortunately, information on the financial cost of landmine clearance going back to 1992 is incomplete and available only from secondary sources. It seems that on average $10 - 15$ million USD dollars were spent just on clearance and technical surveys per year, resulting in a total cost of around $350 - 500$ million USD (in 2017 dollar terms).

access under the counterfactual is moderately higher, 0.13, as we impose the same number of cleared localities. Panel C looks at $1992-2007$ period; 442 localities were fully cleared. This resulted in an observed average (median) increase in log market access of 0.63 (0.31). Had the country pursued a coordinated approach targeting the central nodes of its pre-war transportation network, the increase in market access would have been substantially higher. The mean increase in log market access of the counterfactual is 0.99, 50% higher than the realized one. The median increase of simulated log market access is 0.56, 80% higher than the actual one.

Figure 9 illustrates the costs of the absence of prioritization plotting, the average of realized and counterfactual change in log market access for 4 groups of localities in 2007, when half of the contaminated localities were cleared. (i) Localities that were cleared both in reality and in our counterfactual (156). (ii) Cleared by 2007 localities that are not prioritized by our counterfactual (286). (iii) Contaminated localities that had not been cleared by 2007, but are cleared in our simulation (286). (iv) Localities that were not cleared by 2007 and are not prioritized in our simulation (459). Let us start with localities that were neither cleared in reality nor in our counterfactual. Log market

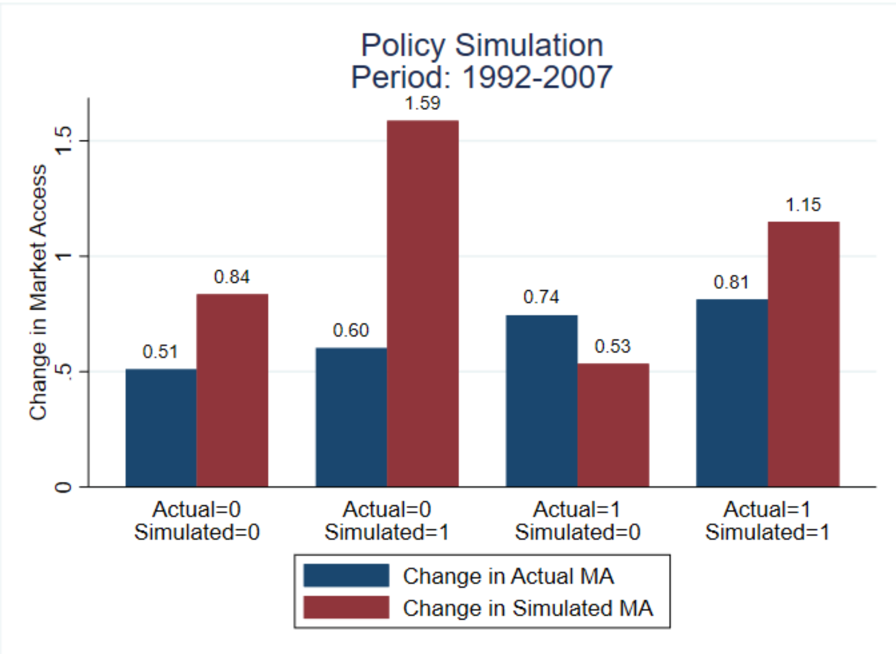


Figure 9: **Policy Simulation Period 2. Luminosity**. The figure plots the mean in 2007 of the realized (blue) and counterfactual (blue) change in (log) market access fixing luminosity and infrastructure to the pre-clearance levels. We divide the localities in 4 groups: (i) 156 localities cleared both in reality and in simulation. (ii) 286 that got cleared but not prioritized by our counterfactual; (iii) 286 contaminated localities cleared in our simulation but not in reality; (iv) 459 localities not cleared by 2007 not prioritized in our simulation.

access increased by 0.51, as they gained from clearance in connected areas. Had clearance targeted the central nodes of the transportation system, log market access would have increased by 0.84. Differences in median changes are also considerable, 0.47 for the counterfactual and just 0.27 for the actual.

Turning now to localities that were fully cleared in reality and in the counterfactual, the average (median) increase of realized log market access is 0.81 (0.56). The counterfactual, mean (median) increase is 1.15 (0.97), as the simulated market access gets a boost from clearance of other central localities. The increase in actual log market access in cleared localities that are not prioritized in our counterfactual is higher. The average change of realized log market access is 0.74, while the change in the counterfactual log market access is 0.53 (medians 0.49 versus 0.25). The "mirror" image of this difference is comparing actual and counterfactual market access in localities that were not cleared in reality, but are cleared in our counterfactual. The average (median) increase of realized log market access is 0.60 (0.24). Market access increased in spite of the absence of clearance, as these localities benefited from landmine removal in other places. But the counterfactual increase in log market access is significantly larger, 1.59 (median 1.21).

This simple counterfactual suggests sizable losses associated with the lack of centralized prioritization. Yet, a word of caution is in order. Our counterfactual analysis does not take into account humanitarian aspects, at-the-time information, coordination, and central planning costs. Hence, this counterfactual is not meant to supplant prioritization strategies, but to complement them. We should stress here that our economic-potential prioritization is not inconsistent with health-motivated concerns, as the scant international data suggest that casualties, amputations, and injuries are equally likely in remote and more connected places (Landmine Monitor (2016, 2017, 2018); Frost, *et al.* (2017)). The simulations offer an informative, hands-off approach in crafting a sound demining strategy in the presence of economic externalities, which the Mozambican case suggests are sizable, though not much-considered by the landmine clearance community.

9 Discussion

We conclude with a discussion of possible paths for future research and some policy implications.

9.1 Future Work

Landmines affect the lives of millions around the world. Cheap to obtain and easy to manufacture, their appeal to warring parties, militias, and rebels is unlikely to fade. Our paper is a first step towards a better understanding of landmines' legacy shedding light on the consequences of demining on local and aggregate economic activity. Clearly, we need more research to assess the mechanisms at work (see for example the subsequent study of Riaño and Valencia-Caicedo (2019) on Laos). Using individual-level data, it will be illuminating to examine how landmines and other improvised explosive devices shape poverty, land use, agricultural productivity, and educational outcomes. Another avenue is examining the effects of landmines on health. Moreover, as landmines entail sizable environmental costs and future work could assess their role in livestock and wildlife conservation.

Landmine contamination is one of the many deleterious facets of civil warfare; not limited to child soldiering, refugee flows, forced labor, extortion, violence against women and children, and mutilations. Future research should dig deeper into these aspects, understand their heritage, spatial interdependencies, and explore how they interact with each other.

9.2 Policy

Our analysis from Mozambique, the only so far heavily contaminated by landmines country to be declared landmine free, carries some policy implications. First, demining operators and governments should take into account the fact that clearance boosts economic performance in areas close to roads and railroads and local agricultural trade hubs. While we need evidence from more countries, the underlying theoretical framework of the market access approach allows for some (cautious) extrapolation. District prioritization is a complex process that factors in various considerations. The Mozambican experience suggests that economics should be one of them. Given the recent evidence on the benefits of transportation infrastructure on regional trade, this finding may not be that surprising. Yet, it stands in contrast to the traditional *modus operandi* of demining operators that -if anything- often prioritize remote areas.

Second, the comparison of the small-to-moderate "local" effects of demining with the larger "economywide" estimates and the associated counterfactual policy simulations revealing significant losses from the scattered and non-coordinated process that characterized Mozambique in the 1990s and early 2000s, stress the importance of coordination and central planning. This has immediate implications for the design of mine-action programmes in Cambodia, Afghanistan, Colombia, and other heavily-mined countries, where the international community is currently working on. Scattered demining based on operator-specific fund-raising for ad-hoc clearance operations is likely not optimal.

Third, our findings offer some backing to the efforts of the international community to persuade governments to expand the International Mine Ban Treaty on Anti-Personnel landmines of 1999 to also cover anti-tank (anti-vehicle) landmines. By debilitating the transportation network, anti-tank landmines hinder economic recovery, as development is fueled by the flow of goods, people, and ideas.

References

Alder, S. (2017): "Chinese Roads in India: The Effect of Transport Infrastructure on Economic Development," *Work. Pap., Univ. North Carolina, Chapel Hill.*

Alemu, Z. G., and H. D. Van Schalkwyk (2008): *Market Integration in Mozambican Maize Markets.* African Books Collective.

Arcand, J.-L., A.-S. Rodella-Boitreaud, and M. Rieger (2014): "The Impact of Land Mines on Child Health: Evidence from Angola," *Economic Development and Cultural Change*, 63(2), 249–279.

Ascherio, A., R. Biellik, A. Epstein, G. Snetro, S. Gloyd, B. Ayotte, and P. R. Epstein (1995): "Deaths and Injuries Caused by Land Mines in Mozambique," *The Lancet*, 346(8977), 721–724.

Atkin, D., and D. Donaldson (2015): "Who's getting globalized? The size and implications of intra-national trade costs," Discussion paper, National Bureau of Economic Research.

Barjamovic, G., T. Chaney, K. A. Coşar, and A. Hortaçsu (Forthcoming): "Trade, Merchants, and the Lost Cities of the Bronze Age," *The Quarterly Journal of Economics.*

Bastos, S. P. (2006): "In Mozambique, We didn't have Apartheid, Identity Constructions on Inter-Ethnic Relations during the Third Portuguese Empire," *Cadernos de Estudos Africanos*, (9/10), 77–99.

Bates, R. H. (2007): "Political Conflict and State Failure," *The Political Economy of Economic Growth in Africa, 1960-2000.*

Blattman, C., and E. Miguel (2010): "Civil War," *Journal of Economic Literature*, 48(1), 3–57.

Cameron, M., J. Gibson, K. Helmers, S. Lim, J. Tressler, and K. Vaddanak (2010): "The Value of Statistical Life and Cost–Benefit Evaluations of Landmine Clearance in Cambodia," *Environment and Development Economics*, 15(4), 395–416.

Chodorow-Reich, G., J. Coglianese, and L. Karabarbounis (2018): "The Macro Effects of Unemployment Benefit Extensions: a Measurement Error Approach," *The Quarterly Journal of Economics*, 134(1), 227–279.

Collier, P., and J. W. Gunning (1999): "Explaining African Economic Performance," *Journal of Economic Literature*, 37(1), 64–111.

Collier, P., and A. Hoeffler (2007): "Civil War," *Handbook of Defense Economics*, 2, 711–739.

Collier, P., and N. Sambanis (2005): "Understanding Civil War,(2 vols.)," *Washington: The World Bank.*

Costinot, A., and A. Rodriguez-Clare (2014): "Trade Theory with Numbers," *Gopinath, G., Helpman, E. and K. Rogoff.(eds.) Handbook of International Economics*, 4.

Darch, C. (2018): "A Success Story Gone Wrong? The Mozambican Conflict and the Peace Process in Historical Perspective," Discussion paper, Friedrich-Ebert-Stiftung. New Aproaches to Collecive Security.

Davis, D. R., and D. E. Weinstein (2002): "Bones, Bombs, and Break Points: the Geography of Economic Activity," *The American Economic Review*, 92(5), 1269–1289.

Dell, M., and P. Querubin (2017): "Nation Building through Foreign Intervention: Evidence from Discontinuities in Military Strategies," *The Quarterly Journal of Economics*, 1, 64.

DFID (2014): "Mine Action: Evaluation report," Discussion paper, Department for International Development.

Donaldson, D. (2015): "The Gains from Market Integration," *Annual Review of Economics*, 7(1), 619–647.

——— (2018): "Railroads of the Raj: Estimating the Impact of Transportation Infrastructure," *American Economic Review*, 108(4-5), 899–934.

Donaldson, D., and R. Hornbeck (2016): "Railroads and American Economic Growth: A "Market Access" Approach," *The Quarterly Journal of Economics*, 131(2), 799–858.

Donaldson, D., and A. Storeygard (2016): "The view from above: Applications of satellite data in economics," *Journal of Economic Perspectives*, 30(4), 171–98.

Durante, R., P. Pinotti, and A. Tesei (2019): "The political legacy of entertainment TV," *American Economic Review*, 109(7), 2497–2530.

Easterly, W., and T. Pfutze (2008): "Where does the Money go? Best and Worst Practices in Foreign Aid," *Journal of Economic Perspectives*, 22(2), 29–52.

Eaton, J., and S. Kortum (2002): "Technology, Geography, and Trade," *Econometrica*, 70(5), 1741–1779.

Elliot, G., and G. Harris (2001): "A Cost-Benefit Analysis of Landmine Clearance in Mozambique," *Development Southern Africa*, 18(5), 625–633.

Frost, A., P. Boyle, P. Autier, C. King, W. Zwijnenburg, D. Hewitson, and R. Sullivan (2017): "The Effect of Explosive Remnants of War on Global Public Health: A Systematic Mixed-Studies Review using Narrative Synthesis," *The Lancet Public Health*, 2(6).

Government of Mozambique (2008): "Request for an Extension of the Deadline for Completing the Destruction of Anti-Personnel Mines in Mined Areas," Discussion paper.

Halo Trust (1994): "The Halo Trust / UNOHAC Mines Survey of Mozambique," Maputo.

——— (2007): "Baseline Assessment Of Minefields in South & Central Mozambique," *Maputo.*

Henderson, J. V., A. Storeygard, and D. N. Weil (2012): "Measuring Economic Growth from Outer Space," *The American Economic Review*, 102(2), 994–1028.

Human Rights Watch (1997): "Still Killing. Landmine in Southern Africa," Discussion paper.

ICRC (2002): "Anti-Vehicle Mines: Effects on Humanitarian Assistance and Civilian Populations," Discussion paper, International Committee of the Red Cross.

IGC (2018): "Escaping the Fragility Trap," Discussion paper, International Growth Center.

Jedwab, R., and A. Storeygard (2018): "The Heterogeneous Effects of Transportation Investments: Evidence from sub-Saharan Africa 1960-2010," Discussion paper.

KEELEY, R. (2006): *The Economics of Landmine Clearance.* dissertation.de.

KIM, Y., V. MOLINI, AND D. C. MONCHUK (2012): "Estimating Fair Value of Agricultural Land Based on Potential Agricultural Productivity and Market Access in Mozambique," Discussion paper, World Bank wp.

LANDMINE MONITOR (2017): "Landmine Monitor 2017," Discussion paper, International Campaign to Ban Landmines (ICBL) and the Cluster Munition Coalition (CMC).

LIN, E. (2016): "How War Changes Land: The long-term economic impact of US bombing in Cambodia," *unpublished.*

MERROUCHE, O. (2008): "Landmines and Poverty: IV evidence from Mozambique," *Peace Economics, Peace Science and Public Policy*, 14(1).

MICHALOPOULOS, S., AND E. PAPAIOANNOU (2018): "Spatial Patterns of Development: A Meso Approach," *Annual Review of Economics.*

MIGUEL, E., AND G. ROLAND (2011): "The Long-Run Impact of Bombing Vietnam," *Journal of Development Economics*, 96(1), 1–15.

NAGY, D. K. (2018): "Trade and urbanization: Evidence from Hungary," .

OLKEN, B. A. (2009): "Do television and radio destroy social capital? Evidence from Indonesian villages," *American Economic Journal: Applied Economics*, 1(4), 1–33.

RIAÑO, J. F., AND F. VALENCIA CAICEDO (2019): "Collateral Damage: The Legacy of the Secret War in Laos," Discussion paper, mimeo.

SIMONOVSKA, I., AND M. E. WAUGH (2014a): "The Elasticity of Trade: Estimates and Evidence," *Journal of international Economics*, 92(1), 34–50.

——— (2014b): "Trade Models, Trade Elasticities, and the Gains from Trade," Discussion paper, National Bureau of Economic Research.

Table 1: **Summary Statistics**

	Full Sample					
	Observations	Mean	Standard Deviation	Median	Min	Max
Share of Contaminated localities in 1992	1187	0.720	0.449	1	0	1
Number of Threats in 1992	1187	6.253	14.164	2	0	238
Lit 1992	1187	0.098	0.297	0	0	1
Lit 1999	1187	0.177	0.382	0	0	1
Lit 2007	1187	0.227	0.419	0	0	1
Lit 2015	1187	0.422	0.494	0	0	1
Log Luminosity 1992	1187	-10.579	2.924	-11.5	-11.5	2.51
Log Luminosity 1999	1187	-9.858	3.736	-11.5	-11.5	2.83
Log Luminosity 2007	1187	-9.344	4.197	-11.5	-11.5	3.11
Log Luminosity 2015	1187	-7.633	4.800	-11.5	-11.5	3.15
Paved Road 1973 (dummy)	1187	0.171	0.377	0	0	1
Unpaved Road 1973 (dummy)	1187	0.021	0.144	0	0	1
Trail 1973 (dummy)	1187	0.660	0.474	1	0	1
Railway 1992 (dummy)	1187	0.130	0.336	0	0	1
Navigable River (dummy)	1187	0.228	0.420	0	0	1
Cantinas (dummy)	1187	0.584	0.493	1	0	1
Log Total MA Light 1992	1187	-15.767	3.127	-16.4	-22.3	-5.54
Log Total MA Light 1999	1187	-14.104	3.274	-14.6	-20.9	-4.49
Log Total MA Light 2007	1187	-12.809	3.190	-13.2	-20.9	-1.75
Log Total MA Light 2015	1187	-10.214	2.409	-10.5	-16	-.765
Log Total MA Population 1992	1077	-12.116	2.188	-12.2	-17.8	-4.27
Log Total MA Population 1999	1077	-11.306	2.387	-11.4	-17.1	-3.65
Log Total MA Population 2007	1077	-10.664	2.464	-10.9	-16.6	-2.53
Log Total MA Population 2015	1077	-9.185	2.082	-9.32	-14.7	-2.43
Log Total MA Luminosity (Initial) 1992	1187	-15.767	3.127	-16.4	-22.3	-5.54
Log Total MA Luminosity (Initial) 1999	1187	-15.655	3.145	-16.3	-22.2	-5.54
Log Total MA Luminosity (Initial) 2007	1187	-15.139	3.075	-15.7	-22.2	-5.54
Log Total MA Luminosity (Initial) 2015	1187	-14.561	3.141	-15.1	-22.1	-5.3
Log Total MA Population (Initial) 1992	1077	-12.116	2.188	-12.2	-17.8	-4.27
Log Total MA Population (Initial) 1999	1077	-12.065	2.208	-12.2	-17.8	-4.27
Log Total MA Population (Initial) 2007	1077	-11.846	2.260	-12	-17.5	-4.05
Log Total MA Population (Initial) 2015	1077	-11.574	2.316	-11.8	-17.5	-3.81

Notes: This table reports the summary statistics of the main variables at the locality level.

Table 2: **Land Mine Removal and Local Development**

	Yearly				Demining-Phase Estimation (1992, 1999, 2007, 2015)			
	Log Luminosity		Lit		Log Luminosity		Lit	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Cleared Threats	0.329***		0.037***		0.469***		0.058***	
	(0.073)		(0.007)		(0.098)		(0.011)	
	[0.071]		[0.080]		[0.107]		[0.129]	
Cleared (dummy)		0.373***		0.038***		0.755***		0.083***
		(0.109)		(0.011)		(0.182)		(0.020)
		[0.037]		[0.038]		[0.082]		[0.088]
Number of Localities	1,187	1,187	1,187	1,187	1,187	1,187	1,187	1,187
Locality FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time x Province FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	.168	.166	.124	.121	.241	.238	.224	.22
Observations	27,301	27,301	27,301	27,301	4,748	4,748	4,748	4,748

Notes: This table reports panel fixed effects OLS estimates associating luminosity with landmine clearance. The dependent variable in columns (1)-(2) and (5)-(6) is the log of luminosity plus the half of the minimum positive value of luminosity. The dependent variable in columns (3)-(4) and (7)-(8) is an indicator that takes the value of one if the locality appears to be lit and zero otherwise.. Columns (1)-(4) report yearly specifications (1992-2015). Columns (5)-(8) focus on 4 years that correspond to the three main phases of landmine clearance, namely 1992, 1999, 2007 and 2015. Cleared Threats is the logarithm of one plus the number of accumulated cleared confirmed hazardous areas (CHA). Cleared is an indicator variable the takes the value of 0 when the locality is contaminated and becomes 1 in the year and for all subsequent years that the locality is free of contamination; the indicator equals zero for all localities that were not contaminated. All specifications include locality-specific fixed-effects and province-year fixed effects (constants not reported). Standard errors in parentheses are clustered at the district (admin 2) level. The table also gives standardized "beta" coefficients [in brackets]. ***, **, and * indicate statistical significance at the 1%, 5% and 10% level, respectively.

Table 3: **Land Mine Removal and Local Development. Expected, Unexpected, and Cancelled Threats**

	Demining-Phase Estimation (1992, 1999, 2007, 2015)							
	Log Luminosity				Lit			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Expected and Cleared Threats	0.441***	0.470***			0.053***	0.053***		
	(0.129)	(0.133)			(0.014)	(0.015)		
	[0.075]	[0.080]			[0.088]	[0.088]		
Unexpected and Cleared Threats	0.242**	0.273**			0.033**	0.033**		
	(0.117)	(0.121)			(0.013)	(0.013)		
	[0.045]	[0.051]			[0.060]	[0.060]		
Cancelled Threats		-0.183				-0.001		
		(0.147)				(0.016)		
		[-0.027]				[-0.002]		
Expected Cleared (dummy)			0.798***	0.843***			0.098***	0.099***
			(0.210)	(0.210)			(0.023)	(0.023)
			[0.072]	[0.076]			[0.086]	[0.087]
Unexpected Cleared (dummy)			0.417**	0.451***			0.048***	0.049***
			(0.162)	(0.161)			(0.017)	(0.017)
			[0.045]	[0.049]			[0.050]	[0.052]
Cancelled (dummy)				-0.217				-0.009
				(0.154)				(0.018)
				[-0.023]				[-0.009]
Number of Localities	1,187	1,187	1,187	1,187	1,187	1,187	1,187	1,187
Locality FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time x Province FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	.242	.242	.241	.242	.225	.225	.224	.224
Observations	4,748	4,748	4,748	4,748	4,748	4,748	4,748	4,748

Notes: The table reports panel fixed-effects OLS estimates associating luminosity with landmine clearance, distinguishing among Surveyed/Expected Cleared Suspected Hazardous Areas (SHAs), Not Surveyed/Unexpected Cleared SHAs, and "cancelled" SHAs. The dependent variable in columns (1)-(4) is the log of luminosity plus the half of the minimum value of luminosity. The dependent variable is columns (5)-(8) is an indicator that takes the value of one if the locality emits detectable from the satellite light (lit). All columns give period estimates (1992-1999, 2000-2007, 2008-2015) that correspond to the three main phases of landmine clearance. Expected Cleared Threats is the logarithm of one plus the number of cumulated surveyed/expected cleared suspected hazardous areas (SHAs). Unexpected Cleared Threats is the logarithm of one plus the number of cumulated not surveyed/unexpected cleared SHAs. Cancelled Threats is the logarithm of one plus the number of cumulated cancelled surveyed/expected and not surveyed/unexpected SHAs. Expected Cleared is an indicator variable that takes the value of 0 when the locality is contaminated by surveyed/expected cleared SHAs and becomes 1 the year (or period) and for all subsequent years (or periods) that the locality is free from surveyed/expected cleared SHAs; the indicator equals zero for all localities that were not contaminated. Unexpected Cleared is an indicator variable that takes the value of 0 when the locality is contaminated by not surveyed/unexpected and becomes 1 the year (or period) and for all subsequent years (or periods) that the locality is free from not surveyed/unexpected cleared SHAs; the indicator equals zero for all localities that were not contaminated. Cancelled is a dummy variable that takes value of 0 when in the locality is present a SHAs (both surveyed on not surveyed) and becomes 1 the year (or period) and for all subsequent years (or periods) all the SHAs are cancelled in the locality. All specifications include locality fixed-effects and province-specific year fixed effects (constants not reported). The table reports clustered at the district (admin 2) level standard errors (in parentheses) and standardized "beta" coefficients (in square brackets). ***, **, and * indicate statistical significance at the 1%, 5% and 10% level, respectively.

Table 4: **Heterogeneity Across Intervention Characteristics.**

	Demining-Phase Estimation (1992, 1999, 2007, 2015)			
	Log Luminosity	Lit	Log Luminosity	Lit
	(1)	(2)	(3)	(4)
	Cleared Threats		Cleared (Dummy)	
- Road and Railway (100m)	0.381**	0.054**	0.433**	0.057**
	(0.191)	(0.022)	(0.218)	(0.024)
	[0.045]	[0.063]	[0.037]	[0.048]
- Border (10000m)	-0.388	-0.027	-0.532	-0.017
	(0.267)	(0.031)	(0.371)	(0.048)
	[-0.029]	[-0.020]	[-0.019]	[-0.006]
- Cantinas (1000m)	0.580**	0.063**	0.643*	0.063*
	(0.259)	(0.027)	(0.327)	(0.036)
	[0.050]	[0.053]	[0.042]	[0.040]
- Civil War (1000m)	0.558	0.030	1.325***	0.087*
	(0.357)	(0.037)	(0.439)	(0.045)
	[0.037]	[0.019]	[0.060]	[0.038]
- River (100m)	0.090	0.048	0.149	0.038
	(1.126)	(0.136)	(0.798)	(0.099)
	[0.002]	[0.010]	[0.004]	[0.009]
- Village (1000m)	0.785***	0.061***	0.988***	0.089***
	(0.189)	(0.020)	(0.224)	(0.025)
	[0.087]	[0.067]	[0.082]	[0.072]
- Electricity Grid (100m)	0.350	0.021	0.365	0.041
	(0.283)	(0.030)	(0.393)	(0.046)
	[0.017]	[0.010]	[0.012]	[0.013]
- Residual	-0.078	0.008	0.008	0.019
	(0.097)	(0.011)	(0.157)	(0.018)
	[-0.015]	[0.015]	[0.001]	[0.020]
Number of Localities	1,187	1,187	1,187	1,187
Locality FE	Yes	Yes	Yes	Yes
Time x Province FE	Yes	Yes	Yes	Yes
R-squared	.26	.235	.264	.236
Observations	4,748	4,748	4,748	4,748

Notes. This table reports panel fixed effects OLS estimates exploring whether the association between demining and development varies by the type of Confirmed Hazardous Areas (CHA) categories cleared. The dependent variable in columns (1)-(2) is the log of luminosity plus the half of the minimum positive value of luminosity. The dependent variable is columns (3)-(4) is an indicator that takes the value of one if the locality is lit and zero otherwise. All columns focus at 4 years that correspond to the three main phases of landmine clearance, namely 1992, 1999, 2007 and 2015. Estimation distinguishes CHA between seven non-mutually exclusive categories, according to some GIS-based distance thresholds. Columns (1)-(2) report the Cleared Threats split into the seven categories; Columns (3)-(4) report the corresponding dummy version of each GIS category. We classify the different categories as follows: i) Roads and Railways if a threat's centroid is within 100 meters from a road or a railway; ii) Border if a threat's centroid is less than 10,000 meters from the country border; iii) Cantinas if a threat's centroid is less than 1,000 meters from a village with a colonial commercial hub; iv) Civil War if a threat's centroid is in a buffer of 1,000 meters from an event of the Civil War; v) River if a threat's centroid is less than 100 meters distant from a river or lake; vi) Village if a threat's centroid is within 1,000 meters from a village; and Electricity Grid if a threat's centroid is in a buffer of 100 meters from the electric grid or pylon. The Residual category includes all the remaining threats. All specifications include locality-specific fixed-effects and province-year specific fixed effects (constants not reported). Standard errors in parentheses are clustered at the district (admin 2) level and standardized "beta" coefficients [in brackets]. ***, **, and * indicate statistical significance at the 1%, 5% and 10% level, respectively.

Table 5: **Market Access. Baseline Estimates.**

	Contemporaneous				Initial				2SLS			
	Log Luminosity	Lit	Log Luminosity	Lit	Log Luminosity	Lit	Log Luminosity	Lit	Log Luminosity	Lit	Log Luminosity	Lit
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Log Total Market Access, Light	0.296***	0.032***			0.326***	0.033***			0.362***	0.037***		
	(0.064)	(0.007)			(0.117)	(0.012)			(0.135)	(0.014)		
	[0.262]	[0.278]			[0.250]	[0.248]			[0.320]	[0.317]		
Log Total Market Access, Population			0.248***	0.025***			0.766***	0.068***			0.811***	0.073***
			(0.069)	(0.008)			(0.184)	(0.020)			(0.199)	(0.021)
			[0.150]	[0.148]			[0.413]	[0.361]			[0.491]	[0.428]
Number of Localities	1,187	1,187	1,077	1,077	1,187	1,187	1,077	1,077	1,187	1,187	1,077	1,077
Locality FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time x Province FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	.248	.229	.249	.228	.237	.218	.255	.231				
Observations	4,748	4,748	4,308	4,308	4,748	4,748	4,308	4,308	4,748	4,748	4,308	4,308

Notes: The table reports panel fixed effects estimates associating luminosity with market access. The dependent variable in columns (1), (3), (5), and (7) is the log of luminosity plus the half of the minimum positive value of luminosity. The dependent variable is columns (2), (4), (6), and (8) is an indicator that takes the value of one if the locality is lit. All specifications focus on 4 years that correspond to the three main phases of landmine clearance, namely 1992, 1999, 2007 and 2015. Market Access, Light is the logarithm of luminosity-weighted market-access. Market Access, Population is the logarithm of population- weighted market-access. Columns (1)-(4) report OLS estimates, using contemporaneous values of the market access measures. Columns (5)-(8) report OLS estimates, using market access measures that impose pre-clearance transportation network (in 1973) and population (1980) and luminosity (1992). Columns (9)-(12) report two-stage-least-squares (2SLS) panel specifications, where the contemporaneous market access measures are "instrumented" by their analogues imposing the pre-clearance transportation network and population/luminosity. All specifications include locality-specific fixed-effects and province-year fixed effects (constants not reported). Standard errors in parentheses are clustered at the district (admin 2) level and standardized "beta" coefficients [in brackets]. ***, **, and * indicate statistical significance at the 1%, 5% and 10% level, respectively.

Table 6: **Market Access and Direct Effects fixing Initial Network and Initial Development**

Panel A. Total Market Access Luminosity

Accounting For:	Direct Effect		Direct Effect, New Road Old Road Improvement		Excluding Neighbors, Direct Effect New Road, Old Road Improvement	
	Log Luminosity	Lit	Log Luminosity	Lit	Log Luminosity	Lit
	(1)	(2)	(3)	(4)	(5)	(6)
Log Total Market Access, Light (Initial)	0.260**	0.025**	0.261**	0.025**	0.271**	0.025**
	(0.113)	(0.012)	(0.114)	(0.012)	(0.110)	(0.012)
	[0.199]	[0.186]	[0.200]	[0.188]	[0.191]	[0.169]
Cleared Threats	0.424***	0.053***	0.387***	0.049***	0.392***	0.050***
	(0.092)	(0.010)	(0.091)	(0.010)	(0.091)	(0.010)
	[0.097]	[0.119]	[0.089]	[0.110]	[0.090]	[0.111]
Cleared Threats	Yes	Yes	Yes	Yes	Yes	Yes
New Road (dummy)	No	No	Yes	Yes	Yes	Yes
Old Network Improved (dummy)	No	No	Yes	Yes	Yes	Yes
Number of Localities	1,187	1,187	1,187	1,187	1,187	1,187
Locality FE	Yes	Yes	Yes	Yes	Yes	Yes
Time x Province FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	4,748	4,748	4,748	4,748	4,748	4,748

Panel B. Total Market Access Population

Accounting For:	Direct Effect		Direct Effect, New Road Old Road Improvement		Excluding Neighbors, Direct Effect New Road, Old Road Improvement	
	Log Luminosity	Lit	Log Luminosity	Lit	Log Luminosity	Lit
	(1)	(2)	(3)	(4)	(5)	(6)
Log Total Market Access, Population (Initial)	0.663***	0.054***	0.665***	0.055***	0.572***	0.053***
	(0.178)	(0.019)	(0.178)	(0.019)	(0.131)	(0.014)
	[0.358]	[0.285]	[0.359]	[0.288]	[0.305]	[0.275]
Cleared Threats	0.334***	0.046***	0.303***	0.043***	0.315***	0.043***
	(0.106)	(0.012)	(0.104)	(0.011)	(0.102)	(0.011)
	[0.077]	[0.104]	[0.070]	[0.096]	[0.072]	[0.096]
Cleared Threats	Yes	Yes	Yes	Yes	Yes	Yes
New Road (dummy)	No	No	Yes	Yes	Yes	Yes
Old Network Improved (dummy)	No	No	Yes	Yes	Yes	Yes
Number of Localities	1,077	1,077	1,077	1,077	1,077	1,077
Locality FE	Yes	Yes	Yes	Yes	Yes	Yes
Time x Province FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	4,308	4,308	4,308	4,308	4,308	4,308

Notes: The table reports panel fixed effects OLS estimates associating luminosity with market access, fixing both the transportation network and luminosity (population). All specifications control for direct effect of demining activity. Column (3)-(6) also control for new roads and improvements on the old network. In Column (5) and (6), Market Access is computed excluding the adjacent localities by setting their population/luminosity to zero. The dependent variable in odd-numbered columns is the log of luminosity plus the half of the minimum positive value of luminosity. The dependent variable in even-numbered columns is an indicator that takes the value of one if the locality is lit. All specifications focus on 4 years that correspond to the three main phases of landmine clearance, namely 1992, 1999, 2007 and 2015. Total Market Access, Light (Initial) is the logarithm of luminosity-weighted market access imposing pre-clearance transportation network to 1973 and fixing all localities' luminosity at their 1992 level. Total Market Access, Population (Initial) is the logarithm of population- weighted market access fixing the transportation network to 1973 and holding all localities' population fixed at their 1980 level. All specifications include locality-specific fixed-effects and province-year specific fixed effects (constants not reported). Standard errors in parentheses are clustered at the district (admin 2) level and standardized "beta" coefficients [in brackets]. ***, **, and * indicate statistical significance at the 1%, 5% and 10% level, respectively.

Table 7: **Market Access. Isolating the Unexpected Component of Market Access.**

	Log Luminosity		Lit		Log Luminosity		Lit	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Log Market Access, Light (Initial)	0.261**	0.287**	0.025**	0.030**				
	(0.114)	(0.125)	(0.012)	(0.013)				
	[0.200]	[0.220]	[0.188]	[0.223]				
Log Market Access Expected, Light (Initial)		-0.169		-0.031				
		(0.394)		(0.041)				
		[-0.129]		[-0.233]				
Log Market Access, Population(Initial)					0.665***	0.688***	0.055***	0.057***
					(0.178)	(0.211)	(0.019)	(0.021)
					[0.359]	[0.371]	[0.288]	[0.298]
Log Market Access Expected, Population (Initial)						-0.084		-0.007
						(0.458)		(0.045)
						[-0.044]		[-0.038]
Cleared Threats	0.387***	0.389***	0.049***	0.049***	0.303***	0.304***	0.043***	0.043***
	(0.091)	(0.091)	(0.010)	(0.010)	(0.104)	(0.104)	(0.011)	(0.011)
	[0.089]	[0.089]	[0.110]	[0.110]	[0.070]	[0.070]	[0.096]	[0.096]
Cleared Threats	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
New Road (dummy)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Old Network Improved (dummy)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Number of Localities	1,187	1,187	1,187	1,187	1,077	1,077	1,077	1,077
Locality FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time x Province FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	.245	.245	.227	.227	.261	.26	.237	.237
Observations	4,748	4,748	4,748	4,748	4,308	4,308	4,308	4,308

Notes: The table reports panel fixed effects OLS estimates associating luminosity with market access, isolating the population fixed at their 1980 level. Market Access Expected, Light (Initial) is the logarithm of luminosity-weighted market access obtained by removing only surveyed/expected cleared SHAs and fixing the transportation network to 1973 and holding all localities' luminosity fixed at their 1992 level. Market Access Expected, Population (Initial) is the logarithm of population-weighted market access obtained by removing only surveyed/expected cleared SHAs and fixing the transportation network to 1973 and holding all localities' population fixed at their 1980 level. All specifications condition on the logarithm of one plus the number of accumulated cleared confirmed hazardous areas (Cleared Threats), an indicator that takes the value of one when new roads are constructed (and zero otherwise), and an indicator that takes the value of one when there are improvements in the pre-independence (in 1973) transportation network (and zero otherwise). All specifications include locality-specific fixed-effects and province-year specific fixed effects (constants not reported). Standard errors in parentheses are clustered at the district (admin 2) level and standardized "beta" coefficients [in brackets]. ***, **, and * indicate statistical significance at the 1%, 5% and 10% level, respectively.

Table 8: **Counterfactuals I. No Land Mine Clearance**

	Percent Decline MA without Demining Activities	Percent Decline in Luminosity without Demining Activities
Market Access, Light	2007 (obs=1187)	
No demining activities	57	21.1 (8.3)
No demining activities & Assuming the Luminosity Distribution in 1992	41	31.7 (10.2)
Market Access, Light	2015 (obs=1187)	
No demining activities	87	52.7 (10.1)
No demining activities & Assuming the Luminosity Distribution in 1992	88.5	65.8 (8.4)

Notes. Each row reports the counterfactual impact on luminosity assuming non-clearance of contamination. Panel A reports the counterfactual in 2007; while Panel B give the counterfactual in 2015. In the first row of each panel, actual luminosity shares are used for computing the counterfactual. In the second row of each panel, country-wide luminosity in (2007) 2015 is distributed based on the pre-clearance (in 1992) shares. Robust standard errors clustered by admin-2 are reported in parentheses.

Table 9: **Counterfactual II. Policy Experiment Simulation**

Dependent Variable	Δ Market Access Network and Luminosity (Initial)			
	Mean	Median	Observations	# of Affected used in Simulation
		Panel A. *Period: 1992-2015*		
Actual (log)	1.21	0.83	1187	855
Simulated (log)	1.21	0.83	1187	855
		Panel B. *Period: 1992-1999*		
Actual (log)	0.11	0.00	1187	39
Simulated (log)	0.13	0.01	1187	39
		Panel C. *Period: 1992-2007*		
Actual (log)	0.63	0.31	1187	442
Simulated (log)	0.99	0.56	1187	442

Notes. This Table reports the results of a policy experiment simulation, comparing the change of the actual Market Access with its simulated counterpart. The simulation prioritizes demining interventions as follows: i) in the first period, demining activities take place on the three main corridors starting from Maputo, Beira, and Nacala, going inland; ii) in the second period, clearance targets the N1 highway, connecting capital Maputo the central provinces, paved roads, unpaved roads and trails; iii) in the last period, all the rest of the country is cleared. In the first two periods, we match the number of simulated cleared localities to the actual cleared ones (39, 442). All measures are constructed using the pre-clearance components of market access i) the transportation network in 1973 and ii) the development proxies weighting the bilateral transportation costs are held fixed to their 1992 values. Actual (log) is the actual change in log Market Access. Simulated (log) is the change in log Market Access obtained under the simulated prioritization of demining efforts.