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Landmines and Spatial Development*

Giorgio Chiovelli†
Universidad de Montevideo

Stelios Michalopoulos‡
Brown University, CEPR and NBER

Elias Papaioannou§
London Business School, CEPR

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

‡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;

Abstract

Landmines affect the lives of millions in many conflict-ridden communities long after the cessation of hostilities. However, there is little research on the role of demining. We examine the economic consequences of landmine removal in Mozambique, the only country to go from heavily contaminated in 1992 to mine-free in 2015. First, we present the self-assembled georeferenced catalog of areas suspected of contamination, along with a detailed record of demining operations. Second, the event-study analysis reveals a robust association between demining activities and local economic performance, reflected in luminosity. Notably, economic activity does not pick up in the years leading up to clearance, nor does it increase when operators investigate areas mistakenly marked as contaminated in prior surveys. Third, recognizing that landmine removal reshapes transportation access, we use a "market access" approach to explore direct and indirect effects. To advance on identification, we isolate changes in market access caused by removing landmines in previously considered safe areas. The positive impacts of clearance extend well beyond immediate areas, with indirect effects twice as large as direct ones. Fourth, policy simulations underscore the substantial economy-wide dividends of clearance, but only when factoring in market-access effects. Additionally, policy counterfactuals uncover significant aggregate costs when demining does not prioritize the unblocking of transportation routes. These results offer insights into the design of demining programs in Ukraine and elsewhere, highlighting the need for centralized coordination and prioritization of areas facilitating commerce.
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eliasp@london.edu. Web: https://sites.google.com/site/papaioannouelias/home

1 Introduction

"*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.[1] Despite the extensive use of landmines in civil wars after WWII and the importance of this topic for the international community, little research has been done quantifying their role. We try to fill this gap by focusing on Mozambique, the only country to date that has moved from "heavily contaminated by landmines" in 1992 to "landmine-free" status in 2015.

Landmines have been called "*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 unsurprising that landmines have been extensively used, among others, in Cambodia, Congo, Afghanistan, the Caucasus, and during the breakup of Yugoslavia. Today, mine contamination remains a threat in around 60 countries. Alarmingly, there is ongoing use in Syria, Iraq, Libya, Yemen, Myanmar, and most noticeably, Ukraine, which has become one the world's most heavily mined places since Russia's annexation of Crimea and its full-scale invasion in February 2022. The numbers are staggering. Human Rights Watch (HRW) and news agencies report modest and severe contamination spanning almost a third of Ukraine. Besides, the problem will intensify due to the widespread use of cluster munitions that scatter explosives indiscriminately. The World Bank estimates demining Ukraine will cost more than 37 billion US dollars.

Since the historic visit of Princess Diana to Angola to raise awareness on minefields and the United Nations (UN) Mine Ban Treaty in 1997, the attention of the international community and media has been on the immediate victims: the lives lost, the incapacitated and the isolation of rural communities. This is also reflected in the various cost-benefit analyses of landmine removal, mainly centered around the lives saved and the value of land released. Such valuations of demining often reach contradictory conclusions due to the wide range of assumptions regarding the statistical value of life and the (often considerable) degree of under-reporting. For example, Cameron et al. (2010) estimate positive returns from demining in Cambodia, while Elliot and Harris (2001) and Harris (2000) calculate negative returns from clearance in Mozambique and Cambodia, respectively. Similarly, most impact assessment reports, which focus on a single or a few communities, do not uncover significantly positive effects of clearance (e.g., DFID, 2014). And the scant medical research that shows considerable adverse effects of mines is based on tiny samples, see Frost et al. (2017) for a review.[2]

It is instinctive to focus on the direct victims of landmine detonations. However, even in the absence

[1] Landmines are containers of explosive material with detonating systems that are triggered by contact. They are designed to incapacitate that person or vehicle by an explosive blast. Unexploded ordnance (UXO) refers to explosive weapons that did not detonate upon deployment and persist as hazardous remnants, presenting an ongoing risk.

[2] 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 $1,000$; these are ten times larger than the ones based on hospital or amputee-assistance programs. Roughly 75% of fatalities occur before the victim reaches a health center.

of physical harm, landmines disrupt the daily lives and economic activities of millions in affected regions. For example, the United Nations Development Program calculates that about 10.7 million Ukrainians require services to clear mines. In the context of our study, the 2001 Mozambique Landmine Impact Survey found that approximately 3 out of 18 million lived in communities significantly affected by remnants of war. The economic consequences appear important. Yet a detailed assessment is missing. Our study is a first step to quantify the economic consequences of demining.

1.1 Results Preview

We examine the economic impact of freeing Mozambique of contamination, a country that in 1992 had hundreds of thousands of landmines scattered across roughly $8,000$ minefields across its vast territory. In September 2015, Mozambique was officially declared "landmine free".

Our analysis proceeds in four steps. First, we provide for the first time a complete documentation of all landmine operations for any country, a non-negligible contribution as such data are neither available from governments nor the UN. Specifically, we present the self-assembled, validated, and georeferenced data on the areas suspected of contamination according to the nationwide surveys and the thousands of operations conducted by dozens of demining actors.

Second, we trace the dynamics of economic activity as the clearance evolved within Mozambican localities. To bypass data unavailability for one of the world's poorest nations, we use a harmonized satellite series of light density at night from 1992 till 2017.[3] The difference-in-difference analysis, estimated with the staggered event "imputation" method of Borusyak, Jaravel, and Spiess (2023) reveals that compared to non-mined and not-cleared-yet localities, economic activity picks up following the removal of landmines. Luminosity stabilizes at a higher level four to six years from the commencement of clearance, the average time it takes operators to clear a locality from all hazards. Crucially, luminosity neither increases in anticipation of clearance nor changes when operators visit areas erroneously recorded in the preceding surveys as suspected of contamination. We then explore the relationship between demining and World Bank (WB) aid and road maintenance to shed some light on the mechanisms. Both outcomes seem to respond to the clearance of hazards, uncovering two plausible mechanisms. Nonetheless, the clearance-development link is still strong when we exclude all localities with either a WB project or road improvements.

Third, we explore the economy-wide effects, recognizing that clearing landmines in one area may impact economic activity in other interconnected regions. The "market access' analysis reveals that besides the direct effects, landmine removal entails significantly positive spillovers, by unblocking the prewar transportation network. Indirect effects are twice as large as the direct ones, revealing a quantitatively important aspect of clearance. To advance on causation, we develop an identification strategy that takes advantage of the numerous errors in the country-wide surveys that guided the

[3] In Chiovelli et al. (2023), we construct a yearly luminosity series from 1992-2020 harmonizing the underlying information from satellites with different characteristics, accuracy, and resolution.

demining. To isolate changes in market access that could not have been part of any centralized prioritization scheme, we leverage the clearance of hazards that previous surveys missed. There is a strong association between market access increases from such "not-in-surveys" landmine removals and economic activity, telling of a significant dividend of clearance.

Fourth, we conduct policy counterfactuals to assess the countrywide consequences of clearance. We start by approximating the evolution of luminosity without any clearance; in this extreme scenario, aggregate luminosity in 2017 would have been roughly 17% lower, which, given a lights-GDP elasticity of around $0.2 - 0.3$, yields an output boost of about $3.5 - 5.5\%$ from clearance. Notably, our cost-benefit analysis suggests that it is only when one also considers the indirect benefits of clearance, humanitarian demining becomes cost-effective. We then estimate a counterfactual removal sequence that prioritizes the "development/trade corridors" connecting the main port cities (Maputo, Beira, and Nacala) with the interior, followed by the clearance of the single highway connecting the south to the central regions. The comparison of actual demining with this counterfactual reveals substantial losses from the absence of prioritization of central nodes with sizable spillovers.

1.2 Related Literature

Our study connects to several research strands that have developed in parallel. First, on a broad scale, our findings contribute to our understanding of the economic legacy of civil wars (see Blattman and Miguel, 2010, for a thorough overview). Cross-country comparisons and case studies show that, while growth resumes after conflict, the strength and timing of the recovery vary considerably. Landmine contamination may partially account for the observed heterogeneity, a point the literature has not stressed. Second, as landmine removal actions are often funded by foreign donors and agencies (as in our setting), our study also connects to works on foreign aid (see Easterly and Pfutze, 2008, for a review), showing that such assistance may be quite beneficial, especially when one factors positive spatial spillovers. Third, few academic research studies have assessed the role of landmine clearance, and no attention has been devoted to its aggregate economic impact. Exceptions include the cross-sectional works of Merrouche (2008), and Arcand, Rodella-Boitreaud, and Rieger (2014), linking contamination to poverty, health, and socioeconomic outcomes across Mozambican and Angolan regions, respectively. In subsequent work Mounu, Purroy, and Vargas (2023), distinguish between military and humanitarian demining in Colombia, finding that the latter is more conducive to local growth. Besides estimating the local consequences of clearance, we bring into this body of research a theoretically grounded approach well-suited to quantify spatial spillovers. We find that landmine clearance generates sizeable spatial externalities, to our knowledge, a novel result. Hence, our framework helps address some policy-relevant questions. What are the aggregate effects of removing landmines? How shall international organizations, state agencies, and NGOs design clearance, a critical issue nowadays in Ukraine and elsewhere?

Fourth, from a methodological point of view, our paper relates to recent works in spatial economics that apply insights from general equilibrium trade theory to study the aggregate effects of transportation infrastructure (see Donaldson, 2015, for an overview). Donaldson and Hornbeck (2016) adopt the Ricardian model of Eaton and Kortum (2002) to derive an expression linking changes in regional welfare to changes in its proximity to all other markets (see Harris, 1954, and Redding and Venables, 2004, for early contributions). A considerable body of research uses (variants of) the market-access framework to quantify the impact of railroads and roads on land values, income, population, and other development proxies in agricultural economies similar to our setting. For example, Donaldson (2018) studies the role of colonial railroads in India, where agriculture's share in GDP was around 66%, and most Indian farmers were engaged in farming. Alder (2017) quantifies the impact of the expansion of India's highway system in the 2000s on development, while Alder et al. (2022) study the impact on luminosity of a large-scale road project in Ethiopia between 1997-2016. Jedwab and Storeygard (2022) study roads' role on population growth via market access across Sub-Saharan Africa.

Paper Structure The following section gives an overview of the use of landmines in Mozambique and the 23 year-long clearance process. In Section 3, we describe the underlying data on demining. Section 4 reports specifications that examine the (dynamic and static) correlation between landmine clearance and local development. Section 5 reports on the market access estimates that quantify the aggregate effects of landmine clearing. Section 6 presents counterfactual policy experiments that evaluate the losses from the absence of prioritization. In Section 7, we discuss the 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 during the War of Independence and the ensuing civil war ($1964 - 1992$), the situation in 1992, and the subsequent clearing ($1993 - 2017$). The Additional Web Material (not for publication) provides a detailed overview.

2.1 Conflict and Landmine Use

Mozambique's experience with landmines started with the War of Independence ($1964 - 1974$). The Portuguese planted extensive minefields along the border with Tanzania to prevent the fighters of the Front for Liberation of Mozambique (FRELIMO), the main independence movement, from entering the country. They also mined critical infrastructure to protect it from the insurgents, including a ring of $80,000$ mines along the Cahora-Bassa dam, one of Africa's largest. In turn, FRELIMO used landmines in its military operations, to demoralize the colonial army, destabilize the countryside, and impair road transportation. Mozambique became independent in 1975, but conditions did not improve, as one of the most disruptive civil wars since WWII began shortly after. The two main warring parties, FRELIMO, now in government, backed by socialist countries, and the Mozambique

Resistance Movement (RENAMO), initially supported ($1977 - 1980$) by Rhodesia and subsequently by South Africa's apartheid regime, used landmines extensively; for military purposes, to protect infrastructure (e.g., electricity pylons and roads), to terrorize civilians, to block rearmament, and to protect towns, villages, and labor camps. Militias, rebels, and other groups also used landmines.

2.2 Mozambique in 1992. The Problem of Landmines

According to the statistics of the Penn World Table, Mozambique was at the end of the civil war the third poorest country in the world. Landmines and unexploded ordnance, the destruction of infrastructure and the return of about $3 - 4$ million internally and externally displaced (from a population of 12 million) posed significant challenges. The Peace Accord signed in Rome in September 1992 required that FRELIMO and RENAMO "*organize and implement mine-clearing operations*."

The HALO Trust $1993 - 1994$ survey (SHAMAN), the first attempt to characterize contamination throughout the country, revealed the following. First, "*the use of landmines is characterized by a highly dispersed pattern*", as suspected hazardous areas (SHAs) were spread across all provinces and most districts. Second, even the presence of a few contaminants could have adverse effects.[4] Third, infrastructure was deemed heavily mined, with the report specifying that in the southern and central provinces "*all dams, railway lines, electricity substations, and pylon lines should be assumed to be mined*", with a somewhat better assessment for the northern districts. Fourth, mines had been planted around schools and government buildings, often used as rebel or government headquarters. Fifth, detection and eventual removal were challenging because floods and landslides had moved landmines and unexploded ordnance, blending them with mud.

2.3 Landmine Clearance. Process and Periods

Mozambique is among the first countries in the world, alongside Afghanistan in 1989 and Cambodia in 1992, to experiment with humanitarian demining (in 1992), where NGOs and commercial firms, rather than the military, led clearance. Best practices had not been developed; expertise was limited; civilians had to be trained to detect and clear minefields; survey standards were missing; and the use of IT was limited. There was little (if any) coordination among operators, and the government's capacity was minimal. The clearance process was *ad hoc*, localized, and fragmented. The country's vast size and the limited transportation made surveying and clearance challenging. Unlike contamination during wars involving conventional armies that keep records of minefields (facilitating their subsequent clearance), maps of landmine placement were unavailable, as multiple actors laid the mines, and the warring parties, both with decentralized structures, were not keeping records. Besides, many mines

[4]For example, eight mines cleared in 1996 were preventing 20,000 people in Mahniça valley from returning to their villages. Similarly, HRW (1997) reads: "*During a Norwegian Peoples Aid mine clearance operation in Maputo province, a team was sent to clear the village of Mapulenge, the center of a community of about 10,000 people. It had been deserted for 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.*"

were planted years ago, and those who placed them had passed or returned to their hometowns. As a result, clearance proceeded slowly. The mistakes and lessons from Mozambique became the basis for the standardization of practices in the humanitarian demining community after the mid-2000s.

Periods The process of freeing Mozambique from landmines spanned three periods. Each phase started with a nationwide survey that set the stage for subsequent demining.

Initial Phase. 1993-2000/1 The 1993/4 SHAMAN survey set the stage for the commencement of clearance. Resources were scarce, and the survey was done in a rush.[5] Until the late October 1994 elections, the return of refugees was the priority; thus, the handful of interventions targeted war camps and border passages. Then, demining formed along three parallel programs. First, The HALO Trust (HT), a British-American NGO, started operating in the less-developed northern provinces. Second, in the central provinces, the Norwegian People's Aid (NPA) and, after 1999, Handicap International (HI), now Humanity and Inclusion, took the lead. Third, with the UN's help, the government established the Accelerated Demining Program (ADP) in 1995 that contracted with commercial operators in the southern provinces of Maputo, Gaza, and later Inhambane. The first phase was preparatory; SHAMAN provided a rough contamination mapping, and training centers were established. But progress on clearance was limited, as besides on-the-ground challenges, humanitarian demining was in its infancy. Given the flaws of the SHAMAN survey (discussed below), the government, the UN, and NGOs had an incomplete picture. 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).

Second Phase. 2001/2-2007/8 The second phase starts with the 2000/1 Landmine Impact Survey (LIS), commissioned by the then-established National Institute of Demining to serve as the road map of Mozambique's five-year $(2002 - 2006)$ mine-action plan.[6] While the survey was noisy (as shown below), it followed some standards for the first time. Besides, surveyors could visit more areas as security was restored, the displaced had long returned, and more information was becoming available. Guided by the new survey, clearance proceeded quicker until 2004, when allegations of corruption and the government's shortcomings in coordination and planning led to donor fatigue.

[5]The survey in the four Northern provinces, whose size combined is approximately that of Italy, was done by two teams of four people in less than six months. The survey in the Southern provinces and Tete, combined size of Spain, was carried out by three teams of four people in five months.

[6]The request of the Government of Mozambique for the extension in 2008 summarizes the challenges of 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 lack of comprehensive and accurate national gazetteer (i.e., the 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 protocol for false-negative sampling, and the nature, availability, and quality of expert opinion.*"

Third Phase. 2008/9-2015/7 The 2007/8 Baseline Survey combined information from many operators, serving as the key document for the government's final Mine Action Program. The survey was more accurate than the previous ones, as specialized NGOs, now with considerable experience, provided most of the information. The survey revealed three times as many mines as previously thought. Donors returned, and aid increased fourfold. Clearance proceeded at a steady pace, as the government and NGOs had learned from past mistakes, and process standardization was now in place. In September 2015 Mozambique was declared "landmine free", although some new minefields were identified and cleared in 2016 and 2017.

3 Data

This section presents the newly compiled data on clearance and digitizing the three nationwide surveys. We then discuss the harmonized yearly series of nighttime lights that proxy local development and other data. Mozambique is divided into 10 provinces and Maputo, the capital. There are 140 districts (admin-2 units) and 416 *postos administrativos* (admin-3). We conduct the analysis across $1,184$ localities (admin-4 units) using the 2007 administrative boundaries. Mozambican localities have an average (median) size of 655.77 (413.63) km^2; median population was $8,629$ in 1997 and $11,515$ in 2007. Agriculture is the dominant sector. The traditional cash crops include sugarcane, cotton, tobacco, cassava, maize, tea, and cashews whereas horticultural crops such as bananas, mangos, sesame, baby corn, green beans, and tomatoes are also important (IMF, 2014).

3.1 Contamination and Clearance

The backbone of our database is the $24,719$ progress and clearance completion reports, technical surveys, work plans, and tenders, which describe the interventions that took place from 1993 to 2017. Homogenizing this material into a coherent database is part of our contribution, as such data is unavailable for any other heavily contaminated country. We briefly discuss the data collection and plot the initial contamination and subsequent clearance, reserving for the Web Appendix (not for publication) a detailed overview of the institutional setting, additional details on the data sources/construction, examples, and visualizations.

Demining starts with collecting information on SHAs. A SHA turns to either a confirmed hazardous area (CHA), which means clearance eventually takes place, or it is reclassified as "canceled". Updating the status of an SHA is usually done via non-technical surveys. When the latter delivers sufficient evidence of contamination, a technical survey follows that concludes with the clearance of the CHA, detailed in a completion report. If the non-technical survey finds no evidence of contamination, the SHA is canceled. Our dataset stores $8,436$ clearance operations ("interventions") in $7,657$ CHAs. Most CHAs (91%) were cleared in one 'intervention", lasting on average (median) four (zero) months. The remaining 680 CHAs had 2.1 interventions (and reports). We will be using these two terms interchangeably.[7]

3.1.1 Constructing the Clearance Database

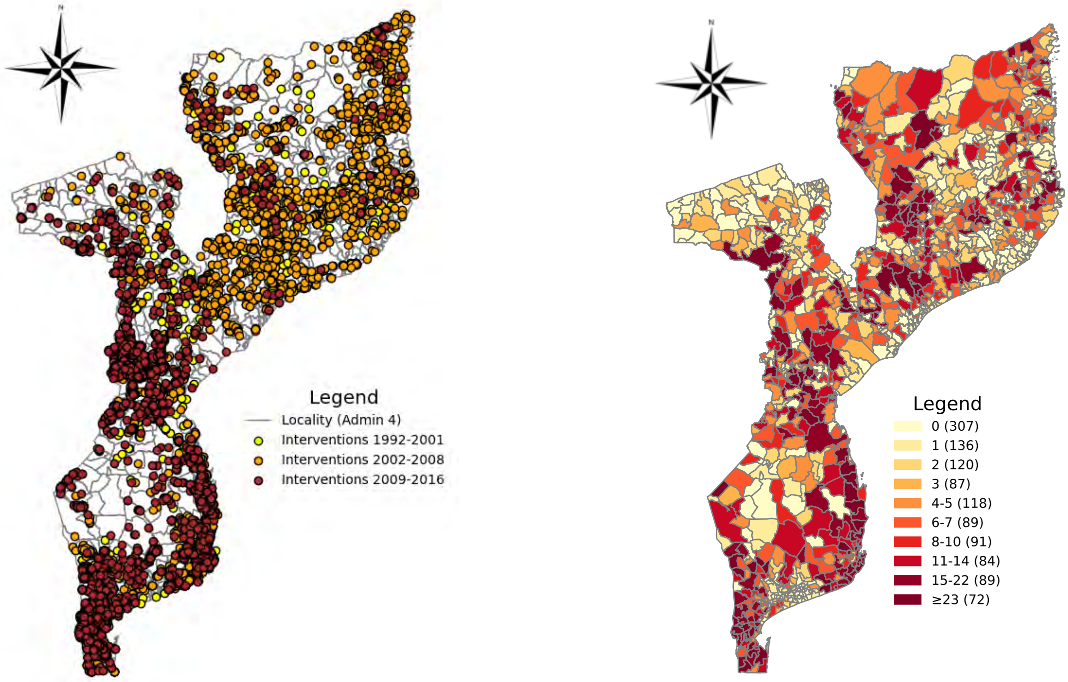
We proceeded as follows: First, we accessed the Information Management System for Mine Action (IMSMA) database at the National Institute of Demining in Maputo. During the initial phase, entries' quality, accuracy, and detail are rather imprecise, and coverage is incomplete, as the Institute started using this system in the mid-2000s. Coverage improves somewhat in the second phase (2002 – 2008) but becomes precise only after 2007, when, according to officials and practitioners, the database is (almost) complete. We corrected inconsistencies after reading the reports and interviewing dozens of deminers and officials. Our dataset includes 7,032 interventions from the IMSMA database. Second, we collected, processed, and digitized Halo Trust and NPA clearance reports. Doing so allowed us to validate and improve the detail of the IMSMA entries and expand coverage pre-2007. We also adjusted, when necessary, the exact year of clearance. We added 1,033 clearances from HALO Trust's inventory and 38 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 19 interventions from the German Agency for Technical Operations with MineTech in Manica and 35 from ADP's operations interviewing deminers. Fourth, we digitized maps of interventions in 1993-4 from the UN archives in New York and USAID. Fifth, from the digitization of the national surveys, we uncovered 236 clearance operations, not recorded elsewhere.

3.1.2 Mapping Contamination and Clearance

Figure 1 - Panel A illustrates the spatial distribution of clearance, providing an *ex-post* visualization of the extent of the contamination. 1,813 operations took place in the first, 3,783 in the second, and 2,840 in the third phase. Contamination, though widespread, is higher in the southern and central provinces, Maputo (1,365), Zambezia (1,182), Manica (1,095), Inhambane (1,095), and Sofala (962), where RENAMO was active in the brutal phases of the civil war in the mid/late 1980s. [Web Appendix Table W2 gives the statistics by province and period]. Figure 1 - Panel B aggregates clearances across localities, our unit of analysis. Appendix Table C1 reports summary statistics. 886 (of 1,184) localities were affected, having, on average, 9.52 hazards (median 5, standard deviation, 16.52); it takes, on average (median), seven years (6 years) to clear a locality from all hazards.

Correlates of Contamination To better understand contamination, we examined its correlates, running linear probability and Poisson ML models associating the likelihood (and number) of CHAs

[7] The average (median) size of CHAs with information in the clearance report on the land area (typically available for interventions after 2007) is 79,751 (2,782) squared meters. This is a square of side 282 (52) meters. SHAs are, on average, larger. In the 2001 LIS, the average (median) area was 409,094 (5,000) squared meters, corresponding to a square of side 639.6 (70.7) meters. Some hazards regard large (suspected) minefields close to the border, dams, and big farms, while others consider much smaller areas, mines, for example, blocking access to wells, rivers, and buildings. We use the centroids of SHA and CHA to assign them to localities.

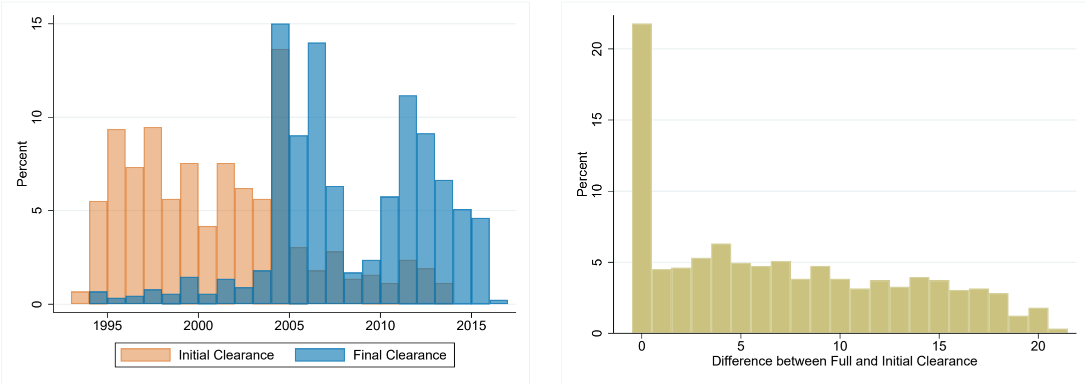


Panel A: Clearance Interventions **Panel B: Clearance Interventions across Localities**

Figure 1: **Confirmed Hazardous Areas (CHAs).** Panel *A* portrays the spatial distribution of 8,436 CHAs, alongside information on the period of clearance. Panel *B* portrays the distribution of contamination across 1,184 localities using the 2007 administrative boundaries. In parentheses, the legend reports the number of localities with the corresponding interventions.

with geographic / location characteristics (e.g., presence of roads, railroads, border indicators), early development proxies (e.g., population density in 1980), and civil war intensity. Contamination is higher in larger localities, along the transportation network with major civil war events. However, the explanatory power of the empirical models is low, in line with anecdotes and surveys on the indiscriminate use of landmines. [Web Appendix Figure W3.]

Timing of Clearance Figure 2 Panel *A* plots (in orange) the share of localities where demining occurs for the first time by year. By 1994, some demining had occurred in just 55 localities. By 2002, 563 of 886 localities had seen some clearance; the share jumps to 93,45% in 2009. The blue bars depict the share of fully cleared localities. At the end of 1994, only 6 localities were fully cleared. This increases to 7.11% in 2002 and 57.34% in 2009. The average (median) number of years to clear a locality, plotted in Panel *B*, is 7.09 (6). The extended time to completely clear a locality does not reflect the duration of operations per se, as clearing a CHA typically takes four months, but from the multiple hazards in a locality, the piecemeal approach to demining, and inaccuracies in surveys.



Panel *A*: Initial and Full Clearance

Panel *B*: Difference Between Full and Initial Clearance

Figure 2: **Timing of Clearance.** Panel *A* plots for every year in orange the share of contaminated localities where clearance operations begin, and in blue the share of localities that get fully cleared. There are 886 contaminated localities. Panel *B* gives the histogram of the difference in number of years between the final and initial clearance.

Correlates of the Timing of Clearance We associated the years elapsed until the initial and the final intervention with locality features, see Web Appendix Figure W4 and W5. First, the timing of the initial intervention is primarily influenced by proximity to borders, aiming to facilitate the return of refugees. The economic significance of these variables is weak, and the model's explanatory power is poor. When we turn to the correlates of years elapsed till full clearance, most variables enter with small and statistically insignificant estimates, telling of the challenges of prioritizing localities and removing all hazards. By and large, clearance did not follow a systematic pattern, reflecting, among other constraints, the lack of coordination, IND's limited capacity, the *ad-hoc*, and the short-term nature of contractors (as financially constrained NGOs were doing fund-raising for specific CHA), the flaws of the surveys, the massive floods of $2000 - 2001$, and the irregular ebb and flow of funding.

3.2 Nationwide Surveys. Suspected Hazardous Areas (SHA)

We processed, cleaned, and georeferenced the three nationwide surveys to grasp the information that authorities, funding agencies, and demining teams had at different times. Figure 3-Panel *A* maps (i) the 1993/4 SHAMAN survey that recorded 980 SHAs (in 787 villages), (ii) the 2000/1 Landmine Impact Survey (LIS) that identified $1,373$ SHAs affecting 779 villages, and (iii) the 2007/8 Baseline Survey that listed 536 SHAs.

3.3 Surveys: Challenges and Errors

3.3.1 Clearance Close and Far from the Nationwide Surveys

By comparing the SHA with the CHA, we can assess the precision of the surveys. To group the clearance operations into "in-survey" and "not-in-survey", we matched, where possible, the clearance

Panel A: Suspected Hazardous Areas in Nationwide Surveys **Panel B: Clearance Interventions close to Nationwide Surveys** **Panel C: Clearance Interventions far from Nationwide Surveys**

Figure 3: **Suspected Hazardous Areas (SHAs).** Panel A portrays 2,889 SHAs, as identified in the three nationwide surveys. Panels B and C plot CHA distinguishing by whether clearance occurred within a $2km$ radius of a SHA recorded in the preceding surveys [Panel B] or further [Panel C.]

completion reports with the entries in the national surveys describing suspected contamination. Often, there is a direct mention in the clearance report that the hazard had been previously identified as a SHA.[8] In addition, we use a $2km$ buffer around SHAs to group clearances. About 40% of the interventions explicitly correspond to national surveys or are very close by (3,339), see Figure 3 Panel B. But, there are 5,097 clearance operations far from SHA; Figure 3 Panel C.[9] Both types of clearance operations occurred in all provinces (in 138 out of the 140 districts). The tabulations in Table 1 reveal two patterns. First, across all periods, surveys provided an incomplete picture of contamination, as many interventions occurred far from the survey entries. Second, the 1993/4 survey was quite deficient, with less than 30% (500) of the 1,813 interventions in the first phase occurring in SHAs.

We compared various geographic and location attributes of "not-in-survey" versus "in-survey" interventions across Mozambique and within a locality. "In-survey" interventions are closer to trails, paved roads, and civil war events, consistent with surveys conducted in more accessible locations. Besides road proximity, there are no significant differences between the two sets of interventions across numerous geographic, location, and economic features [Web Appendix Figure W6 Panel A]. There is no significant difference in the timing of clearance, with the average year for "out-of-surveys" interventions being 2005.5 and for "in-surveys" 2005.9. Besides, the correlations between geography/location/development proxies and the timing of "in-survey" and "not-in-survey" clearances are

[8]For example, ADP cleared 3,189 Anti-Personnel mines on the "protective ring" of Moamba between 1994 and 1998, an area that the 1994 survey pinpointed as potentially contaminated [SHA]. The survey reads "*perimeter minefield around entire village approx 12 km long...minefield is clearly visible from the road*".

[9]For example, "*HALO Trust cleared 8 mines and 1 UXO on Djuba bridge located in Matola Rio (Maputo Province)*" in 2010; this area was neither identified as potentially contaminated nor in the vicinity of an SHA in the national surveys.

Table 1: Clearance Interventions, Nationwide Surveys, and Cancellations

	Clearance Interventions			**Cancellations**	
	(1) Total	(2) In-Survey	(3) Not In-Survey	(4) Total	(5) Drop 2km
Phase 1: 1993-2001	1813 (331)	500 (89)	1313 (242)	1009 (27)	918 (23)
Phase 2: 2002-2008	3783 (645)	1721 (344)	2062 (301)	937 (133)	520 (57)
Phase 3: 2009-2017	2840 (265)	1118 (150)	1722 (115)	172 (18)	135 (18)
Total	8436 (1241)	3339 (583)	5097 (658)	2118 (178)	1573 (98)

The table tabulates for the three main periods of demining: (i) Clearance interventions and their classification to "in-survey " and "not-in-survey", columns (1)-(3); (ii) All Cancellations of SHAs, column (4), and those that took place more than 2km further from a clearance intervention in the same year, column (5). The numbers in parentheses reflect CHAs and cancelations within 100 meters of the transportation network. In period 1, we consider only the 1993-1994 Survey (SHAMAN); in period 2, we consider the SHAMAN and the 2000-2001 LIS; in period 3, we consider the 2007-2008 Baseline Survey and the two previous ones.

similar [Web Appendix Figures W8 and W9].

Location and Year of SHA Cancellations

Figure 4: **SHA Cancellations** The figure plots all cancellations of Suspected Hazardous Areas (SHAs), distinguishing by the source.

3.3.2 Cancellations of SHA

The information in the nationwide surveys was fragmentary, often based on rumors and word of mouth. Hence, not only did they fall short of charting the actual extent of contamination, but several SHAs turned out to be landmine-free. For example, the 1993 − 1994 survey listed Namigonha in Zambezia, as suspected of contamination (SHA) since *"a motorcyclist died near the city"* even if the information was *"not confirmed by the residents."* When the LIS team visited in 2001, they declared it "unaffected by landmines." The bridge over the Messalo River (connecting the Macomia and Muidumbe districts in Cabo Delgado) was, according to the 1993 − 1994 survey *"[..] mined on both sides of the road, immediately at the end of the concrete"*. The LIS update of 2007 canceled this SHA. Another example is the *"Old Track of Guiriro [Cheringoma district, Sofala], abandoned in 1983 due to a suspected anti-tank mine."* The IMSMA dataset records an APOPO in-site check in 2013 "canceling" the SHA. To pinpoint SHAs reclassification as "canceled", we read operator reports and the assessment reports on the nationwide surveys. Often upon visiting the areas, the demining teams realized the initial information was erroneous as the communities already used the SHA. [10]

Figure 4 maps all 2, 118 cancellations. Often, cancellations occur alongside actual clearance operations in nearby areas. When we exclude cancellations in the same year in a radius of 2 km of actual clearance, we have a total of 1, 573. Canceled SHA are spread across 754 localities in all provinces. Most cancellations happened in villages suspected to be contaminated in the nationwide surveys. Overall, canceled SHA compared to CHA are in locations with similar geographies, proximity to (primary) cities, the coast, and borders. Canceled SHA are somewhat further away from the transportation network and main civil war areas [Web Appendix Figure W6 Panel B]. The within-locality comparisons suggest even smaller differences between the two. Section W1.1 of the Web Appendix gives institutional details of in-survey and out-of-survey interventions and cancellations.

3.4 Local Development. Nighttime Luminosity

Obtaining a time-varying, fine-resolution proxy of economic activity for one of the world's poorest countries, ruined by years of violence, is challenging. Following Henderson, Storeygard, and Weil (2012) and subsequent works, we proxy local development using satellite imagery on light density, available since 1992. Building on parallel research, we adjust, merge, and calibrate annual luminosity series available from satellites with different resolutions and accuracy to have comparable data from 1992 till 2017. After adjusting the DMSP (National Geophysical Data Center, 2010) series for three well-documented deficiencies, sensor calibration, top-coding, and blooming, Chiovelli et al. (2023) use

[10] For the first phase (1993-2001), the LIS 2001 lists 932 villages, initially considered by experts as contaminated, but when visited in 2001, were reclassified as *"unaffected by landmines"*. We also assign a canceled status to the 77 entries in SHAMAN within 2km of these 932 landmine-free villages. In the second phase (1992-2008), there are 937 cancellations. A 2007 update explicitly states and lists that 721 (of the 1, 373 SHA in the LIS 2001) had been canceled due to insufficient evidence. Another 40 cancellations appear in the IMSMA dataset. We also assigned as canceled, 176 SHAs in the SHAMAN survey since they were within 2km (of these 721 and 40 cancellations). In the last period, there are 172 cancellations; 167 in the IMSMA database and 5 from the SHAMAN (in a 2km radius).

an *"ensemble"* (extremely randomized forest) machine learning method to merge the pre-2013 data from DMSP with a "downgraded" version of the higher resolution VIIRS series, available post-2013 (Elvis et al., 2017). As shown in Appendix Section B, the harmonized luminosity series correlates strongly in the cross-section and over time with proxies of well-being (schooling, household wealth, access to electricity) from 139 georeferenced Demographic and Health Surveys (DHS) across 34 African countries. Besides, there is a significant (within) association between luminosity and schooling across Mozambican localities. As of 1992, only 6% of the localities had detectable luminosity. The proportion of lit localities increases to 10.1% in 2002; rises to 16.6% in 2009 and about a third in 2017.

3.5 Other Data

For the market access analysis, we need information on transportation infrastructure and population. We collected data on the length and quality of railways, primary and secondary roads, and trails in 2011, 2003, and 1998. We also digitized maps on the network conditions in 1973 that we merged with (rail)road status (functioning or destroyed at the end of the civil war (1992)). The three rail lines connect the main coastal cities to the interior. The Northern line links Nacala to Malawi; the central line connects Beira to Harare, and the Southern route goes from Maputo to South Africa (Zimbabwe and Swaziland). The railroads are not connected, as the objective during the colonial times was to export minerals and agricultural produce from the interior out of Mozambique. As during colonial times, Mozambique was split into three semi-autonomously ruled areas, the main cities were (and still are) hardly connected. Except for the Zambezi, rivers do not accommodate large or medium-sized boats. Colonial investments in transportation were minimal, 17% of the localities at independence had some primary roads, and railroads were present in only 11%. For population, we accessed and digitized the censuses of 1980, 1997, 2007, and 2017 from the National Institute of Statistics. Appendix A provides definitions and sources of all data.

4 Landmine Clearance and Local Development

This section explores the association between landmine clearance and local development. Note that the correlations do not necessarily identify causal effects. Although the clearance timing does not seem to follow a systematic pattern, demining was not an outcome of strict randomization. Moreover, spatial interdependencies are likely, as clearing may have spillovers in nearby localities. We first lay down the specification and discuss estimation. Second, we report the baseline estimates alongside pre-trend tests. Third, we use canceled SHA as a placebo. Fourth, we conduct a preliminary exploration of mechanisms. Appendix C and the Web Appendix Section W1.5 give further evidence.

4.1 Empirical Framework

4.1.1 Event-Study Design

The specification that explores the dynamics of luminosity $[y_{i,t}]$ and clearance $[CLEAR_{i,t}]$ reads:

$$y_{i,t} = \mu_{\mathbf{i}} + \mu_{\mathbf{t,p}} + \beta^{\mathbf{I,F}}\mathbf{CLEAR^{I,F}_{i,t}} + \mathbf{X'_{i,t}\Gamma} + \zeta_{\mathbf{i,t}}. \tag{1}$$

$y_{i,t}$ denotes economic activity in locality i, in year, t, proxied by nighttime lights between 1992 – 2017. 1992 is the first year of the lights series and the end of the civil war, and 2017 is the year of the last intervention. As many localities registered zero light (especially in the early years), we focus on the extensive margin with an indicator that equals one if any pixel in the locality is lit. The explanatory variable is an indicator switching to one either in the year of *initial* clearance and all subsequent years ($CLEAR^{I}_{i,t}$) or when the locality gets *fully* cleared ($CLEAR^{F}_{i,t}$), and all subsequent years. We distinguish between initial and full clearance, as interventions spanned several years in the more heavily mined localities. $\mu_{\mathbf{i}}$ are locality-specific constants. The province-year constants, $\mu_{t,p}$, account for the idiosyncratic process of demining and heterogeneous growth dynamics across provinces. $X'_{i,t}$ are locality-year controls or interactions of year indicators with locality-specific geographic/location characteristics.

The dynamic specification reads.

$$y_{i,t} = \mu_{\mathbf{i}} + \mu_{\mathbf{t,p}} + \sum_{\mathbf{h=-a}}^{\mathbf{b}} \beta^{\mathbf{I,F}}_{\mathbf{h}}\mathbf{1}[\mathbf{CLEAR^{I,F}_{i,t}} = \mathbf{h}] + \mathbf{X'_{i,t}\Gamma} + \zeta_{\mathbf{i,t}}. \tag{2}$$

The estimates on the lead indicators (a) allow for detecting differential dynamics between non-contaminated and mined localities before clearance ("pre-trends"). The coefficients of the lags (b) capture the dynamic path of luminosity following the initiation/completion of demining.

4.1.2 Estimation

Recent works demonstrate that least squares (LS) estimation of difference-in-difference designs with a staggered treatment, like ours (as demining starts/completes in different years across contaminated localities), may fail to produce unbiased estimates when the effects change over time (de Chaisemartin and D'Haultfoeuille, 2020). The problem emerges because LS with staggered rollout not only leverages comparisons between cleared units and "pure" control observations (noncontaminated localities and those where no intervention has occurred) but also compares cleared units to those cleared earlier. These, often referred to as "forbidden", comparisons, are problematic when the dynamic correlations are not constant over time. Various diagnostics indicate time heterogeneity when considering initial, though not full, clearance.[11] We, thus, estimate the static and dynamic correlation between clearance

[11] The decomposition of Goodman-Bacon (2021) that splits the LS estimate into all possible $2x2$ comparisons shows that with the initial clearance indicator, half of the LS coefficient (52.3%) stems from "forbidden" comparisons. When

and luminosity using the "imputation" method of Borusyak, Jaravel, and Spiess (2023), well-suited to our setting. First, the locality and the year-province constants are estimated using *only untreated* observations, i.e., all yearly observations of non-mined localities and the pre-clearance years of contaminated ones. Second, the estimate is the average post-clearance luminosity minus the imputed value from the locality and the province-year constants (first step). We compute the mean of all post-clearance years (static) and of each year (dynamic).

4.2 Baseline Event Study Estimates

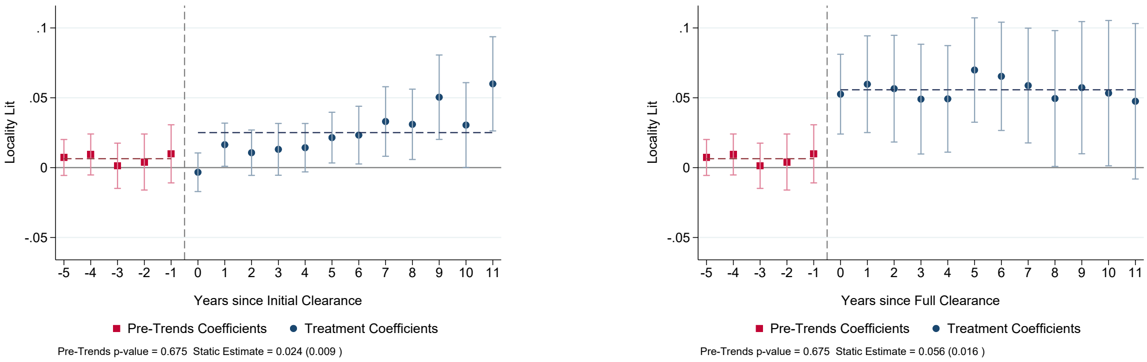
Figure 5 plots the imputation estimates, examining the correlation between clearance and the lit indicator twelve years after the first intervention (Panel A) and the complete removal of all hazards (Panel B), dropping years between the first and the last intervention. The figure also gives the estimates on the five leads before any clearance commences (so the coefficients are the same in both Panels). Standard errors are clustered at the admin-2 (district) level, as this accounts for serial correlation and spatial (within-district) inter-dependencies.

Pre-Trends It is instructive to examine pre-trends in development between contaminated and non-mined localities *before any clearance takes place*, as this sheds light on the potential targeting of growing areas. Borusyak, Jaravel, and Spiess (2023) suggest comparing the coefficients on the leads that capture differences in the dynamics of luminosity between not-yet-cleared, on the one hand, and non-contaminated localities, on the other hand, before clearance begins.[12] All lead indicators enter with small and insignificant coefficients. The F-test fails to reject the null hypothesis of no differences in luminosity between the two groups. We also checked for "anticipation" effects; assuming that clearance begins three, or five years earlier, we estimate placebo "treatments" with the imputation estimator (Liu, Wang, and Xu, 2022) finding no evidence (Appendix Figure C1). These results square well with the fragmented, *ad hoc*, non-centrally coordinated, and based on imprecise information process of landmine removal in the 1990s and 2000s. It is also in line with our interviews with deminers and officials that prioritizing high-growth (potential) areas was neither logistically feasible nor part of the contracts nor applied by operators.

Dynamic Estimates Figure 5 Panel A plots the coefficients of the twelve post-clearance indicators (including the year of initial clearance, $T = 0$), as blue dots. Luminosity increases gradually and steadily after the operations start. The coefficients on the post-indicators for the years 1 to 5 suggest

we look at full clearance, "forbidden comparisons" get a 26% weight. In the Web Appendix Section W1.4, we show that a similar picture emerges when we perform the intuitive tests of Jakiela (2021) to detect the observations with "negative weights" and check the homogeneity of the coefficients. Negative weights emerge late for localities cleared early, especially with the initial clearance indicator that switches to one much earlier than the full clearance indicator. The coefficient homogeneity assumption is rejected with the initial but not with the full clearance indicators.

[12] The test (i) avoids the pre-testing problem in OLS blending post and pre-event observations by restricting estimation of the leads to "untreated" observations (Roth, 2022); (ii) is robust to treatment heterogeneity; and (iii) is conceptually appealing as it separates the estimation of landmines' role in development from pre-clearance dynamics.



Panel A: Initial Clearance **Panel B: Full Clearance. Excl. Inter. Clearance**

Figure 5: The figure reports event study coefficients (in blue circles) with the Borusyak, Jaravel, and Spiess (2023) imputation method that estimates the response of luminosity in the year of clearance and 11 years after. In Panel A, $T = 0$ corresponds to the initial year of clearance. In Panel B, $T = 0$ corresponds to the year when the locality is completely clear of all contamination. Panel B drops years of partial clearance, i.e., locality-year observations where clearance has commenced but not completed. The outcome variable is an indicator that takes the value of one if the locality is lit and zero otherwise. All specifications include province-specific year-fixed effects and locality-specific constants. The legends give the static estimands (and standard errors) for the twelve post-clearance years (including the event year). The red squares report the coefficients of the lead indicators, testing for common trends between not-yet-cleared localities and non-contaminated localities in the five years before clearance commences. The figure also reports the p-value of an F-test of the null hypothesis of no differences in the outcomes between the two groups of localities. 95% confidence intervals based on standard errors clustered at the district level are given alongside the simple (unweighted) mean (in dashed lines) of the twelve post- and the five pre-clearance indicators.

an increase in the likelihood of lit of about 1.2 percentage points (pp). The coefficients rise and turn significant five to six years after the initial operations; this is when the median mined locality gets cleared of all hazards. Panel B focuses on *full* clearance, dropping all years with partial clearance.[13] These estimates, our preferred ones, compare development in contaminated localities before any clearance and after removing all hazards. The likelihood that the locality is lit after demining teams have cleared all hazards is about 5.5 *pp*; for comparison, 12.9% of localities are lit in the middle of our sample in 2005.

Static Estimates Table 2 gives the static estimates. The coefficient in column (1) suggests an average increase of about 4.8 pp in the likelihood that the locality will be lit after clearance commences, compared to non-contaminated and not-yet-cleared localities. The coefficient, estimated across the whole sample, is higher than when we focus on the twelve post-clearance years (Figure 5, Panel A), as estimation leverages all post observations. In column (2), we focus on the years following the final intervention, omitting observations when clearance has started but not completed. Clearing a locality from all hazardous areas increases the likelihood of being lit by roughly 5.4 pp compared to the period of full contamination. The estimates with the imputation method are comparable to the LS ones when omitting "forbidden" comparisons between cleared early and late localities (Goodman-Bacon, 2021), 0.036 with the initial and 0.047 with the full clearance indicator. As the median

[13]Dropping the years with demining teams on the ground, conducting technical surveys, drafting action plans, and completing their tasks addresses concerns that the estimates pick up their presence.

Table 2: **Landmines Removal and Local Development**

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Initial Clearance	Full Clearance						
Clearance	0.048***	0.054***	0.049***	0.056***	0.054***	0.049***	0.065***	0.052***
	(0.012)	(0.017)	(0.017)	(0.013)	(0.017)	(0.017)	(0.017)	(0.017)
Estimate per Cleared SHA	.005	.00566	.00512	.00587	.00568	.00515	.00681	.00551
Number of Localities	1,184	1,184	1,184	1,184	1,184	1,184	1,184	1,184
Specification	Unconditional	Excluding Interm. Clearance	Drop Limited Info Operations	Stop 2013	Controlling Rain (Log)	Location X Year FE	Geography X Year FE	District X Year FE
Locality FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time x Province FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
# Treated Observations	15,270	8,990	8,646	5,492	8,990	8,990	8,990	7,125
Observations	30,784	24,504	24,964	19,814	24,504	24,504	24,504	22,639

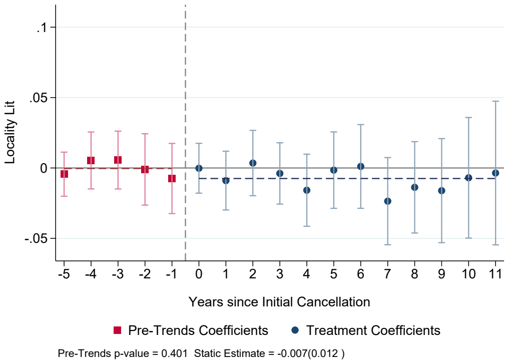
The table reports difference-in-difference estimates using the imputation estimator associating luminosity with landmine clearance. The dependent variable is an indicator that equals one if the locality is lit and zero otherwise. The main independent variable in column (1) is an indicator that takes the value of one when clearance operations start in a locality and all subsequent years; the indicator equals zero when clearance has not started. In columns (2)-(8), the main independent variable takes the value of one when the locality is fully cleared of all hazards and all subsequent years; these specifications omit locality-year observations in contaminated localities where clearance has started but not yet completed. Column (3) restricts the sample to $7,410$ clearance interventions with detailed completion reports; in column (4), the analysis stops in 2013, using luminosity series only from the DMSP-OLS satellites; column (5) controls for the log of yearly rainfall; column (6) controls for a third order polynomial of latitude and longitude interacted with year indicators; column (7) includes interactions between geographic controls (log distance from Swaziland, South Africa, Zimbabwe, Zambia, Malawi, or Tanzania, elevation, malaria, suitability of agriculture) and year indicators. The specifications in (1)-(7) include province-year fixed effects, while specification (8) includes district-year fixed effects. Standard errors (in parentheses) are clustered at the district (admin 2) level. **, *, and * indicate statistical significance at the 1%, 5% and 10% level, respectively.

(mean) number of CHA in contaminated localities is 5 (9.3), the estimates imply that clearing a single hazard increases luminosity by about 0.005 pp, on average. To better understand magnitudes, we estimated the elasticity between lights and development proxies using 139 geo-referenced DHS surveys in 34 countries and all Mozambican Censuses (1997, 2007, and 2017) [Appendix Section B]. The DHS analysis implies an increase of about 0.10 standard deviations in the standardized composite wealth index when a locality turns from unlit to lit. The Mozambican censuses suggest an increase in schooling of about 0.40 years when a locality turns from unlit to lit.

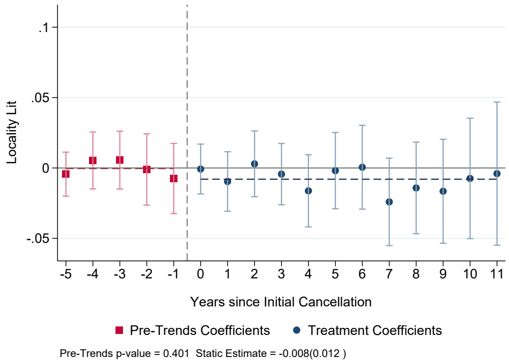
Sensitivity Columns (3)-(4) explore measurement errors in luminosity and clearance. In (3), we drop 1,107 interventions before 2007 with limited reporting information as they might capture technical checks or action plans. In (4), we stop in 2013 to use nighttime data only from the DMSP satellites. The specifications in (5)-(8) aim to account for omitted variables. In (5), we control for annual rainfall, which is crucial for agricultural economies and may affect clearance. In (6), we add interactions between year constants and a third-order latitude-longitude polynomial to account for differential trends across space. In column (7), we interact year constants with time-invariant geographic features (border localities, elevation, soil suitability, malaria) to account for heterogeneous growth across localities with different geographies. In (8), we replace the province-year with district-year fixed effects to account for unobserved features at a fine level. The estimates across all perturbations are similar to the baseline, and precision often improves. The Web Appendix reports additional sensitivity checks.

4.3 SHA Cancellations as Placebos

As described earlier, our database records instances when the demining teams visited a SHA to verify the contamination only to find out that it was *"landmine free"*, as either the community was using the suspected area already or no one could confirm the presence of a hazard. We examined the dynamics



Panel A: Cancellation.



Panel B: Cancellation Control for Clearance

Figure 6: The Figure reports difference-in-difference coefficients (in blue circles) with the imputation method that estimates the response of luminosity in the year of cancellation and eleven years after. $T = 0$ corresponds to the year when the first SHA that was erroneously classified is canceled in a given locality. Panel A plots the unconditional estimates. As clearance and cancellation can happen in the same locality, Panel B controls for actual clearance in the locality. The outcome variable is an indicator equal to one if the locality is lit. All specifications include province-year and locality-specific constants. The legends give the static estimands (and standard errors) for the twelve post-cancellation years (including the event year). The red squares report coefficients of lead indicators, testing for common trends in the five years before cancellation occurs for the first time between not-yet-canceled localities and localities without cancellations. The Panel legends report the p-value of an F-test of the null hypothesis of no outcome differences between the two groups of localities. 95% confidence intervals based on standard errors clustered at the district level are given alongside the simple (unweighted) mean (in dashed lines) of the twelve post- and the five pre-cancelation indicators.

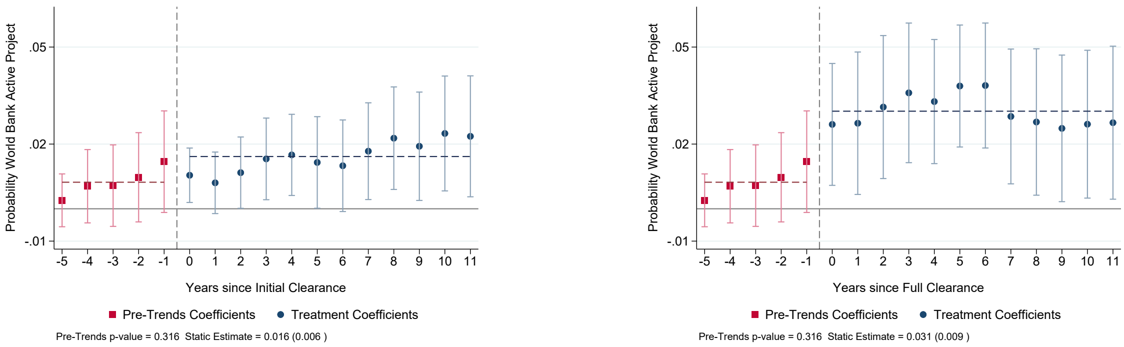
of luminosity when operators reclassify SHAs as canceled or non-affected by landmines to shed light on two issues. First, if operators, donors, or the National Institute of Demining target areas with growth potential, we should observe luminosity increase before or shortly after the arrival of demining teams, even when no contamination is present. Second, if the mere presence of deminers boosts activity, luminosity should spike around the year of reclassification. Figure 6 plots the coefficients of the imputation estimator.[14] Three results emerge. First, as with actual clearance, there is no evidence of differential trends in luminosity between localities to be visited by clearance squads and localities without any cancellations, i.e., non-mined and contaminated ones with no cancellations. Second, there is no jump in luminosity in the year of and around the cancellation. Third, development does not respond dynamically to the cancellation, in line with the reports that, in most cases, locals were using the SHA. Appendix Table C2 further shows luminosity's non-response to cancellations.

4.4 A Primer on the Mechanisms

In this Section we shed some light on the landmine removal development nexus.

[14]Several reports explicitly state that deminers reclassify SHA as canceled while removing mines from nearby minefields. Therefore, we omit instances where clearance occurs simultaneously in a $2km$ radius to avoid capturing the impact of clearance. There are 1,573 re-classifications of SHA as not contaminated in 682 localities. In 523 localities, cancellations occur once, whereas in 159 localities, cancellations occur over multiple years. For the latter, we take the first cancellation as the event year.

Aid First, we examine the evolution of donor investments around clearance, using WB-funded projects from 1992 to 2017. There are 234 projects that cover water supplies, sanitation, flood protection, power generators, roads, and public administration in 108 localities. Figure 7 plots the estimates with the imputation estimator. There is a roughly 3 (1.5) pp increase in the likelihood of an active WB project after full (initial) clearance, suggesting that landmine removal opens the road for aid, indicating a plausible mechanism. However, although donor support appears to react to clearance and WB projects move in tandem with local development, the correlation between luminosity and clearance retains its economic and statistical significance both when accounting for WB projects and when we drop all localities with WB projects (Appendix Table C3).



Panel A: Initial Clearance **Panel B: Full Clearance. Exclud. Interm. Clearance**

Figure 7: The figure reports difference-in-difference coefficients with the imputation estimator estimating the response of World Bank-funded projects twelve years after clearance operations commence (Panel A) and complete (Panel B). Panel B drops observations with partial landmine clearance. The outcome variable is an indicator that takes the value if there is at least one active World Bank-funded project in the locality in a given year and zero otherwise. All specifications include province-year and locality-fixed effects. The Panel legends also give the static estimands (and standard error) for the twelve post-clearance years (tau). The red squares report estimates testing for parallel (common) trends between not-yet-cleared localities and non-contaminated localities five years before clearance commences (Panel A) or completes (Panel B). The Panel legends give the p-value of an F-test of the null hypothesis of no differences in active WB projects between the two groups of localities before the clearance. 95% confidence intervals based on standard errors clustered at the district level are also shown, alongside the simple (unweighted) mean (in dashed lines) of the 12 post and the 5 pre-clearance indicators.

Roads and Population Density Second, we examined the within-locality correlation between clearance and changes in the road network. Since we do not have yearly information, we run Panel specifications associating indicators for new road construction and improvements (e.g. from unpaved to paved) in the 1973 networks and clearance at four points in time. The LS estimates, reported in Appendix Table C4, show that landmine removal correlates with improvements in the at-independence road network, revealing a possible mechanism linking clearance to local development. Moreover, clearance does not seem to spur urbanization, unless the interventions take place along the transportation network.

Heterogeneity Third, we explore the heterogeneity of the landmine removal-development link. As a preliminary step in looking at the role of landmines in facilitating the flow of goods and services, we distinguish between clearance operations along the transportation network and elsewhere. When we run the imputation estimator separately for these two sets of interventions, we find much stronger correlations with luminosity when looking at the clearance of mines blocking roads and railroads.

5 Landmines and Development. A Market-Access Approach

Motivated by the stronger correlation between luminosity and the clearance of mines along the transportation network, in this Section, we examine the economy-wide implications of landmine removal. We first review the theoretical underpinnings of the market-access (MA) approach and describe the estimating equation. Second, we discuss the construction of the MA measures. Third, we report the baseline estimates along with the sensitivity analysis. Fourth, we develop an identification design that isolates clearance of hazards not pinpointed as potentially contaminated in earlier surveys. Appendix Section D gives summary statistics, descriptives, and additional results.

5.1 Foundations

5.1.1 Setting

The conceptual framework behind the empirical analysis follows Donaldson and Hornbeck (2016), who transpose the Ricardian trade model of Eaton and Kortum (2002) to a within-country inter-region framework and derive an expression linking regional income to MA. The origins of this approach can be traced to Harris (1954) that stresses the role of the "market potential,", which captures the number and size of locations close to origin (see also Redding and Venables, 2004). In the Web Appendix, we sketch the model that features regional differences in efficiency/technology (absolute and relative advantage), consumers with love-for-variety preferences, and costly trade with an "iceberg" formulation yielding a gravity equation of bilateral trade that reflects these features. Alder (2017) shows that the log-linear association between income and market access is present both when labor is immobile and when workers can move between regions.

This setup approximates commerce in agricultural economies, like Mozambique, where the share of employment in agriculture exceeded 80% in the 1990s, while nowadays, it hovers around 70%. Mozambique's agriculture sector has grown and, most importantly, become more integrated. International policy institutions' reports tell of the rising role of local markets in the trade of agricultural produce across districts and provinces (WFP, 2016, IMF, 2014, World Bank, 2008). The reports emphasize Mozambique's poor and limited, even by African standards, transportation system for internal commerce, facilitating exports of agricultural produce, and importing fertilizers and insecticides. They also pinpoint the connection between transportation system upgrades and domestic market integration.[15]

[15] The World Food Program's detailed analysis of local markets in Central Mozambique gives many cases. For example,

5.1.2 Market Access - Development Relationship

The framework yields a "reduced-form" log-linear relationship between a locality's income, market access, and productivity, as well as model parameters.

$$\ln\left(Y_{o,t}\right) = \underbrace{\mu \ln MAo, t}_{\substack{\textbf{Market Access} \\ \textbf{[Hazards, Roads-Rail]}}} + \underbrace{\lambda \ln Ao, t}_{\substack{\textbf{Productivity} \\ \textbf{[Hazards, Other]}}} + \underbrace{\gamma_o}_{\textbf{Endowments}} + \underbrace{\gamma_{p,t}}_{\substack{\textbf{Utility,} \\ \textbf{Int. Rate, Wage}}} \tag{3}$$

Market Access The first term gives the income-market access relationship with a constant elasticity, μ, which captures the strength of comparative advantage in this economy and the share of labor and land in the production function. The locality's, o, market access, MA_o, is approximately the sum of the population (and, for robustness, luminosity as Alder, 2017) of all other destination localities, $N_{d,t}$, discounted by the bilateral transportation costs ($\tau_{o,d} > 1$), in turn, shaped by the clearing of hazards, new road-railroads, and improvements of the transportation network over time, t. Bilateral costs (in each period), which we approximate with travel time, are scaled by a "trade elasticity" parameter, θ, which inversely maps into localities' comparative advantage.

$$MA_{o,t} \approx \sum_{d \neq o} \tau_{o,d,t}^{-\theta} N_{d,t}. \tag{4}$$

MA reflects effective proximity to populous destinations. Hence, besides capturing the intensity of the flow of imported and exported goods and services, it may also reflect accessibility to government and NGO services, commuting, and internal migration. It is challenging to distinguish between these plausibly highly correlated aspects, so we note that MA might also reflect these forces.

Productivity The second term suggests a log-log relationship between a locality's income and (time-varying) productivity. Hazard clearance might increase (agriculture) productivity through a lower risk of incapacitation and casualties, land release, improved accessibility to buildings and other public infrastructure, and increased livestock survival, among others. To capture this, we add the number of cleared hazards on the RHS (using the log yields similar results).

Endowments and Time-Varying Common Factors Locality-fixed effects, γ_o, collect time-invariant (land) endowments (shaping absolute advantage), related, in our setting, to the intensity of civil war and pre-war development, among other features. Period-province constants, $\gamma_{p,t}$, absorb

maize in the Northern parts of Tete is sold not only in nearby localities and other districts but also in Manica, Zambezia, and Nampula. Maize produced in the North is shipped to the big markets in central provinces and Tete. Cowpeas in Gaza supply Maputo and the North. Rice produced in Xai-Xai gets shipped to Gaza's and Manica's interior. The World Bank (2008) writes, *"partly as a result of improved security and road network conditions, domestic market integration has improved significantly, domestic trade is growing, and prices are converging across subregions"*.

factors common to all localities in a given period-province linked in the theoretical framework to utility, the interest rate, and potential wages.

5.1.3 Estimating Equation and Identification

We estimate variants of Equation (3) with LS in a Panel of $1,043$ localities with data from all censuses (1980, 1997, 2007, and 2017). We conduct the analysis across the three phases of clearance [period 1: 1992-2001; period 2: 2002-2008; period 3: 2009-2017].

$$Lit_{o,t} = \mu lnMA_{o,t} + \lambda ClearHaz_{o,t} + \kappa_t G_o + \gamma_o + \gamma_{p,t} + \zeta_{o,t} \quad (5)$$

Landmine removal affects income, proxied by luminosity, $Lit_{o,t}$, directly via the number of CHAs cleared, $ClearHaz_{o,t}$, and through market access, $MA_{o,t}$ (shaping transportation costs). This treatment spillover (MA) framework cannot quantify common-to-all-locality shocks, absorbed by the province period-specific constants, $\gamma_{p,t}$, which also account for changes in the socioeconomic environment across provinces, policies, and provincial shocks.

There are four main identification challenges. First, the evolution of market access reflects the changing population and transportation costs, in turn, driven perhaps by localities' unobserved potential. Besides, in the underlying theoretical set-up, the population evolves jointly with income. Therefore, we will mainly use MA statistics using the pre-clearance network of 1973 to avoid capturing (potentially endogenous) concurrent changes in the roads-railroad network. To avoid capturing local population swings, we use the destination localities' population as recorded in the 1980 Census, well before clearance and the more destructive period of the civil war.

A second issue is measurement error in the market access statistic, stemming from noise in the projection of the transportation network and the exact location of minefields, but also from the parameterization of bilateral costs (equation 4). We experiment with alternative parameters and relax the assumption of landmines blocking the network to assess the stability of our results. Besides, the MA statistics may not properly capture effective proximity to relevant agricultural markets or export hubs. Therefore, we explore sensitivity using measures, which weigh more connectivity to the main port cities of Maputo, Beira, and Nacala.

A third concern regards the potential strategic clearance of landmines in areas with growth potential (although the pre-trends of the event study analysis and the history of clearance suggest that this was the case). To address this, we develop an identification design that isolates clearance of hazards not pinpointed as potentially contaminated in the previous surveys, which, therefore, could not have been part of any central strategic prioritization or targeting.

Fourth, time-varying factors may be correlated both with clearance and productivity. To account for unobserved localized productivity dynamics, we add a time-varying third-order latitude-longitude polynomial, and for robustness, we also add interactions of geographic and locational characteristics with period constants, $\kappa_t G_o$ (see also Jedwab and Storeygard, 2022, and Alder et al., 2022).

5.2 Market Access across Mozambican Localities

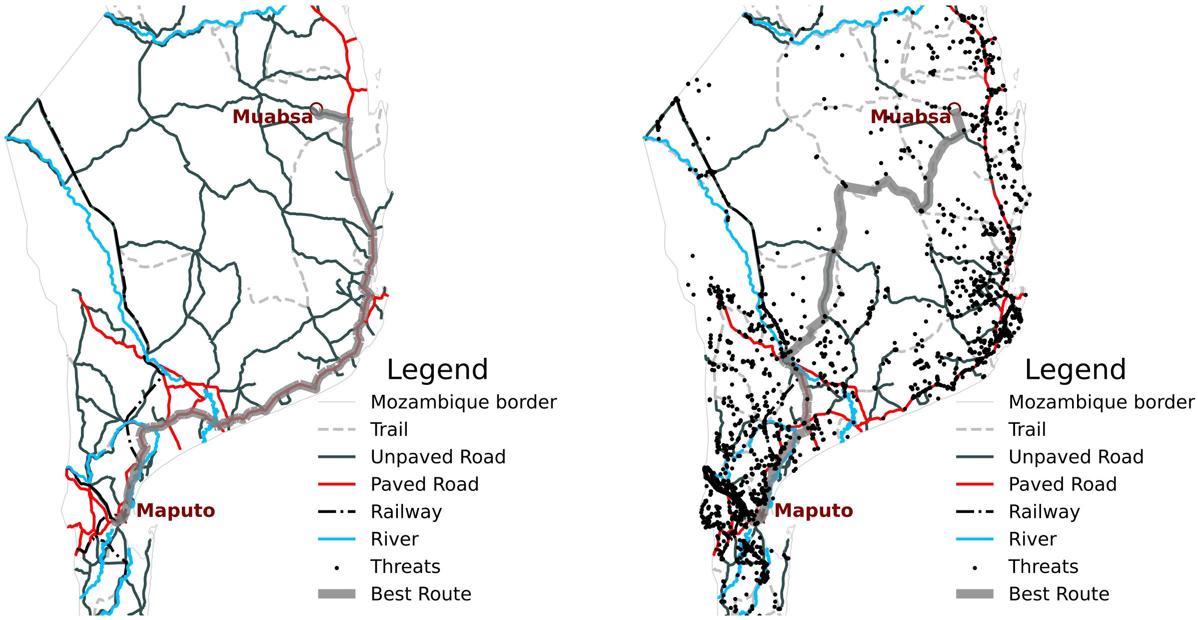
5.2.1 Construction of Market-Access Statistics

Transportation Costs The construction of bilateral costs, $\tau_{o,d}$, involves four steps. First, we create the transportation network composed of railroads, paved and unpaved roads, trails, and navigable rivers for each of the three main periods of demining using the 1999, 2003, and 2011 network elements, respectively. For the pre-clearance network, we use the at-independence one. We connect the localities' centroids to the closest transportation element and allow for straight-line connection on foot among localities' centroids (there is no within-locality trade). Second, we parameterize the relative cost of the network's elements. Following studies on transportation in Africa (Kim, Molini, and Monchuk, 2012, and Alemu and Van Schalkwyk, 2008) and Mozambique in particular, we assume the following. Railway is the most efficient (trade) technology and its cost is normalized to 1. We set the relative price of paved roads to 2 and unpaved roads to 4. The relative cost of trails is 10, as they are in poor conditions and not used during the rainy season. The relative cost of walking is 20. For navigable rivers, we assign a cost of 15. Third, following our interviews with deminers, reports, and surveys, we impose that a CHA within 100 meters of a transportation segment blocks its usage. The buffer accounts for measurement errors in the clearance reports and the network. Fourth, we approximate the transport cost by the product of bilateral distance via the transportation network and the relative costs of the respective modes. This is equivalent to using travel time, which factors the speed of going from origin to destination (e.g., Jedwab and Storeygard, 2022, Alder et al., 2022). Finally, we apply Dijkstra's algorithm that solves for the lowest-cost path between two localities' centroids.

Example Figure 8 illustrates the algorithm-derived optimal route between Maputo and the town of Muabsa in Inhambane province, $700km$ north of the capital. Panel A shows the path in 2017. As all hazards have been cleared, the algorithm employs the most efficient network elements, which yields a cost of $1,553$. The route for 1992, in Panel B, is very different. As dozens of minefields block the highway $N1$, linking Maputo to the Central districts along the Indian Ocean, and the secondary road linking Muabsa to $N1$, the algorithm relies on unpaved roads and trails, resulting in a significantly more expensive (lengthier) route. The shortest path is more than a four-fold increase in travel time.

Trade Elasticity A key parameter is the trade elasticity, θ, reflecting (inversely) the strength of comparative advantage (or variety differentiation). As a benchmark, we use a value of 3.8, which is in the middle of the estimates that Simonovska and Waugh (2014) produce in their careful work of the trade elasticity in comparative advantage settings.[16] Below, we explore the sensitivity of our estimates

[16] Jedwab and Storeygard (2022) and Alder et al. (2022) also settle for a value of 3.8 as Atkin and Donaldson (2015) estimate that the effect of log distance on trade costs within Ethiopia and Nigeria is three times larger than in the US,



Panel A: Optimal Route in 2017 **Panel B: Optimal Route in 1992**

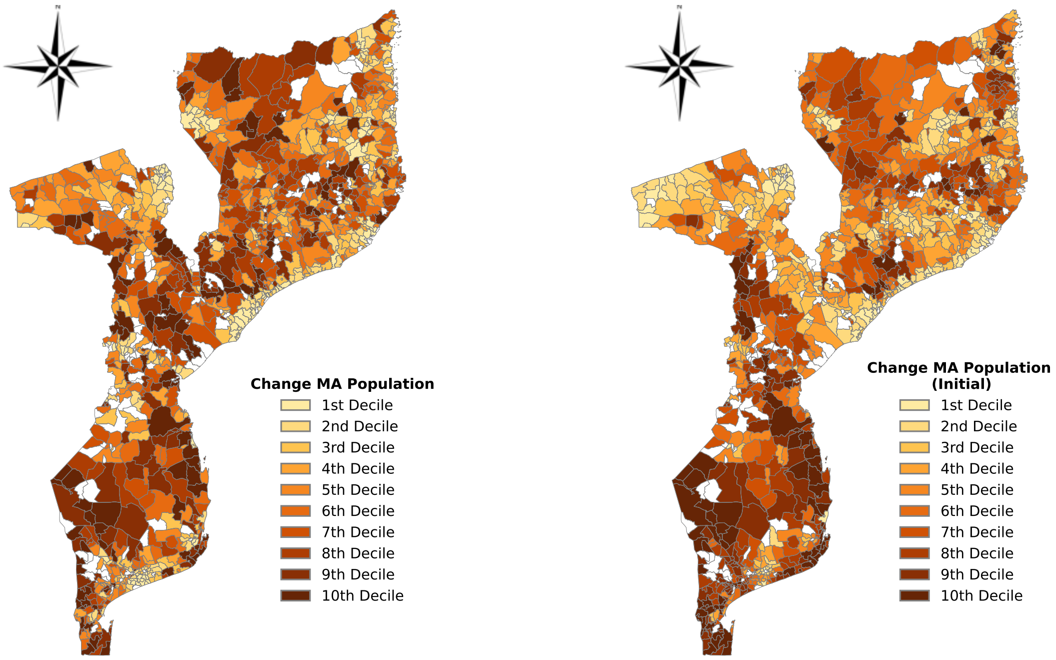
Figure 8: **Least-Cost/Time Route, Dijkstra's Algorithm.** Panels A and B give the optimal route from Maputo to Muabsa (Inhambane Province) in 2017, without any minefields, and in 1992, when dozens of minefields/threats (black dots) block access to paved roads (red), unpaved roads (grey), trails (dashed grey), and rivers (blue).

to alternative values of the trade elasticity and the network elements' parameterization costs.

5.2.2 Market-Access Measures

First, we compile yearly contemporaneous MA statistics using the transportation network of each period, the yearly extent of contamination, and the yearly population derived by interpolating across the four censuses. Based on these yearly MA statistics we compute the per-period MA averages. Second, we use the transportation network at independence using localities' population in 1980, ($MA_{o,init}$); this measure isolates the role of landmine removal from subsequent changes in population, new roads, and improvements in the network. Figure 9 maps the changes between the last and the first period in contemporaneous (log) market access (Panel A) and the analogous difference using the pre-clearance transportation network and 1980 population ($MA_{o,initial}$, Panel B). The correlation between the two measures is around 0.60. There is considerable variation in changes in market access within provinces, as province constants explain only 6% of the variance. Even when we add admin-2 constants, there is sizeable residual variation, as the R^2 is 0.30. A noteworthy feature of the changes in log MA is their (very) low correlation with geographic, location, and early development proxies (Appendix Figure D4), reflecting the colonial legacy of railroads and roads connecting the ports with the interior instead of linking the main cities (see also Jedwab and Moradi, 2016).

which according to Duranton, Morrow, and Turner (2014) is about -1.27 .



Panel A: Change in Log MA Population Contemporaneous

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

Figure 9: **Change in Population Market Access.** Panel *A* plots the change in the log of the population-weighted market access between the third (2009-2017) and the first phase of demining (1992-2001). Panel *B* plots the change in the log of population market access, using the 1973 transportation network and the 1980 population.

5.3 Baseline Results

Contemporaneous Table 3 gives the estimates of equation (5). The development-MA elasticity is positive and highly significant with both the baseline population market access and the luminosity-weighted measure (columns (1) and (3)). A one-standard-deviation increase in MA (around 2.4 log points) raises the likelihood the locality is lit by 9.6 pp. In columns (2) and (4), we add the number of *Cleared Hazards* to capture the direct effects of clearance. The coefficient is significantly positive, implying an increase in the light likelihood of 3.5% when the average in terms of contamination mined locality gets fully cleared. To put these numbers in context, 7.2% and 36% of the contaminated localities were lit in 1992 and 2017, respectively.

Isolating Landmines' Role These estimates do not only capture the role of landmine removal, as localities' market access also increases due to the expansion/improvement of transportation networks and increases in their trading partners' population (luminosity). In columns (5)-(6), we isolate the component of market access from landmine removal, using the pre-clearance transportation and population [Figure 9, Panel *B*]. The coefficient in $MA_{o,initial}$ in (5) is highly significant. In column (6), we use an initial MA statistic that excludes adjacent localities to account for localized shocks. Omitting neighboring localities may also account for spatially correlated error-in-variables. Swings in market access from removing landmines along the pre-war transportation network of non-adjacent localities boost luminosity. The comparison of the standardized coefficients on market access and the cleared hazards suggests that the former, working via the unblocking of the network, is roughly three times as important as the local role of clearance.

IV Columns (7)-(10) report IV estimates where the MA measure capturing initial conditions serves as the instrument for contemporaneous MA. In (11)-(12), we use the initial MA, excluding neighboring localities. So the specification in (5) is the corresponding "reduced form" for the IV estimates in (7)-(10), while column (6) denotes the "reduced form" for the IVs in (11)-(12). The first-stage fit is strong, as swings in market access over 1992-2017 reflect, to a significant extent, landmine removal operations along the colonial network.[17] The 2SLS estimate in (8) suggests that a one-standard-deviation increase in contemporaneous MA increases the likelihood a locality is lit by 17.5 pp. As in other market access studies, the 2SLS estimates are (approximately) twice as large as the LS ones.[18] The difference may stem from a reduction in measurement error that the 2SLS deals with.

First, officials of the National Institute of Statistics and foreign specialists consider the 1980 population census of much higher quality than the 1997 one and around the same as the 2017 one (National Institute of Statistics, 2019). Second, the 1973 network consists of the road segments and rail lines that Mozambicans have been using for decades until today. Third, the 1998 and 2003 mappings may be more noisy, as changes sometimes appear erratic (for example, segments initially classified as paved may subsequently be reclassified as unpaved before reappearing in 2011 as paved). Fourth, while one would have expected the country to expand transportation in more developed, with higher potential areas, the few new roads post-1993 were mainly built far from the coast. Besides, improvements in the network do not correlate with proximity to big cities or province capitals (see Jedwab and Storeygard, 2022 for similar patterns in Sub-Saharan Africa).

Alternative Parameterizations In Figure 10, we explore two important issues: the parameterization of the trade elasticity, θ, and the relative costs of the transportation modes. Both Panels report 2SLS estimates instrumenting the contemporaneous MA with Log MA Population (Initial). Blue dots give standardized coefficients with our baseline relative transportation costs, while the specifications in red diamonds use the corresponding values from Jedwab and Storeygard (2022). The main difference between the two is the somewhat higher costs of railroads than paved roads the authors assume and the absence of rivers.[19] The first row gives 2SLS estimates using a trade elasticity value of one; while

[17]The first-stage coefficients are about 0.88 (0.06) (standard error clustered at the district level) and a bit lower, around 0.55 (0.06), with the initial MA measure that drops adjacent localities.

[18]In Appendix Table D3 we replace luminosity with log population finding significant but smaller in magnitude results.

[19]In their framework, highways is the most efficient mode, normalized to 1 (speed: 80 km/h). The relative cost for railroads and paved roads is 1.33 (60km/h) and for unpaved roads is 2 (40km/h); for trails is 6.66 (12km/h), and for

Table 3: **Landmine Clearance, Market Access, and Spatial Development**

	OLS				Reduced Form		2SLS					
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Log MA Population	0.040***	0.033**					0.087***	0.073***			0.088**	
	(0.013)	(0.013)					(0.026)	(0.027)			(0.036)	
	[0.221]	[0.181]					[0.486]	[0.406]			[0.489]	
Log MA Light			0.030***	0.027***					0.092***	0.075***		0.070**
			(0.009)	(0.009)					(0.027)	(0.027)		(0.028)
			[0.233]	[0.212]					[0.722]	[0.588]		[0.545]
Log MA Population (Initial)					0.064**							
					(0.025)							
					[0.332]							
Log MA Population (Initial) Doughnut						0.045**						
						(0.019)						
						[0.228]						
Cleared Hazards		0.004***		0.005***	0.004**	0.004**		0.003**		0.004**	0.003**	0.004**
		(0.002)		(0.002)	(0.002)	(0.002)		(0.002)		(0.002)	(0.002)	(0.002)
		[0.077]		[0.082]	[0.068]	[0.073]		[0.062]		[0.070]	[0.057]	[0.071]
Number of localities	1,043	1,043	1,043	1,043	1,043	1,043	1,043	1,043	1,043	1,043	1,043	1,043
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
Cubic Poly Lat and Lon	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Kleibergen-Paap F-test	.	.	.	.	.	.	267	237	152	150	79.8	75.7
Observations	3,129	3,129	3,129	3,129	3,129	3,129	3,129	3,129	3,129	3,129	3,129	3,129

The table reports Panel fixed effects estimates associating luminosity with market access across a balanced sample of 1,043 localities. The dependent variable is an indicator that takes the value of one if the locality is lit and zero otherwise. Estimation is across the three periods/phases of landmine clearance in Mozambique: 1992-2000, 2001-2008, and 2009-2017. Log MA Population denotes the logarithm of the contemporaneous population-weighted market access. Log MA Light denotes the logarithm of the contemporaneous luminosity-weighted market access. Log MA Population (Initial) is the logarithm of the population-weighted market access using the pre-civil-war transportation network and fixing all localities' populations at their 1980 level. Log MA Population (Initial) Doughnut is similar to the Log MA Population (Initial) but drops neighboring localities in the calculation. Cleared Hazards denote the cumulative number of cleared CHA. Columns (1)-(6) report OLS estimates. Columns (7)-(10) report 2SLS coefficients, instrumenting the contemporaneous MA with Log MA Population (Initial). Columns (11)-(12) report 2SLS coefficients, instrumenting contemporaneous MA with the Log MA Population (Initial) Doughnut. All specifications include locality-fixed effects, province-period fixed effects, and period-specific cubic polynomials in latitude and longitude. Standard errors in parenthesis 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.

this implies an unrealistically high specialization, it is a helpful benchmark. A value of one corresponds, in our setting of proportional-to-distance trade costs, to Harris (1954) "market potential". The market access-development nexus strengthens. Then, we experiment with the low (2.74) and high (5.4) estimates of Simonovska and Waugh (2014). The latter is close to the median value from Head and Mayer (2014) meta-analysis (5.03). The 2SLS coefficients are quite similar to the estimates with the baseline value. Finally, we use θ equal to 8.22.[20] The MA coefficient is significantly positive and stable. The main reason why the relative parameterization of primary roads versus rails appears quantitatively less important is related to the unusual nature of the Mozambique network. Very few railroads, all going East-West, and the country's North-South orientation, render the road network the key transportation element; see, for example, the Maputo-Muabsa example in Figure 8.

Sensitivity Analysis We performed various robustness checks that we report in the Appendix D. First, to account for omitted variables and differential dynamics in development and market access between localities with heterogeneous geographies, we added interactions between the period indicators and locational/geographic characteristics. Second, in a restrictive test, we replaced the province-period

walking to places with no roads/trails is 13.33 (6km/h). As river transportation is not considered, we assign it our baseline relative cost of 15.

[20]Buys, Deichmann, and Wheeler (2010) report travel-based trade elasticities across Sub-Saharan African countries between 2.05 and 3.84. Donaldson (2018) estimates somewhat larger trade elasticities of 7.80 in colonial India. Donaldson and Hornbeck (2016) use a value of 8.22, based, however, on iceberg trade costs rather than travel-time/distance.

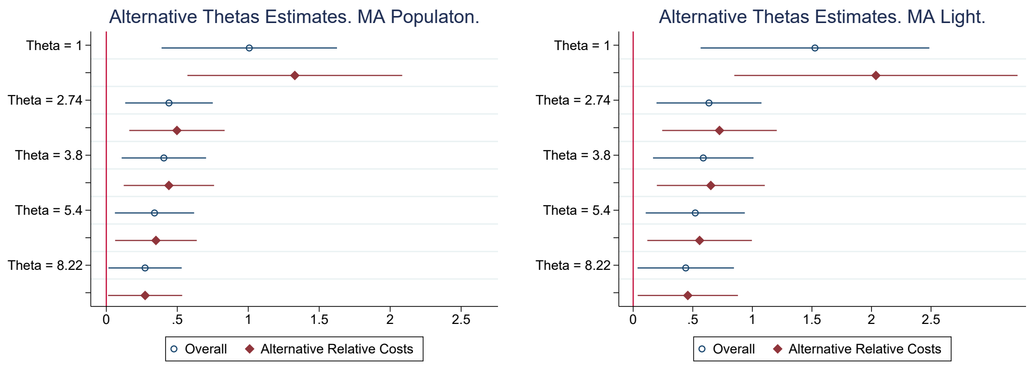


Figure 10: **Alternative Parameterization.** The Figures plot the standardized beta coefficient of the 2SLS estimates associating the lit indicator with the logarithm of the population-weighted MA (Panel A) and the luminosity-weighted MA (Panel B). In all specifications, the instrument is the logarithm of the population-weighted MA initial. The blue hollow circles give 2SLS estimates with the baseline parameterization of relative transportation costs, while the red diamonds give the corresponding 2SLS estimates with the parameterization of Jedwab and Storeygard (2022). All specifications control for the cumulative number of cleared CHA, locality-fixed effects, province-period fixed effects, and a cubic polynomial of latitude and longitude interacted with period constants. Standard errors are clustered at the admin-2 level.

constants with district-period ones to account at a finer level for time-varying unobservables. Third, we dropped interventions with incomplete clearance reports. Fourth, we stopped in 2013 to use nighttime data only from the DMSP satellites. Fifth, given the importance of Maputo, Beira, and Nampula-Nacala for trade, we inflated the population/luminosity of these cities, adding the values of Johannesburg, Harare, and Lilongwe, respectively. Sixth, we used on the LHS the log of luminosity plus a small number. Seventh, we run weighted OLS and 2SLS specifications using localities populations in 1980 as weights to alleviate concerns that the estimates are driven from sparsely populated areas. Eighth, rather than assuming that minefields block the usage of affected modes, we double the passage costs. Ninth, we use the log of Cleared Hazards on the RHS to reduce the role of outliers. Tenth, we repeated estimation at the annual frequency (although error-in-variables may be magnified). Finally, to minimize any concerns that the estimates pick up the return of the refugees and the internally displaced people (IDPs), we rerun the annual specifications, dropping the initial five years. Almost all displaced had returned to their birthplaces or settled elsewhere by the October 1994 elections (see Web Appendix Table W5). The results are robust to these perturbations.

5.4 Isolating the "Not-in-Surveys" Component of Clearance

5.4.1 Approach

In this Section, we exploit the fact that more than half of the clearance operations regarded minefields that the three nationwide surveys, which guided demining in each phase, missed, see Section 3. Out of the 8,436 landmine removals, 5,097 were in contaminated areas that were neither identified as SHA in preceding surveys nor located within a two-kilometer radius.

We first construct MA statistics that reflect the removal of hazards correctly identified in previous nation-wide surveys as contaminated (*in-surveys*), assuming the rest of the contaminants remain in the ground. To isolate the role of clearance from new roads and population swings, we compile the "in-surveys" MA measures using the pre-clearance transportation network and the 1980 localities' population. We then subtract from the overall initial MA the "in-surveys" MA. The difference captures the component of the initial MA driven by the clearance of mines that the national surveys missed.

Borusyak and Hull (2023) point out that even exogenous transportation investments may yield omitted-variables bias, as they may propagate more strongly in central areas. By taking the difference between the two market access measures, we account for the inherent correlation between market access and a locality's centrality. Nevertheless, it is crucial to stress the following. Due to the peculiar structure of Mozambique's transportation network, which does not much connect its main cities, even the baseline market access statistics are weakly at best correlated with geography, location, and early development proxies. Hence, it is not surprising that the "recentered" (residualized) MA is not a significant correlate of these features (see Appendix Figure D4).

5.4.2 Results

One way to isolate the component of market access from the clearance of "in-survey" hazards is to include on the RHS of equation (5) both the MA initial and the corresponding statistic that only reflects the removal of landmines correctly identified as SHA, "in-surveys" MA initial. Columns (1) and (2) of Table 4 report the LS estimates. The initial MA coefficient is stable and highly significant. As the "in-survey" MA captures any potential central coordination, these results suggest that the luminosity-MA association is strong even when we exploit variation only from the clearance of hazardous areas that could not have been part of concerted prioritization.

Columns (3)-(5) associate luminosity with the "recentered" MA that eliminates the variation that comes from "in-survey" interventions. Not only is the coefficient on the recentered MA highly significant, but the coefficient in column (4) is very close to the one estimated with the baseline initial MA (Table 3, column (5)). Besides, $ClearHaz_{o,t}$ also enters with a significantly positive estimate; this also applies when we only use "not-in-surveys" Cleared Hazards in (5). Columns (6)-(8) give 2SLS estimates using the recentered MA as an instrument for the contemporaneous one. Specification (8) also instruments $ClearHaz_{o,t}$ with not-in-surveys cleared hazards.[21] These specifications, our preferred ones, illustrate the dual role of landmine removal on development. First, the direct effect implies that the full clearance of the average mined locality leads to a 3.4 pp increase in the lit likelihood [0.0035∗9.7 CHA]. Second, clearance boosts economic activity by stimulating market access. A one log point increase in MA, from the removal of hazards that the surveyors missed, increases the likelihood of light by about 7.6 *pp*. The comparison of the standardized "beta" coefficients tells of clearance's

[21] Hence, the specifications in (3)-(5) are the corresponding "reduced forms" for the IVs in (6)-(8). The first-stage fit is strong, as a sizable part of the variability of contemporaneous MA stems from the clearance of mines not identified as SHA. The first-stage coefficient is 0.80 (s.e. 0.07) with a within R^2 of 0.30.

much larger role via MA considerations. The "beta" coefficients on the MA are about 0.43, comparable to Donaldson and Hornbeck (2016) on the railroad-driven increases in market access on land values in the US and somewhat lower than the Jedwab and Storeygard (2022) estimates of road building driven changes in market access on African urbanization.

Table 4: **Landmine Clearance, Market Access, and Spatial Development**

Isolating the "Not-In-Survey" Landmine Removals

	Control for Expected MA		Reduced Form			2SLS		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Log MA Population						0.095***	0.076**	0.078**
						(0.032)	(0.034)	(0.034)
						[0.527]	[0.425]	[0.433]
Log MA Population (Initial)	0.080***	0.063**						
	(0.026)	(0.027)						
	[0.415]	[0.327]						
Log MA Population (Initial) In-Survey Only	-0.007	0.003						
	(0.052)	(0.053)						
	[-0.035]	[0.016]						
Recentered Log MA Population (Initial)			0.079***	0.061**	0.067**			
			(0.026)	(0.027)	(0.027)			
			[0.095]	[0.073]	[0.081]			
Cleared Hazards		0.004**		0.004**			0.003**	0.003**
		(0.002)		(0.002)			(0.002)	(0.001)
		[0.068]		[0.071]			[0.061]	[0.056]
Not-In-Survey Cleared Hazards					0.005**			
					(0.002)			
					[0.054]			
Number of localities	1,043	1,043	1,043	1,043	1,043	1,043	1,043	1,043
Locality FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time x Province FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Cubic Poly Lat and Lon	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Kleibergen-Paap F-test	.	.	.	.	.	168	129	59.4
Observations	3,129	3,129	3,129	3,129	3,129	3,129	3,129	3,129

The table reports Panel fixed effects LS (in columns (1)-(5)) and 2SLS estimates (in columns (6)-(8)) across the three main phases of landmine clearance, 1992-2000, 2001-2008, and 2009-2017. The dependent variable is an indicator that takes the value of one if the locality is lit and zero otherwise. Log MA Population is the logarithm of contemporaneous market access. Log MA Population (Initial) is the logarithm of the population-weighted market access with the at-independence transportation network and localities' population in 1980. Recentered Log MA Population (Initial) is the difference between Log MA Population (Initial) and an otherwise similarly constructed MA measure that reflects only the removal of "in-survey" hazards. Cleared Hazards denotes the cumulative number of cleared CHA. Not-In-Survey Cleared Hazards denote the cumulative number of cleared CHA not pinpointed as SHA in preceding surveys. The 2SLS specifications in columns (6), (7), and (8), instrument the Log MA Population with the "Recentered" Log MA Population (Initial). Column (8) also instruments Cleared Hazards with Not-In-Survey Cleared Hazards. All specifications include locality fixed effects, province-period fixed effects, and a cubic polynomial of latitude and longitude interacted with periods' constants. 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.

6 Policy Counterfactuals

The market access framework allows for the comparison of alternative landmine removal scenarios. In this section, we first approximate the aggregate effects of clearance to a counterfactual without any demining. Second, we consider a clearance protocol that prioritizes the core attributes of the transportation network, as this sheds light on the ongoing demining planning efforts in Ukraine and elsewhere.

6.1 Mozambique without Demining

What would have been Mozambique's aggregate economic activity in 2017, had the international community, donor agencies, and the government left the contamination problem unresolved? We address this scenario by comparing reality to three counterfactuals, considering alternative scenarios of the evolution of the transportation network in the absence of clearance. We assume that worker utility is held fixed in these counterfactuals. As the removal of landmines affects population dynamics, we reallocate the Mozambican population of 2017 to reflect the localities' population shares in 1980. Table 5 gives the estimates of three counterfactuals in terms of market access in column (1) and luminosity in columns (2)-(3c). We quantify the probability that a locality is lit in 2017, factoring in the role of landmines on development only via market access (column (2)) and also taking into account the direct effects of clearance (columns (3a-3c)). For all counterfactuals, we use the IV estimates from specifications (6) and (7) in Table 4.[22]

Using the At-Independence Transportation Network In row (1), we calculate actual and counterfactual market access in 2017 using the 1973 transportation network, effectively voiding the role of new roads and transportation improvements. Market access is, on average, 36.5% lower than the realized (median 30%). Lower market access results in a decrease in the likelihood that the average Mozambican locality is lit in 2017 by 5.7%; i.e., $59-60$ fewer lit localities in 2017 ($0.057*1043$). As a share of the lit localities in 2017, 17% would remain dark in this counterfactual (59/349). However, removing landmines impacts development not only through market access but also directly. In columns (3a)-(3c), we take into account both mechanisms. As the luminosity-market access elasticity drops somewhat when we account for the number of cleared hazards, this counterfactual yields a lower likelihood of light from the decline in market access of 5%, i.e., about 52 localities. Factoring in the direct effect (the coefficient on *Cleared Hazards*) yields a decrease in the probability of observing a lit locality of 2.6%. Considering both effects of demining suggests that in the absence of clearance, about $79-80$ lit localities in 2017 would not have been lit; this is about one-fifth of lit localities in 2017.

Using the Contemporaneous Transportation Network For the second simulation in row (2), we calculate the counterfactual and the realized MA using the 2011 transportation network, effectively assuming that Mozambique would have been able to build new roads and rails and improve the colonial transportation network without tackling contamination. The comparison suggests a decline in market

[22]The change in the probability a locality is lit is computed as: $\sum((exp(\widehat{\beta}_{2SLS} * (\log \text{MA counterfactual}_{2017} - \log \text{MA actual}_{2017}) - 1)/1,043)$. The unconditional β_{iv} on MA is 0.095, and the conditional is 0.076; these are similar to the baseline 2SLS estimates in Table 3, columns (7)-(8) [β_{iv} 0.087 and 0.073]. As shown in Appendix Figure D2, the relationships between locality development and log market access and cleared hazards are approximately (log) linear.

access by 58.8%; the larger difference stems from the fact that landmines in this counterfactual block an upgraded and somewhat expanded transportation network. The impact of non-clearance is a decline in the mean likelihood of lit of about $11-12\%$; 120 localities would not have been lit in 2017.

Allowing the Transportation Network to Evolve For the counterfactual in row (3), we assume that the absence of landmine clearance would have prevented the expansion and improvements of the transportation network. This scenario is motivated by the observation that the rehabilitation of the colonial network went in tandem with clearance. Thus effectively, this exercise compares the observed evolution of market access to a scenario where neither clearance nor transportation upgrades occurred. The decrease in market access is 80%, translating into an average decrease in the lit probability of 17.7%; this implies that 185 localities would not have been lit, approximately half of the lit ones in 2017. The two counterfactual estimates in row (3) yield similar aggregate losses, as the unconditional MA-driven decline in column (2) is quantitatively similar to the sum of the direct and indirect losses estimated in 3a and 3b, respectively.

Cost-Benefit Approximation We conclude by approximating the aggregate benefits and costs of landmine clearance. Chiovelli et al. (2023) estimate a GDP-lights elasticity around 0.30 (mean) and 0.21 (median). Combining these estimates, with the counterfactual losses estimated in the third counterfactual, and Mozambique's GDP in 2017 of $17.18 billion (in 2015 dollars), we estimate the demining benefits to be between $630 and $900 million.[23] When we use the most conservative counterfactual in row (1), we get a dividend of between 275 and 400 million $[17.17 * 0.076 * 0.21(0.30)]$. Mozambique's growth has been strong, adding 14 billion in GDP since the civil war ended, starting from $3.115 in 1993.[24] So the benefits from demining are about 5% of this sizable increase; 4.5%-6.4% for counterfactual (3) and 2%-3% based on counterfactual (1). Turning now to the costs, the data is scant, sporadic, and of low quality. We reviewed all reports of the *Landmine Monitor*, which collects funding information from major donors and local authorities. The numbers of the Mozambican Ministry of Foreign Affairs and Cooperation (in the 1990s) and the National Institute of Demining (after 2001) are (inflated) estimates. Besides, the information covers not only clearance activities (removal of hazards, surveys, materials, and training), but also victim assistance, mine awareness, and even military aid to the armed forces. Our calculations, after cleaning the data, suggest that total aid to Mozambique for mine action accounts for about $\$365-400$ million (constant 2015 USD). If we assume that 20% went to other-than clearance-related activities, the totals are about $290-320$ million.

[23]We assume that when a locality gets lit, it attains a luminosity value equal to the average across localities in 2017. So, the 17.7% increase in the probability of light calculated in the counterfactual translates into an equivalent percentage increase in luminosity across the country

[24]In per capita terms, GDP grew by about 7% per year, rising from $219.3 in 1993 to $601.3 in 2017. GDP data come from the World Bank's World Development Indicators Database.

Policy While there is ambiguity about the actual costs, their comparison with the benefits reveals a noteworthy result, which, to us, appears not very sensitive to the underlying assumptions. Comparing the costs to the direct economic benefits of landmine removal shows that the former are larger than the latter, which might explain the focus of specialized agencies, donors, and operators on the humanitarian aspects, deaths, injuries, psychological trauma, and exclusion. But when we consider the market access gains from removing landmines, the cost-benefit analysis yields an entirely different picture, even with the most conservative counterfactual. Now, the benefits considerably outweigh the costs.

Table 5: **Counterfactuals I. No Land Mine Clearance**

		Decline in the Probability of a Lit Locality due to:			
	Percent Decline in MA No demining (1)	Only MA Unconditional (2)	MA. Control Removal CHAs (3a)	Nmbr of Removed CHas (3b)	Total Effect (3c)
Colonial Network	-0.365	-0.061 (0.019)	-0.050 (0.021)	-0.026 (0.012)	-0.076 (0.020)
Contemporary Network	-0.588	-0.112 (0.034)	-0.092 (0.038)	-0.026 (0.012)	-0.118 (0.036)
Colonial vs. Contemporary Network	-0.800	-0.183 (0.054)	-0.151 (0.060)	-0.026 (0.012)	-0.177 (0.057)

Each row reports the counterfactual impact on market access and luminosity assuming non-clearance of contamination in 2017. In row (1), we calculate actual and counterfactual market access using the 1973 transportation network. Row (2) compares actual and counterfactual market access using the most recent transportation network (as of 2011). Row (3) assumes that the absence of landmine clearance would have prevented the expansion and improvements of the 1973 transportation network. Column (1) reports the percent drop in market access. Column (2) tabulates the average decline in the probability of a locality being lit only through market access. Columns (3a), (3b), and (3c) disaggregate the total effect of non-clearance into market access (3a), direct effect (3b), and the total effect (3c). For all counterfactuals, we reallocate the total Mozambican population in 2017 to reflect localities' population shares in 1980.

6.2 Coordination and Prioritization

We now ask how MA would have evolved had demining operators followed a coordinated strategy (under perhaps the UN or the government) that would prioritize clearance of the transportation network. Approximating the benefits of such a prioritization is relevant nowadays, as the UN and governments worldwide are designing clearance plans for many landmine-impacted countries.

We consider the following protocol based on the history of landmine clearance and Mozambique's economic geography. In the first period (1992/3−2000/1), operators prioritize the three "development" corridors, where primary roads and railroads connect Maputo, Beira, and Nampula to the interior. During the second period (2002−2008), clearance continues across the three corridors and then targets the highway ($N1$) connecting the South to the Central coastal areas and the North. Operators clear all remaining hazards in the third period (2009 − 2017). Consistent with the at-the-time constraints, the number of cleared localities is the same in the counterfactual and in reality every period, that is, 55, 453, and 358 localities are cleared in the first, second, and third phases, respectively.

Figure 11 illustrates the benefits of prioritization by plotting the increase in market access between

1992 and 2009 when half of the mined localities were cleared. In the MA calculations, we use the at-independence transportation network and fix the population to the 1980 level. The realized MA changes are depicted in the beige bars and the counterfactual changes are in the blue bars. The difference reveals the losses of non-prioritizing "central" areas. Market access for the average locality would have increased by 21 log points, had operators coordinated the clearance of minefields close to the main transportation segments. To better understand how these losses are distributed, Figure 11 further distinguishes between four groups. Let us start with the 310 localities that were neither cleared in reality [$Actual = 0$] nor in the counterfactual [$Simulated = 0$]. In reality, log market access increased by 0.20; while no clearance occurred, market access rose due to clearance in other areas (mainly proximate and well-connected). Had clearance targeted the central nodes of the transportation system, log market access would have increased significantly more by 0.31. For the 174 fully cleared localities in reality and the counterfactual, the average increase in actual log market access is 0.57. The counterfactual increase is 0.75, since the simulated market access gets a boost from the clearance of other central localities. The mean increase in actual log-market access in the 282 localities, which were cleared but not prioritized in our counterfactual, is 0.28, while the change in the counterfactual log MA is lower 0.15. The "mirror" image of this difference is the 277 localities that were not cleared in reality but targeted in the counterfactual. The average increase of realized log market access is 0.70. Market access increased despite the absence of clearance, as these localities benefited from landmine removal elsewhere. However, the counterfactual increase in log MA is significantly larger, 1.37.

Policy This simple counterfactual illustrates the sizable losses from the lack of prioritization. It further shows that operators, the UN, and governments should take into account the fact that clearance of areas close to roads and railroads generates strong spillovers. While we need evidence from more countries, the underlying conceptual market access framework allows for some (cautious) extrapolation. Yet, a word of caution is in order. Our counterfactual analysis does not consider humanitarian aspects, at-the-time information, and coordination 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 concerns, as the scant international data suggest that casualties, amputations, and injuries are equally likely in remote and more connected places (Landmine Monitor, 2017; Frost, *et al.*, 2017). Nonetheless, the simulations offer an informative, hands-off approach to crafting an informed demining strategy in the presence of economic externalities, which the Mozambican case suggests are sizable, though not much considered by the landmine clearance community. The uncovered sizable economic costs of landmines blocking roads also offer some backing to the international community's efforts to expand the International Mine Ban Treaty on Anti-Personnel Landmines of 1999 to anti-vehicle (anti-tank) landmines.

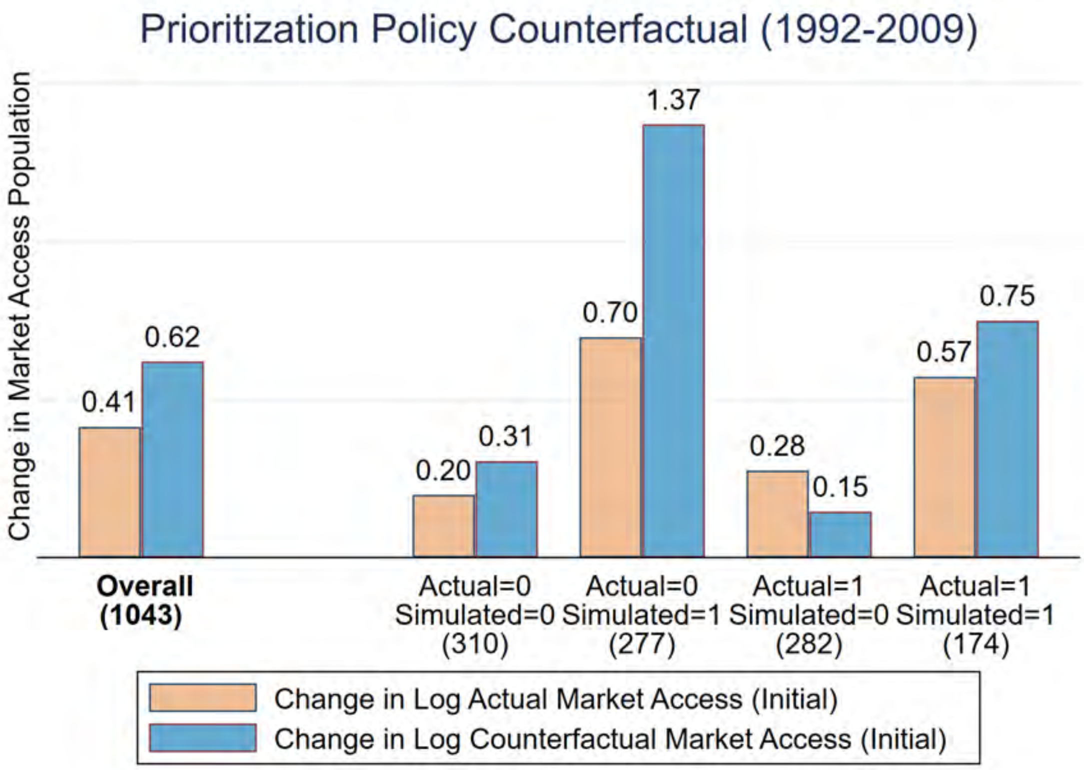


Figure 11: **Prioritization Counterfactual** The figure plots the mean in 2009 of the realized (beige) and counterfactual (blue) change in (log) market access, fixing population and transportation to the pre-clearance levels across 5 groups: (*i*) all 1043 localities. (*ii*) 310 localities neither cleared by 2009 nor in the counterfactual simulation. (*iii*) 277 contaminated localities cleared in the simulation but not in reality. (*iv*) 282 cleared in reality localities but not in the counterfactual; (*v*) 174 localities cleared both in reality and the counterfactual.

7 Discussion

Two to three decades ago, there was hope that the International Campaign and the signing of the Anti-Personnel Landmine Ban Convention would make landmines a legacy of the past. But landmines still affect the lives of millions around the world. Cheap to obtain and easy to manufacture, their appeal to warring parties, militias, governments, and rebels has not faded. Alarmingly, news, policy briefs, and reports tell of the widespread use of all sorts of contaminants, including cluster munitions, in Ukraine, Syria, and Myanmar. The focus of the media, the UN, international organizations, and policy institutions is on the lives lost, the injured, and the handicapped, who face lasting traumas and social exclusion even when they survive. Likewise, the few studies take a statistical value of life approach, zooming into the lives and injuries saved by clearance.

Our paper is a first step towards a better understanding of the economic impact of landmines. Focusing on Mozambique, the only heavily contaminated country to be declared landmine-free, we uncover significant, albeit modest, local benefits from clearance. However, we establish that clearing roads and railroads from contaminants confers large aggregate economic dividends. We also estimate considerable losses in Mozambique from the fragmented and non-coordinated process of demining. Given recent evidence on the benefits of transportation infrastructure on regional development, this finding is expected. Yet, it stands in contrast to the *modus operandi* of demining operators characterized by limited coordination, often prioritizing remote areas.

Clearly, we need more research quantifying local and economy-wide effects of landmine removal and also uncovering mechanisms at work (see, for example, the subsequent studies of Riaño and Valencia Caicedo, 2019, on Laos and Mounu, Purroy, and Vargas, 2023, in Colombia). Using individual-level data, it will be illuminating to examine how landmines and improvised explosive devices shape poverty, land use, agricultural productivity, commerce, and health. Moreover, as landmines entail sizable environmental costs, future work could assess their role in livestock and wildlife conservation. Landmines are one of the many deleterious facets of (civil) warfare, sadly on the rise; not limited to child soldiering, refugee flows, forced labor, extortion, violence against women, and mutilations. Future research should dig deeper into these aspects, understand their heritage, examine potential (spatial) interdependencies, and interactions.

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