Toxic Roads: Unearthing Waste Dumping*

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Abstract

Illegal disposal of waste is an issue in both developing and developed countries. However, the lack of reliable data represents a significant obstacle to the study of the phenomenon. This paper adopts an innovative strategy to identify where waste might be illicitly dumped. The strategy relies on a crucial premise: roads and road constructions provide an ideal setting in which waste dumping may take place. Guided by the medical literature, we identify three main health outcomes that are directly associated to toxic waste exposure. We then investigate these specific health measures for the case of individuals living along recently built roads in Ethiopia. We find that an additional road within 5 kilometres is associated with an increase in infant mortality by 3 percentage points along the corridors that connect Ethiopia to the coastline. We also provide evidence of lower haemoglobin level and higher incidence of severe anaemia in young children.

JEL: I15, Q51, Q53, O10. **Keywords**: Waste, Health, Infant Mortality, Ethiopia.

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I. Introduction

According to a recent study by the WHO (2016), toxic pollution (indoor pollution and exposure to toxic chemicals) is the major cause of death and diseases in LDCs, accounting for more than three times the number of death and diseases caused by malaria, HIV and TBC together. Illegal disposal of waste, and in particular hazardous waste,[1] is an important component of toxic pollution and has become an issue of concern in both developing and developed countries.[2] Recycling waste, especially hazardous waste, in compliance with existing regulations entails very high costs, which give a strong incentive to companies and individuals to dispose of waste material in an illegal way (Baird, 2014). The profitability of illegal waste management stems from cutting the cost of safe disposal by dumping or burying waste or unsafely recycling it.[3] As any other illicit activity, illegal waste disposal is likely to happen in the presence of weak environmental regulations, poor law enforcement, and where local populations are not informed on the consequences of the exposure to toxic substances. This is indeed the case of many developing countries, where it is much cheaper to dispose of waste[4], and which have become the destinations of loads of hazardous waste produced in developed countries (Rucevska et al., 2015). The health and economic consequences of illegal waste dumping on the local population are potentially devastating. Locating and assessing the distribution of waste, and in particular toxic waste, is therefore a pressing matter, as the incidence of many of the negative health outcomes declines after clean-ups of hazardous waste sites. For

[1] Hazardous waste can take many different forms, such as industrial waste, waste from nuclear energy production, obsolete pesticides or any electronic and electrical waste

[2] See for instance the report by the Global Alliance on Health and Pollution (2013).

[3] Illegal profits may also arise by recovering certain components from waste, such as gold, copper and nickel in the case of electronic waste, an activity that usually ends up with the subsequent dumping of the majority of the remaining waste.

[4] According to Kummer (2005) for instance, the average disposal cost of one ton of hazardous waste in Africa was between USD 2.50 and USD 50 compare to costs in industrialized countries ranging from USD 100 and USD 2,000. Similarly a UN spokesman reported by the Financial Times (2009) argued that disposing of waste in Europe is estimated to cost about $1,000 per ton, while the cost plummets to $2.50 a ton if disposing of the hazardous waste illicitly in Africa.

instance, in relation to exposure to hazardous waste, Currie et al. (2011) shows that superfund clean-ups in New York decreased the incidence of congenital anomalies by 20-25%.[5] Toxic waste sites are recognized as a major global health threat and it is therefore of utmost importance to locate and study the distribution of illegal waste dumping. Nevertheless the available information on illegal dumping of waste is fragmented through various sources and the lack of reliable data represents a significant obstacle to the study of the phenomenon.

This paper introduces an innovative strategy to identify where waste might be dumped. By focusing on specific health outcomes, we measure the extent of health hazard associated with waste exposure, and we identify where waste may have been illegally discarded. This is hardly an easy task, as many confounding factors might explain certain patterns in health outcomes. We tackle this issue by looking at health measures that are directly linked to the potential effects of waste exposure, as outlined by the medical literature.[6]

Our strategy relies on two crucial premises. The first premise is that roads and road construction sites provide an ideal setting for the illegal dumping of waste. The evidence suggests that illegal dumping of waste may happen in the *proximity* of roads. Indeed, according to Biotto et al. (2009), Jorda-Borrell et al. (2014), Seror and Portnov (2018), illegal dumping sites tend to be located close to the road network, particularly to rural roads. Illegal waste dumping may also happen *under* roads, during construction works, *e.g.* in the embankments for building the roads or close to the building construction sites. The use of road construction sites for illegal waste disposal is indeed supported by evidence from both developed and developing countries. This is the case of Italy and what it is called the "*Triangle of Death*", a vast area near Naples which has been the dump of toxic

[5] Many studies have analysed the effect of the Superfund sites on a variety of outcomes. See for example Kiel and Williams (2007) on the effect of Superfund sites on local property values.
[6] In this paper we consider any type of waste, *e.g.* municipal, household, industrial or e-waste.

and industrial waste over the last few years. The second premise of our analysis is that exposure to waste has a number of negative effects on the health status of exposed individuals and in particular of children. The medical literature links specific health conditions, *e.g*. lower fertility, birth defects, anaemia, lower haemoglobin, to the potential effects of waste exposure (Azmi et al. 2009, Khan et al. 2013, Stillerman et al. 2008, WHO 2010).

If waste is dumped close or under road constructions, then we would expect individuals that experience higher road constructions to display worse health outcomes. This should happen along the routes where waste, either household or industrial, is more likely to transit and be disposed of. If we can rule out that the correlation between road construction and health status is driven by confounding factors, such as air pollution due to car exhaust, we could then conclude that it is the presence of waste that negatively influences the health outcomes. In order to identify if and where hazardous waste is dumped, we study the effect of an increase in the number of roads on specific health outcomes of people living within 5 kilometres from road constructions, in particular: infant mortality, haemoglobin level and severe anaemia of children under five years old.

This paper estimates the reduced-form effects of road infrastructures, therefore several confounding factors and endogeneity problems might affect the identification of these effects. First, if new roads were built where health outcomes are worse or where the socio-economic status of households is lower, then our estimation would suffer from reverse causality and omitted variable bias. Second, the worsening of health status might capture the effects of overpopulation due to immigration, or pollution and other local diseases, such as malaria, instead of exposure to waste. In order to deal with these issues, we perform a series of specifications and robustness checks. First, we rule out the existence of pre-trends in health outcomes in areas characterised by higher road constructions; second, we control for the role of urbanization; third, we provide evidence on the lack of relationship between road constructions and other alternative health conditions linked to endemic diseases, such as malaria, or respiratory diseases associated to car exhaust pollution; fourth, we show that the location of new roads is uncorrelated with health outcomes and the economic status of the population nearby. As additional placebo tests, we analyse road construction happening further away, between 10 and 30 kilometres and provide evidence that roads constructed further from the household location do not have any impact on health outcomes. Our results are robust to these and other alternative specifications and are consistent with waste being dumped along roads or during road constructions.

The focus of our study is Ethiopia. According to a report by the UN Environment Program Ethiopia is one of the countries with the highest priorities for increasing technical, policy and institutional capacity and understanding for managing waste.[7] Besides local domestic and industrial waste, a report by the United Nation Office on Drugs and Crime (UNODC, 2009) identifies Eastern African countries to be particularly under threat of waste dumping and toxic waste trafficking originating from developed countries (UNEP 2015, Legambiente 2011).[8]

A major large-scale road development program was implemented in Ethiopia between 1997 and 2010. The Road Sector Development Program (RSDP), which involved various donors, aimed to improve road access to promote agricultural and economic development. Interventions and expansion works touched all of the country's major connectors and a large number of new roads were constructed. We consider road constructions that took place between 2000 and 2005, when the RSDP was at its peak and the country was holding a large number of open building sites. We assemble a unique dataset. First, we use two rounds of the Demographic and Health Survey (DHS,

[7] UNEP, Ethiopia National Report, 2012.

[8] According to a report by Greenpeace (2010), Djibouti's role as a "*logistics hub for goods delivery to Somalia and Ethiopia also makes it a prime entry point for waste delivery to Ethiopia*".

2005, 2011), which contain several indicators of health for adults and children. In particular, we focus on infant mortality and on the level of haemoglobin and severe anaemia of children under five. We then use georeferenced data on the Ethiopian roads network for the years 2000 and 2005. Road maps are available for two points in time, hence allowing us to identify the change between 2000 and 2005.

The results are striking. We analyse all of the corridors connecting the capital Addis-Ababa to the neighbouring countries (Djibouti, Somalia, Eritrea, Sudan and Kenya) and provide evidence that results hold along two main trajectories, which connect Ethiopia to the coastline, *i.e.* towards Djibouti and Somalia. We provide evidence on the worsening of health outcomes for infant and children living near recently built roads along these two main routes. An additional road within 5 kilometres increases the probability that an average mother experiences an infant death by 3 percentage points. The size of this effect is large and corresponds to 35% of the sample mean. In addition, children under-five living near a recently built road show a lower level of haemoglobin and are more likely to suffer from severe anaemia.

Our findings are of high policy relevance, suggesting that international organizations dealing with waste dumping should intensify their monitoring effort during and after construction works related to infrastructure development, especially when these programs take place along the routes most suitable for waste movements. In particular, the results of this study show that governments investing in road constructions are not getting what they could from investments in roads in terms of improvements in outcomes. This is crucial, as the road network is currently massively expanding in Sub-Saharan Africa and infrastructural investments are being scaled up.

The paper contributes to the strand of literature which studies at the effects of toxic waste on health outcomes. A paper by Currie et al. (2011) analyses the impact of superfund clean-ups on infant health. Superfund was intended to provide a mechanism for conducting clean-ups at the most dangerous hazardous waste sites in New York. They find that superfund clean-ups decrease the incidence of congenital anomalies by 20-25%. He and Perloff (2016) provide evidence of a non-monotonic relationship between water pollution and infant deaths, as even moderate levels of pollution are found to be the most dangerous. Almond et al. (2009) analyse the impact of Chernobyl fallout on school outcomes of children in Sweden. The authors find that students born in regions of Sweden with higher fallout performed worse in secondary school. They find no effect on health outcomes, which might be explained by the low level of radiation exposure. [9] Unlike previous studies, we could not use available data to measure directly the presence of waste, as dumping of waste is illegal and, by definition, difficult to detect. Our main contribution is to adopt an innovative strategy that allows us to indirectly measure this illegal activity by looking at a specific form of infrastructure development, namely road construction. In this sense our paper is more generally related to the literature on crime and corruption, which proposes indirect methods to measure illegal activity (see among others: Olken 2006; Olken 2007; Fisman and Wang 2015; Fisman et al. 2015).[10] This paper also contributes to the strand of the literature analysing the effect of transport infrastructures on development. The large empirical evidence on the topic suggests the positive effect of transport infrastructures, including road infrastructures, on trade, firms' location decisions, economic activity, structural transformation, education, health and rural development (Redding and Turner, 2016; Baum-Snow, 2007; Baum-Snow et al. 2016; Donaldson and Hornbeck, 2016; Donaldson, 2018; Duranton and Turner, 2011, Gonzales-Navarro and

[9] Black et al. (2013) exploit the massive presence of nuclear weapon testing in Norway during the 50s and early 60s and provide evidence that exposure to radiation in the early stages of the pregnancy leads to lower IQ, lower education attainment and lower earnings. The authors also show that some of these effects persist over time across generations.
[10] See also Olken and Pande (2012) for a review of these measurement methods in the context of corruption.

Quintana-Domeque, 2016).[11] This paper presents empirical evidence of potential negative and unintended consequences of roads and road constructions, *i.e.* the illegal dumping of waste.

In the rest of the paper, Section II provides background information on waste, presents the Ethiopian context and discusses the health consequences of exposure to waste. In Section III, we describe the data, while Section IV outlines the methodology, presents the main results and shows the validity of the identification strategy. Section V presents further evidence and a series of robustness checks. Section VI concludes.

II. Institutional Background

II.A. Waste: Definition and Trends

Waste can take many different forms, such as municipal waste, industrial waste, electronic and electrical waste (e-waste), or persistent organic pollutants.[12] In general, industrial waste refers to industrial by-products, such as incinerator ash, coolants and insulating fluids. Persistent Organic Pollutants, *i.e.* pesticides, represent another instance of highly toxic material, which needs a high level of sophistication for the correct disposal.[13] In many low and middle-income countries, waste, either municipal or industrial, is often dumped in unregulated landfills or burned in the open, thus leading to serious health, safety, and environmental issues.[14]

Until recently, there were no international directives regulating trade in toxic waste. The 1989 Basel Convention on the Control of Transboundary Movements of Hazardous Waste and their

[11] See also Berg et al. (2017) for an extensive review of the literature.
[12] E-waste has recently raised increasing concern, as a computer can contain up to two kilograms of lead, as well as other heavy metals (United Nations Office on Drugs and Crime, 2009).
[13] In 2001 the Stockholm convention banned the worst toxic chemicals.
[14] http://www.worldbank.org/en/topic/urbandevelopment/brief/solid-waste-management.

disposal, established a system of tracking and regulating the movement of hazardous waste. The Basel Convention, which failed to stop transboundary movements of waste to African countries, was followed by the Bamako Convention, which banned waste trade between the European Union and many developing countries. Today, almost all movements of hazardous waste into Africa would be regarded as trafficking. Notwithstanding the ban, a recent report by the UN office on Drugs and Crime (2009) highlights how African countries "*run the risk of becoming the rubbish dumps of the planet*".[15]

II.B. The Ethiopian Context

Situated in the Horn of Africa, Ethiopia is the second most populous country in Sub-Saharan Africa, with an estimated population of 83 million people as of 2010. The population is highly concentrated in the highlands, while the lowlands are very sparsely populated due to the endemic presence of malaria and other vector borne diseases. According to the World Development Indicators, mortality rate for under-5 was 75.7 (per 1,000 live births) in 2010 and it has been steadily declining over the past decade.

Ethiopia represents an interesting case for two reasons. As in many other developing countries, waste management is inadequate: in 2017, 113 people died due to a trash dump landslide at the outskirts of Addis Ababa.[16] Besides, solid waste is often dumped along roadsides and into open areas (Tadesse et al., 2007). Ethiopia has also been indicated as a potential destination of the toxic waste traffic originating from developed countries (UNEP 2015, Legambiente 2011).

[15] https://www.economist.com/special-report/2009/02/26/down-in-the-dumps
[16] https://edition.cnn.com/2017/03/15/africa/ethiopia-trash-landslide-death-toll/index.html

In 1997 the country initiated the road sector development program (RSDP), a major large-scale public investment program aimed at improving and enlarging the road network.[17] According to the Ethiopian Road Authority (ERA, 2011) between 2000 and 2010 the road network expanded from 26,550 km to 53,997 km and the fraction of roads in good condition increased from 22% to 57%. In the analysis we focus on the period 2000-2011, which was exactly when the country held many open building sites.

II.C. Exposure to toxic waste

According to the medical literature, two main health outcomes emerge from the exposure to toxic waste. First, exposure to toxic waste has been proven to provoke congenital anomalies. In particular, Stillerman et al. (2008) provide evidence of miscarriages and birth defects linked to exposure to organic solvents and pesticides. Since birth defects represent a major cause of infant death (Petrini et al. 2002), we focus on infant mortality as an indicator of potential exposure to toxic waste. Second, exposure to hazardous substances leads to low haemoglobin and severe anaemia. Anaemia is a condition in which the red blood cell count or haemoglobin level is lower than normal. The association between haemoglobin level and cancer has been historically established in the medical literature, as it is estimated that 30% to 90% of individuals with cancer suffer from anaemia (Taylor and Pollack, 1941; Knight et al., 2004). Similarly, a large medical literature has assessed the health impact of being in the vicinity of nuclear waste reprocessing plants (Guizard et al. 2001). In particular, the likelihood of childhood leukaemia increases in areas within 10 kilometres of the plant. Pesticide poisoning has also been found to lead to low

[17] The program was sponsored by the World Bank and involved several donors including the World Bank, the European Union, the Asian Development Bank, Governments of Japan, Germany, the U.K., Italy and Ireland, with an estimated cost of 7.08 USD billions.

haemoglobin levels (Azmi et al. 2009; Khan et al. 2013). Motivated by this medical evidence we use haemoglobin level and the incidence of severe anaemia as additional indicators of potential exposure to toxic substances.

III. Data

We assemble a unique dataset on the basis of two main sources of data. First, we use two waves of the data from the Demographic and Health Survey (DHS), which was conducted in Ethiopia in 2005 and in 2011. The DHS survey is administrated in several countries and covers many aspects of health at the household and individual level.[18] The data contain information on mothers and children within each household in the sample. Many aspects of fertility are covered and detailed information about children under the age of five is available. Haemoglobin is measured and an anaemia assessment is conducted at the time of interview through the HemoCue machine. Most of the population in Ethiopia lives at more than 1200 meters above sea level. This is particularly relevant, as the concentration of haemoglobin in the blood increases with altitude.[19] Therefore, haemoglobin levels are adjusted to take into account altitude and an indicator of severe anaemia is constructed accordingly.

Second, we collected road data for 2000 and 2005 from the Geographic Information Support Team (GIST) Repository at the University of Georgia, a USAID-funded global archive of spatial

[18] The sample selection for the DHS survey takes place in two steps. First, about 500 clusters are selected from a list of enumeration areas from the latest available census (1994, 2007). Second, households are randomly drawn from each cluster. The 2011 DHS survey did not survey 28 of 65 selected clusters in the Somali region due to drought or security issues. Similarly, the 2005 DHS survey only samples 3 of 7 zones in the Somali region. In the light of the exclusion of these riskier areas, we would expect our results to be a lower bound of the effect of roads and waste dumping on health.

[19] See Windsor et al. (2007) for a review of the medical literature.

data. In each map roads are divided into different segments of an average length of about 20 km and the location of each of these segments is provided. The collection of the segments' information gives us the entire road network in Ethiopia at each point in time. We use maps on the road network and the DHS communities. Our premise is that the expansion of the road network can increase exposure to waste for two reasons; on the one hand, waste can be dumped along roadsides or buried under the newly built roads during construction. On the other hand, some remote areas might become more accessible also for loads of waste. In both cases, an additional road segment could lead to a higher exposure to waste for people living nearby. We capture this potential effect of the expansion of the road network, by considering the incremental change in the number of roads segments within a 5 kilometres radius from the centre of the DHS cluster. The change in the number of roads segments between 10 kilometres and 30 kilometres is used as a placebo, as we would expect no effects on the health outcomes of individuals living further away from road constructions.[20]

It is worth noting that clusters in the DHS are randomly displaced to protect household anonymity. The centre of the cluster in urban areas is displaced up to a distance of 2 kilometres, while in rural areas the centre of the cluster might be displaced up to 5 kilometres away from its actual position. The presence of displacement may introduce a measurement error in our estimation. However, given the random pattern of the DHS cluster displacement, it is reasonable to assume that the measurement error caused by the displacement is randomly distributed across clusters and routes.

Since we cannot observe the exact year when a road segment was built, we mainly focus on the increase in the road network happened between 2000 and 2005 and on health outcomes thereafter.

[20] For simplicity, in the paper we will use the expression "number of roads" instead of "number of roads segments".

In this way we avoid studying the effect of roads not yet constructed and we isolate the effect of roads whose construction was completed by the time the health survey took place.[21]

Figure I displays the expansion of the road network occurring between 2000 and 2005, during the implementation period of the road sector development program, while Figure II shows the expansion over the period considered by geographical area.[22] The highlighted routes in Figure I are the main trajectories that connect the capital Addis-Ababa to the neighbouring countries. A visual inspection of Figure I suggests that most of the treated clusters experience the construction of side roads, where waste dumping is more likely to take place. In fact according to the findings in Jorda-Borrell et al. (2014) and Seror and Portnov (2018), illegal waste dumping is mostly observed in the proximity (0-500m) of rural roads and tracks. These spots are characterised by ease of access but also a low probability to get noticed.

[Figure I here]

[Figure II here]

Throughout the empirical analysis we first consider road constructions occurred in Ethiopia as a whole and then we restrict the analysis considering road constructions occurred along the main routes that connect the capital Addis-Ababa to the neighbouring countries. In particular, we repeat the analysis focusing only on clusters that are located within 10 kilometres from primary roads connecting the capital to Somalia, Djibouti, Eritrea and Kenya respectively. Overall the corridors represents about 34 percent of the sample, going from the 6 percent in the case of Kenya to the 11 percent in the case of Somalia (see Table A.1.). From a first inspection of the data, and as reported

[21] Due to data limitations, it is not possible to include roads' reconstructions or upgrading in the analysis.
[22] Third-level administrative divisions in Ethiopia.

in Table A.2., it emerges that the clusters located along the corridors of Somalia and Djibouti, were characterised by a level of roads in the initial period, 2000, significantly higher than the rest of Ethiopia and, than any other corridor. The Somalia and Djibouti routes also appear to be the ones that on average experienced more road construction between 2000 and 2005.

Figure III shows our measure of interest for a random DHS cluster, where the dot is the centre of the cluster. For each cluster, we are interested in the difference between the number of roads within the smallest circle (5 kilometres radius) in 2005 (lighter lines) and 2000 (darker lines).

[Figure III here]

The change in the number of roads in the outer circle (roads that are between 10 kilometres and 30 kilometres away from the centre of the cluster) is used as a placebo – our prior is that the health of individuals living further away should not be affected.

The dataset is enriched with a number of control variables. Control variables at the individual and the household level come from the DHS survey, while other variables at cluster level, such as the distance from a water source, come from the GIST repository by the USAID/OFDA. The information on administrative boundaries comes from GADM (Global Administrative Areas)[23] by the University of California, Berkeley, and it is combined with the GPS of the DHS clusters to calculate the distance from the border for each cluster. In some specifications we include clusters' light intensity at night-time which indicates the average luminosity across pixels that fall within the cluster. This variable comes from the Operational Linescanner System on the Defense

[23] GADM database of Global Administrative Areas. http://gadm.org/

Meteorological Satellite Program and allows us to control for clusters' economic conditions.[24] Descriptive statistics and relative sources are reported in Table A.1 in the Online Appendix.

IV. Methodology

IV.A. Infant Mortality

Roadsides and road constructions provide an ideal setting in which waste dumping may take place, as presented in Section II. As discussed in Section II.C, waste has a number of negative effects on the health status of exposed individuals. Therefore if hazardous waste were dumped along roads or during road construction works, this would especially affect the health status of individuals living close to new roads. In order to identify where waste is dumped, we study the effect of an increase in the number of roads on specific health outcomes of people living nearby, in particular infant mortality, haemoglobin level and severe anaemia of children under five years old. Crucially, we expect the effect to be significant in the areas close to the major routes from the main ports of access to the sea, mainly Somalia, Djibouti and Eritrea, and in areas with more road construction in place which implies more potential dumping spots. The corridors connecting Addis Ababa to Somalia and Djibouti, satisfy both conditions, as it is evident from Table A.2. in the Online Appendix.

DHS provides detailed information at mother-level about fertility. Female respondents are asked about the year of birth and the year of death of any child they gave birth to over their entire lifetime.

[24] Several papers have used light intensity to measure local economic development and income level. For example, see Chen and Nordhaus (2011), Henderson et al. (2011) and Michalopoulos and Papaioannu (2013, 2014) among others.

Using this information on the whole birth history of each mother (up to 20 births), we construct a panel dataset of mothers where the time dimension is the year of child birth given by each mother. Using the 2011 DHS wave and considering mothers' birth history between 2000 and 2010, we compare birth outcomes before and after the construction of new roads for the *same* mother. In particular, we estimate a linear probability model as it follows:

$$Y_{imct} = \beta_1 roads_{ct} + \boldsymbol{Z}'_{\boldsymbol{imt}}\boldsymbol{\theta} + \boldsymbol{I}'_{\boldsymbol{it}}\boldsymbol{\pi} + (\delta X_{ct} +)\eta_t + \mu_m + \varepsilon_{imct} \quad (1)$$

Where Y_{imct} is a dummy equal to 1 if child *i* born in year *t* from mother *m*, in cluster *c*, died before reaching the age of one, and 0 otherwise. Our variable of interest, $roads_{ct}$, is the number of roads within 5 kilometres from the centre of the cluster. This variable is observed in two points in time, in 2000 and in 2005, respectively. It is equal to the number of roads in 2000 for all births occurred between 2000 and 2004, and it is equal to the number of roads in 2005 for the births occurred between 2005 and 2010. The coefficient of interest, β_1, captures the change in probability of an infant death if a mother gives birth between 0 to 5 years after the construction of an additional road between 2000 and 2005. We control for mother fixed effects, μ_m, and birth cohort fixed effects, η_t, which account for unobservables at the mother level and for shocks affecting birth cohorts, respectively. Other determinants of infant mortality at the child level ($\boldsymbol{I}_{\mathbf{it}}$) are included such as gender, the birth order and its square and the twin status of the child. The vector $\boldsymbol{Z}_{\boldsymbol{imt}}$ includes controls at the mother level such as mother age at birth and its square. As a further control, in some specifications we also include night-light intensity (X_{ct}) to account for the level of economic development of each cluster.

[Table 1 here]

Equation (1) can be viewed as a generalization of a difference-in-differences type of estimation with more than one group, where the treatment corresponds to being born within 5 years since the observed road construction. The actual number of new roads represents the intensity of the treatment. Results are reported in Table I. In column 1 we estimate the equation considering all the clusters in the DHS, in column 2 we restrict the analysis to clusters located within 10 kilometres from primary roads connecting the capital to Somalia and/or Djibouti, in column 3 we only consider clusters located along the primary routes coming from Eritrea and in column 4 we do the same exercise restricting the sample to clusters located along the routes to Kenya. In some cases corridors originating from contiguous countries overlap. This event occurs when two primary roads coming from two different countries become a single road in the Ethiopian territory or when the two primary roads are located within a distance of 10 km from each other. In these cases we observe clusters that for instance are located along both the Somalia and Djibouti corridors. The pattern we observe in the data guided us in deciding how to define the sub-samples we use in the empirical analysis. In particular, we have chosen to group Somalia and Djibouti together because 65% of the clusters located along the Djibouti corridors are also located along the Somalia corridors. Similarly we have grouped Sudan and Eritrea together as 100% of the clusters located along the Sudan corridors are also located along the corridors coming from Eritrea. Kenya is considered separately as it only shares 6% of the clusters with the Somalia corridors. Results in Table I show that the construction of an additional road segment within 5 kilometres is associated with a 3 percentage points increase in the probability of infant mortality. Crucially this result only holds when looking at road construction along the routes coming from Somalia and Djibouti, which have been indicated as the potential routes of waste trafficking. At the same time that area hosted a significant number of construction sites between 2000 and 2005. The size of the effect is large and corresponds to 35% of the sample mean. It is not surprising that we find a less robust effect on the Eritrea corridor, as the route from Eritrea could have been a less viable one to travel through. The war between Ethiopia and Eritrea officially ended in 2000 but it has been followed by prolonged tensions along the Eritrea-Ethiopia border. The presence of military forces from both sides along the border might have discouraged the movement of toxic waste on that specific route.

Panel B of Table I presents the results of the placebo exercise where we replicate the estimation of equation (1) by using the number of roads between 10 kilometres and 30 kilometres as the main independent variable. We would expect no effect on infant mortality living further away. This appears to be indeed the case: the number of roads built further away is found to have no statistically significant impact, in any of the routes considered.

IV.B. Endogeneity

The identification of the impact of roads presented in the previous section may suffer from two potential sources of endogeneity. First, new roads could be built in areas characterized by worse health outcomes or with a higher incidence of infant mortality. Second, our results might depend on a spurious correlation between roads construction and unobservable characteristics of the DHS sample of mothers. In order to deal with these issues, we run two specifications. The first allows us to rule out the presence of pre-trends in infant mortality in the treatment group (clusters with road constructions between 2000 and 2005), while the second specification tests whether in the initial period, 2000, the treatment group was characterised by a level of infant mortality and other characteristics, significantly different compare to the control group.

In addition, when we estimate equation (1) we study the lagged effect of road construction, and we consider the birth cohorts born between 2000 and 2004 as not treated, and the birth cohorts born between 2005 and 2010, as treated only by road construction happened over the period 2000 and 2005. By doing so, our estimation does not take into account the potential effect of contemporaneous road construction. As a consequence our results might be biased. At the end of this section we propose two specifications that allow us to distinguish between the effects of lagged and contemporaneous road constructions.

Pre-Trends

The coefficient β_1 in (1) can be interpreted as causal under the assumption that infant mortality would have followed the same trend for mothers living in treated and untreated clusters, in the absence of the treatment, which in our setting corresponds to experiencing a positive road construction. Notwithstanding the assumption is not testable, we can study pre-trends in infant mortality and show that they represent a valid counterfactual for trends of treated and untreated mothers. This section aims at studying pre-trends by investigating the relationship between infant mortality and road construction, at cohort level, from four years before the observed road change to four years after. We introduce a specification which focuses on both the pre- and post-road construction periods, as it follows:

$$Y_{imct} = c + \sum_{j=-4}^{4} \beta_j \, roads_{c\tau} * cohort_{(\tau+j)} + \boldsymbol{Z'_{imt}\theta} + \boldsymbol{I'_{it}\pi} + \delta X_{ct} + \eta_t + \mu_m + \varepsilon_{imct} \qquad (2)$$

Where Y_{imct} is the indicator capturing infant mortality as in equation 1. This specification allows us to distinguish between the effect of roads that are not yet constructed, roads that are potentially still under construction and roads whose construction has been completed. In particular the coefficients $\beta_0, .., \beta_4$ capture the effect of roads that at time 0 are classified as completed, on infant mortality in time 0 and in the following four years. Coefficients $\beta_{-4}, .., \beta_{-1}$ identify the effect of roads on infant mortality in the four years preceding their completion. Not knowing the exact date of completion it is impossible to infer whether these effects are contemporaneous or preceding road constructions. However it seems reasonable to assume that the further one moves from time 0 to time -4, the more likely the relative coefficients are capturing the lead effect of roads, *i.e*. roads whose construction has not yet started.

Figure IV and Figure V report the estimated β coefficients and relative confidence intervals of equation (2), for the overall sample and for the sample restricted to the Somalia/Djibouti corridor. The two graphs provide support for the parallel trend hypothesis: only completed roads lead to an increase in infant mortality, while not yet constructed roads and roads supposedly under construction have a zero effect on the probability of infant mortality. This evidence clearly rules out the existence of pre-trends in infant mortality in treated clusters and supports the assumption that the control group provides a valid counterfactual for the treatment group.

[Figure IV here]

[Figure V here]

Cluster-Level Analysis

In this section, we study whether the change in roads which took place between 2000 and 2005 is correlated with the average infant mortality of the cluster in the pre-construction period (1997-1999) and other initial characteristics at the cluster and mother level, such as the level of economic development, the diffusion of electricity in the households and the education level of the mothers.[25] This exercise should provide an indication of whether clusters that experienced extended road constructions differed from clusters that did not, in some fundamental characteristics. If our results suffer from reverse causality, we should expect a future change in roads to be correlated with initial infant mortality. Similarly, this exercise would produce statistically significant coefficients if our results were driven by the presence of unobservables correlated with road constructions.

Table II reports the results of this estimation conducted at the *cluster level* and gives a first indication that reverse causality and unobserved heterogeneity could indeed be excluded. We find no statistically significant relation between the average infant mortality rate at time t (1997-1999) and the change in the number of roads happening between t and $t+5$ (2000-2005). This result holds also when we restrict the sample to the corridors towards Somalia/Djibouti, Eritrea/Sudan and Kenya. Other initial conditions such as the level of economic development do not predict where new roads are built.[26]

[Table II here]

Road Construction: Contemporaneous vs Lagged Effect

In the baseline regression in (1), the children born between 2000 and 2004 are considered as untreated while the children born after 2005 are considered as treated, with the treatment intensity being equal to the increase in the number of roads within 5 kilometres between 2000 and 2005. In the regression we estimate the effect of roads whose construction has been completed, and we

[25] We use the 2000 wave of the DHS and we study road constructions happening afterwards, between 2000 and 2005, in the clusters where the mothers were living at the time of the interview.

[26] The initial level of economic development is positively correlated with road construction only in the case of clusters located in the Kenya corridor.

disregard the effect of roads under constructions. The rationale behind this choice is that the effect of road construction takes some time to manifest. Whether dumping of waste has happened during construction or after completion in the proximity of the new road, the contamination of the soil and water nearby would take some time to translate into worse health outcomes. However, the birth cohorts between 2000 and 2004 could be considered partially treated as well if they were born during the construction of a new road or even right after the completion of a road that is officially recorded in the road network data only in 2005.[27] If anything our results should be downward biased. On the other hand, the birth cohorts born after 2004 might be not only exposed to lagged road construction happening between 2000 and 2005, but also to contemporaneous road construction happening between 2005 and 2010. To investigate this issue, we run a series of specifications where we disentangle the effect of roads on infant mortality of cohorts of children born at the time of construction from the effect of roads on infant mortality of cohorts of children born after road construction has been completed. We do so by restricting the sample to clusters that experience road construction only between 2000 and 2005, but not in the following period (2005-2010). In addition, considering this restricted sample, we estimate a specification where we interact the change in roads (within 5 kilometres) with the dummies identifying the birth cohorts born from 2001 to 2010. With the latter specification, we distinguish between the effect of road construction on birth cohorts born around the same time of construction and the effect of road construction on birth cohorts born after. Notice that also these specifications, like the previous ones, include mother fixed effects. Results in Table A.6. and Table A.7. of the Online Appendix show that road construction has an even larger effect on infant mortality when excluding birth

[27] Despite this is a possibility, it is plausible to assume that most of the new roads built between 2000 and 2005 and recorded in the road network data in 2005 are completed toward the end of the 2000-2005 period.

cohorts born at the time of construction, and that road construction has a minimum effect on contemporaneous cohorts, while it has the largest and most significant effect on later cohorts.

IV.C. Heterogeneous Effects

The aim of this section is to advance the understanding of the phenomenon of waste dumping, focusing further on the relationship between road constructions and infant mortality. We first provide suggestive evidence on the potential mechanism linking the dumping of waste to infant mortality and second, we give an indication of the areas where most of the effects that we detect is located.

Water Contamination

The most relevant routes of contamination of hazardous waste dumping include air, soil, food and water. Typically ground-water samples collected close to waste sites are found to contain several toxic chemicals.[28] We exploit the information available in the DHS to assess whether the relationship between road constructions and infant mortality depends on the vicinity to water sources. If the toxic waste were buried under or in the proximity of new roads, the ground water close to the area would have been contaminated. As a result, we would expect road constructions to have a higher effect on infant mortality for mother living closer to a water source.

[Table III here]

[28] Among others, Mazza et al. (2015) present findings for the case of the Campania region (Italy).

Table III reports the results when we include in the baseline regression (1) the interaction between the number of roads within 5 kilometres and a dummy that captures the proximity of the household to a source of water. For ease of interpretation, we construct an indicator variable, *water* that takes the value of 1 if the distance from a water stream is less than the median distance across the sample. The interaction term is positive and significant only for clusters located along the Somalia and Djibouti corridor. This result suggests that water is an important vehicle through which toxic waste dumping negatively influences the health status of the population living nearby. Table III further corroborates the hypothesis of the presence of toxic waste dumping along that Somalia and Djibouti route.

Dumping Spots

In the following exercise we aim to identify the locations experiencing a higher increase in infant mortality following the construction of roads within a 5 kilometres radius. In particular we conduct a pooled OLS estimation[29] at the cluster level using all birth cohorts between 2000 and 2010, including the relevant controls[30] as well as the year of birth fixed effects. By exploiting the time dimension of the data on infant mortality, we are able to obtain different coefficient estimates of our variable of interest, *Roads5km*, for different clusters. The picture on the left of Figure VI below maps the coefficients obtained for the clusters located along the Djibouti and Somalia corridors.

The circles represent the clusters, which display an association between the increase in the number of roads within 5 kilometres and the increase in infant mortality. The bigger is the circle, the larger the estimated relation. There are a few cases of a negative relationship identified by very

[29] We do not have enough power to estimate the model in (1) including mother FE.
[30] Birth order and its square, infant sex, mother age at birth and its square and twin status.

small circles, but those coefficients are not statistically significant. The picture on the right of Figure VI shows a similar picture but zoomed around the area of Harar. The figure suggests that the spots where we obtain a strong significant relationship between road constructions and infant mortality are located towards the border with Djibouti and in the surroundings of the chartered city Dire-Dawa and the city Harar.

[Figure VI here]

The two cities are both very close, around two hours' drive, to the border with Somalia, and are connected to the Somali port of Berbera.

V. Robustness

The results obtained in the previous section might be explained by other confounding factors, such as migration, traffic pollution, and the presence of other diseases. This section will address these issues by presenting a number of robustness checks.

V.A. Potential Confounding Factors: Migration and Pollution

One implicit assumption we make in this setting is that there is no immigration of mothers with systematically worse health and socio economic conditions along the Somalia and Djibouti corridor. There are a variety of arguments supporting this assumption: first, according to the 2007 Ethiopian census, the annual internal migration rate is 1% (CSA, 2010, de Brawn, 2018); second, women generally move right after marriage to the husband's place of residence therefore it is unlikely that they move after giving birth (Fransen and Kuschminder, 2009). In addition, focusing on the corridors from the neighbouring countries separately allows us to study what happens along all of the major migration routes. Since a strong effect of road constructions is found only along the routes from Somalia and Djibouti, we can conclude that our results are not generally driven by migration patterns. As a further check, we repeat the same estimation exercise as in (1) restricting the sample and excluding the chartered city Addis-Ababa which attracts most of the immigrants in the country. Table A.3 in the Online Appendix reports the results, which are robust to the exclusion of Addis-Ababa.

A recent study (Knittel et al. 2016) finds that pollution increases the incidence of infant mortality. Our results might therefore be driven by higher air pollution due to increased traffic after the construction of new roads, rather than by the presence of toxic waste. Despite we cannot use actual data on air pollution at the local level[31], a number of facts allow us to rule out this possibility. First, we would expect pollution associated with the construction of new roads to increase along *all entry routes* to Ethiopia and not only along the Somalia and Djibouti corridor. Second, despite the increase in traffic in Ethiopia over the past years, the main area that reaches a significant level of traffic pollution is the one surrounding the capital Addis Ababa (Tiwari, 2012). As a consequence, were the increase in infant mortality due to an increase in traffic pollution, the results should disappear when the chartered city Addis-Ababa is excluded from the sample. As discussed above, the evidence in Tables A.3. in the Online Appendix confirms that the overall results are robust to the exclusion of the capital and surroundings.

[31] We tried to use the data on PM2.5 concentration assembled by the Atmospheric Composition Analysis Group. Unfortunately the spatial resolution of most sources within their PM2.5 estimates, are around 10 km x 10 km, which make the data too coarse to be used for our analysis at the cluster level.

As a further check we repeat the estimation in (1) excluding all the clusters that are classified as urban and our result holds.[32] All in all these results suggest that air pollution is not driving our results.

Pollution is also more likely to affect a different set of health outcomes, *i.e.* respiratory diseases. We further explore issues related to pollution-related diseases later in Section V.C.

V.B. Other Health Effects: Haemoglobin Level and Severe Anaemia

High anaemia and low haemoglobin are two key health conditions, which the medical literature associates with toxic waste exposure. For instance, several contributions in the literature documented a strong link between low haemoglobin levels and pesticide poisoning (Del Prado-Lu 2007, Azmi et al. 2009, Khan et al. 2013). Moreover, low haemoglobin levels can be a sign of childhood cancer, which in turn can be caused by exposure to toxic waste (Stillerman et al. 2008). A recent paper by Rau et al. (2015) provides evidence on the effects of toxic waste on blood lead level, while the connection between blood lead level and anaemia has been established by Jain et al. (2005). This evidence is consistent with a report by the World Health Organization on lead poisoning and high anemia in childhood (WHO, 2010). In this section we study the evidence on these two additional health outcomes, haemoglobin level and severe anaemia in children under five years old. To do so we can use data on haemoglobin levels as measured during the DHS interview through the HemoCue machine that also allows an instantaneous anaemia assessment.[33] We study the effect of road construction on these two health outcomes, using a repeated cross

[32] Results from this specification are available in Table A.4. of the Online Appendix.

[33] From the DHS questionnaire: "*Blood samples were drawn from a drop of blood taken from a finger prick (or a heel prick in the case of young children with small fingers) and collected in a micro cuvette. Haemoglobin analysis was carried out onsite using a battery-operated portable HemoCue analyser*". The HemoCue machine has become the standard to perform mobile anaemia screening programs.

section of children surveyed in 2005 and 2011, respectively. In particular, we stack the two DHS surveys (2005 and 2011) and estimate the following equation:

$$Y_{ihcrt} = \beta_0 + \beta_1 roads_{cr(t-5)} + \boldsymbol{X'_{ihcrt}\gamma} + \boldsymbol{Z'_{hcrt}\eta} + \boldsymbol{K'_{crt}\theta} + \delta_r + v_t + \varepsilon_{rt} + u_{ihcrt} \qquad (3)$$

Where the dependent variable, Y_{ihcrt} , is either haemoglobin level or the presence of severe anaemia, for child *i*, belonging to household *h*, living in cluster *c*, in region *r*, and surveyed in year *t*, where *t* is either 2005 or 2011. The variable of interest, $roads5km_{cr(t-5)}$, is the number of roads within 5 kilometres from the centre of the cluster. This variable is observed in two points in time, in 2000 and in 2005 respectively. It is equal to the number of roads in 2000 for children surveyed in 2005, and it is equal to the number of roads in 2005 for children surveyed in 2011. To account for socio-economic covariates we control for a set of variables at the individual level, $\boldsymbol{X_{ihcrt}}$, such as age and gender, at the household level, $\boldsymbol{Z_{hcrt}}$, such as age and education level of the household head, household size, household wealth, electricity and time to get water. Finally, we include a full set of controls at the cluster level, $\boldsymbol{K_{crt}}$, such as the light intensity at night time to capture the level of economic development, the distance from a border, the distance from a lake or river to control for the effect of water dumping and a dummy for whether the cluster is located in a rural area to take into account urbanization. Regional fixed effects are included to account for time invariant unobservables at the regional level, δ_r, and time fixed effects, v_t, are also included to control for common shocks occurring at the time of the interview. Equation (3) is estimated for the full sample and for the sample restricted to the households located close to the major routes from Somalia and Djibouti, Eritrea and Kenya. The coefficient of interest, β_1, measures the change in the haemoglobin level detected in the blood (or incidence of severe anaemia) of under-fives associated with a unit increase in the number of roads within 5 kilometres. Given the structure of the DHS data, we estimate equation 3 as a repeated cross-section.[34] Table A.10 and Table A.11. of the Online Appendix report the results.

When we consider children between 0-5 years old, we find a negative statistically significant relationship between roads construction and haemoglobin level along the Somalia/Djibouti corridor. In particular, when restricting the analysis to clusters located within the corridor that connects Addis-Ababa to Somalia and Djibouti, an additional road within 5 kilometres is associated with a 0.12 points lower haemoglobin level, which corresponds to 1.1% of the sample mean. Table A.11. provides evidence of a positive and statistically significant relationship between severe anaemia and road construction along the Somalia/Djibouti corridor. In this case, an additional road within 5 kilometres is associated with an increase of 2 percentage points in the incidence of severe anaemia. This effect corresponds to 37% of the sample mean.

According to the available medical literature the length of exposure to toxic substances plays a crucial role, suggesting that the effect of toxic waste should increase with longer exposure. Results in Table A.10. and Table A.11. refer to children aged 0-5 years old who have experienced a different length of exposure to toxic waste buried under or in the proximity of new roads. This exposure could vary between zero and five years depending on the year of birth. Using the information on the age of the children we estimate the model in equation (3) but only for children aged between 2 and 5 years old. In this way we restrict the analysis to age groups that arguably have experienced a longer exposure. When considering Ethiopia as a whole, results, reported in Table IV and Table V show a small negative association between road construction and low

[34] Table A.8. of the Online Appendix presents the estimation results of equation 3 where the dependent variable is infant mortality. The findings are very similar to the panel estimation presented in Table 1.

haemoglobin levels, and a statistically insignificant relation between road construction and the incidence of severe anaemia.

[Table IV here]

However, when we study the different routes connecting the capital to the neighbouring countries, we find that road construction happening along the corridors coming from Djibouti and Somalia is associated with a significantly higher incidence of severe anaemia and lower haemoglobin level. In particular results in column (2) of Table IV point out that an additional road within 5 kilometres is associated with a 0.19 points lower haemoglobin level, which correspond to 1.7% of the sample mean.

[Table V here]

The evidence in Table V highlights a tremendous effect of road construction on severe anaemia; an additional road within 5 kilometres is associated with an increase of over 3 percentage points in the incidence of severe anaemia in children aged 2-5 years old. This corresponds to an increase of 62% relative to the sample mean. No evidence of a statistical significant relation is found when looking at all the other corridors. The results below are consistent with the evidence on infant mortality described in the previous section.[35] Overall, the evidence presented so far corroborates the hypothesis that toxic waste is dumped under, or in the proximity of the roads constructed along the Somalia and Djibouti routes.

[35] The results hold when the capital Addis-Ababa is excluded from the sample (see Tables A.12.-A.13. in the Online Appendix).

V.C. Alternative Health Outcomes

Given the richness of DHS data we are able to run an additional check and estimate specification (3) using an alternative health outcome, specifically respiratory diseases, which can be directly linked to pollution.[36] Panel A in Table VI_a shows no evidence of a significant association between the number of roads and the incidence of respiratory diseases. This result is not surprising considering that most areas in Ethiopia, except for Addis-Ababa, are not affected by air pollution.

This result provides further evidence that the increase in infant mortality we observe along the corridor coming from Somalia and Djibouti is unlikely to be driven by higher pollution.

Our results might also be driven by the presence of other disrupting diseases, such as malaria, which cause an increase in infant mortality. Alternatively, we may conjecture that children with generally worse health outcomes might be living precisely along the corridors from Somalia and Djibouti. To rule out these possibilities, we estimate the repeated cross section model in (3) for a set of alternative health measures for the sample of children aged 0-5 years old.[37] These measures have been chosen since they are the most common symptoms of a large number of health conditions. In particular, the variable *fever* captures one of the main effects of malaria and both fever and diarrhoea are common symptoms of HIV infection in children. Panel B and C in Table VI_a show that there is no significant association between these alternative health outcomes and the number of new roads constructed nearby, also for children living along the relevant corridors.

In Table VI_b we consider additional health outcomes that give a comprehensive picture of the health status of children exposed to road construction in our sample. In Panel A, we study *stunting*,

[36] The medical literature has extensively proven how pollution increases the incidence of respiratory conditions. See for example Dominici et al. (2006).

[37] We cannot estimate a fixed effect model as it was done in specification (1) for mothers, since there are no panel data available on children.

which according to the official definition provided by the WHO, indicates a status of poor nutrition and chronically impaired growth. Results in Panel A show no evidence of an association between the number of roads and the incidence of stunting. The same results are shown in Panel B, where we study the incidence of a small size at birth. All in all, results in Table VI_a and in Table VI_b clearly show that children experiencing higher road construction are not characterised by a generally worse health status.[38] This evidence holds for road construction happening along the single corridors under study and the country as a whole.

V.D. Displacement

As discussed in Section III, clusters covered in the DHS are subject to a displacement process. Throughout the analysis we assume that the measurement error induced by clusters' displacement is randomly distributed across clusters and routes. To further address this issue, we perform alternative specifications where we consider changes in roads at different distances from the centre of the clusters. In particular we study changes within the 3 to 5 kilometres circle from the centre of the clusters and within 5-10 kilometres. As expected results are similar to our baseline specification (0-5 kilometres circle) in the former case while they fade away in the latter case.[39]

V.E. Additional Robustness

When analysing the different routes that connect the neighbouring countries to the capital Addis-Ababa, we have aggregated the routes Somalia and Djibouti, and Sudan and Kenya to get a fairly similar sample sizes across all specifications. In addition, we have taken into account the

[38] Tables A.14. and Table A.15. of the Online Appendix, show that the results hold when restricting the sample to children between 2 to 5 years old.
[39] Results from these specifications are available in Table B.3. of the Online Appendix.

geographical proximity of these countries. As a first robustness check we have repeated the analysis presented in the paper, considering all of the routes separately. In addition, we have estimated equation 1, considering the interaction between our variable of interest, $roads_{ct}$, and the dummy indicating each single corridor. Results from these specifications are consistent with the evidence presented and confirm the presence of a negative effect of roads construction only along the routes coming from Djibouti and Somalia.[40]

[Table VI_a here]

[Table VI_b here]

VI. Conclusions

Exposure to toxic chemicals poses long-term health and environmental challenges, and can significantly hamper economic and social development, for instance restricting access to land and natural resources. According to the WHO (2016) toxic pollution (indoor pollution and exposure to toxic chemicals), is the major cause of death and diseases in LDCs, accounting for more than three times the number of death and diseases caused by malaria, HIV and TBC together.

Illegal dumping of toxic waste is part of the problem and there is an urgent need to study the phenomenon (GAHP, 2013), its consequences and design proper interventions in terms of regulation and enforcement but also direct interventions such as clean-ups that have been found effective in other contexts.

[40] Results from these specifications are available in Table B.1. and Table B.2. of the Online Appendix.

The huge barrier at the moment is the lack of information and so the impossibility to use data to directly measure the extent of the problem. The only available evidence is scattered among different sources and it is mainly anecdotal.

This paper takes a first step in assessing quantitatively the illegal dumping of hazardous waste. By linking road constructions and health outcomes in Ethiopia, we are able to identify where toxic waste dumping might take place. Our exercise relies on a crucial premise: road constructions provide an ideal setting in which the burial of hazardous waste may take place. In addition, the construction of new roads lowers the transportation costs to reach previously remote areas also for loads of toxic waste. Guided by the medical literature we study the effect of road construction on health outcomes and we are able to identify where hazardous waste was dumped. Many confounding factors might explain the observed patterns in health outcomes. We tackle this issue by looking at specific health measures, which are more directly linked to the potential effects of toxic waste on health. Using panel data at mother level from the DHS survey, we provide evidence that infant mortality significantly increases after a positive change in the number of roads within 5 kilometres for the households located along the major routes connecting Somalia and Djibouti to the capital Addis-Ababa. The size of the effect is large; the construction of an additional road segment within 5 kilometres along the Somalia and Djibouti corridor, over the period 2000-2005 is associated with a 3 percentage points increase in the probability of dying before reaching the age of one. This corresponds to a 35% of the sample mean. The repeated cross section evidence corroborates these findings. A series of robustness checks and placebo tests rule out the possibility that our results are affected by endogeneity and by the presence of potential confounding factors, such as pollution and migration. Finally, we show the effect of road constructions on children's anaemia and haemoglobin levels, which act as indicators of exposure to toxic substances.

This paper represents a first attempt to understand the localization of waste dumping by exploiting a very detailed dataset. The results of this study are potentially relevant to other types of infrastructure development. The Programme for Infrastructure Development in Africa (PIDA) has identified four key areas - energy, transportation, Information and Communication technology (ICT) and transboundary water resources – whose expansion would promote significantly Africa’s socio-economic development and integration. The projects in these sectors have been scaled up and are attracting substantial investments from foreign investors. Whether these projects foster illegal activities, such as the dumping of waste, is likely to depend on the different institutional arrangements and quality of institutions across the continent. The evidence presented in the paper recommends that infrastructure development, particularly road constructions, should, at least, be accompanied by actions aimed at preventing toxic waste disposal, especially in regions with weak institutions and a strategic geographical position.

The methodological approach we introduce could be applied to other countries and type of infrastructure development, to identify hazardous waste sites and guide clean-up interventions.

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Figures

FIGURE I
Change in the Road Network

Period: 2000-2005

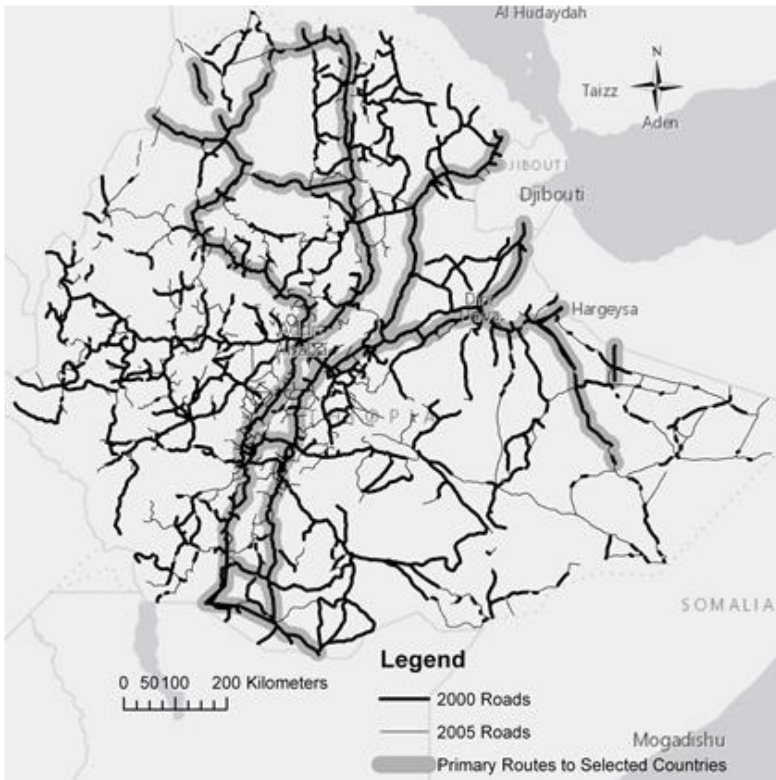


FIGURE II
Change in the Road Network by Zones
Period: 2000-2005

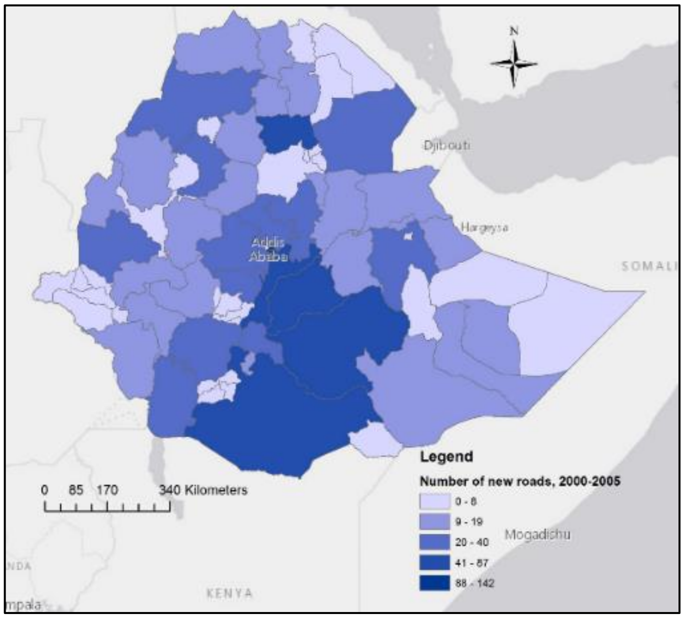


FIGURE III
Increase in the Road Network for a Random Cluster

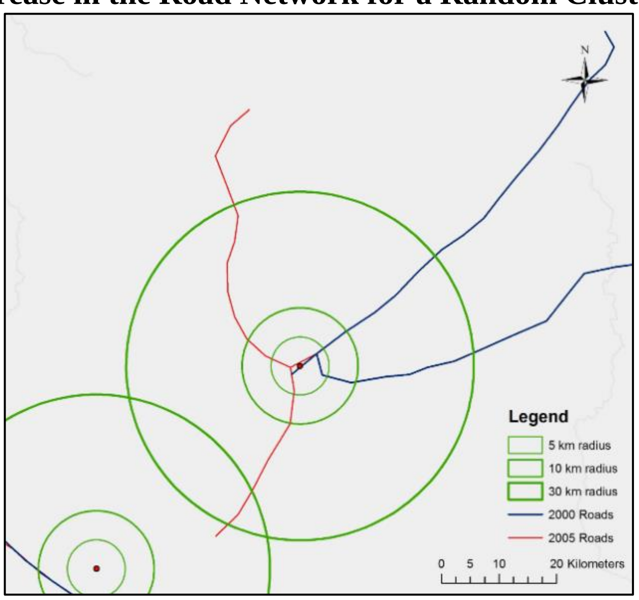
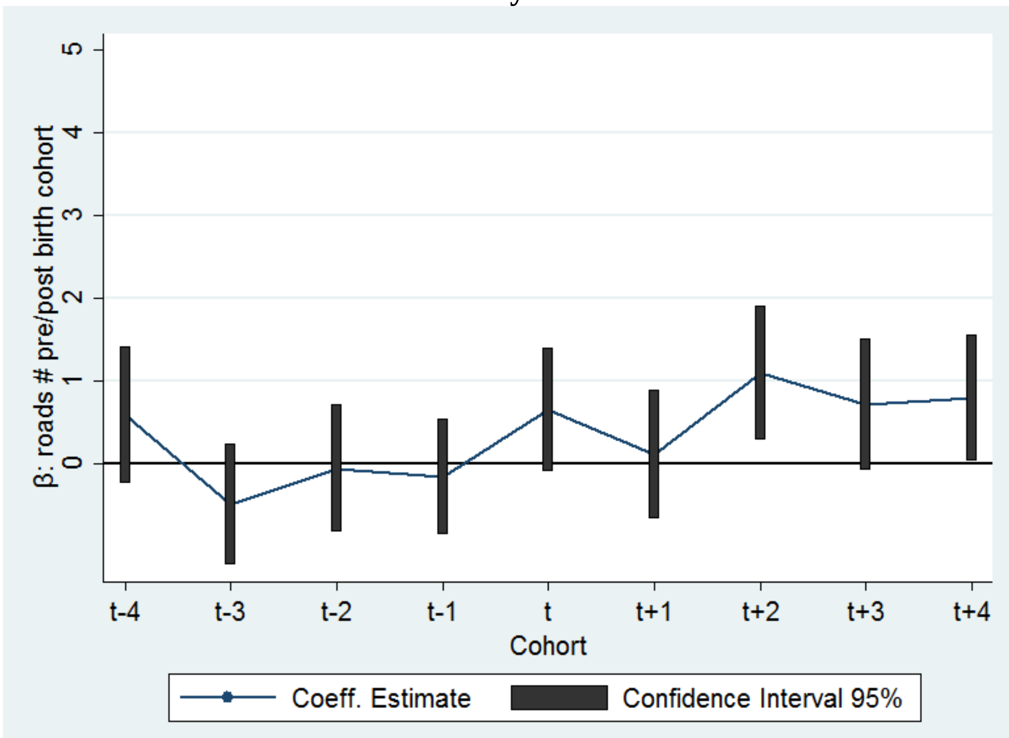


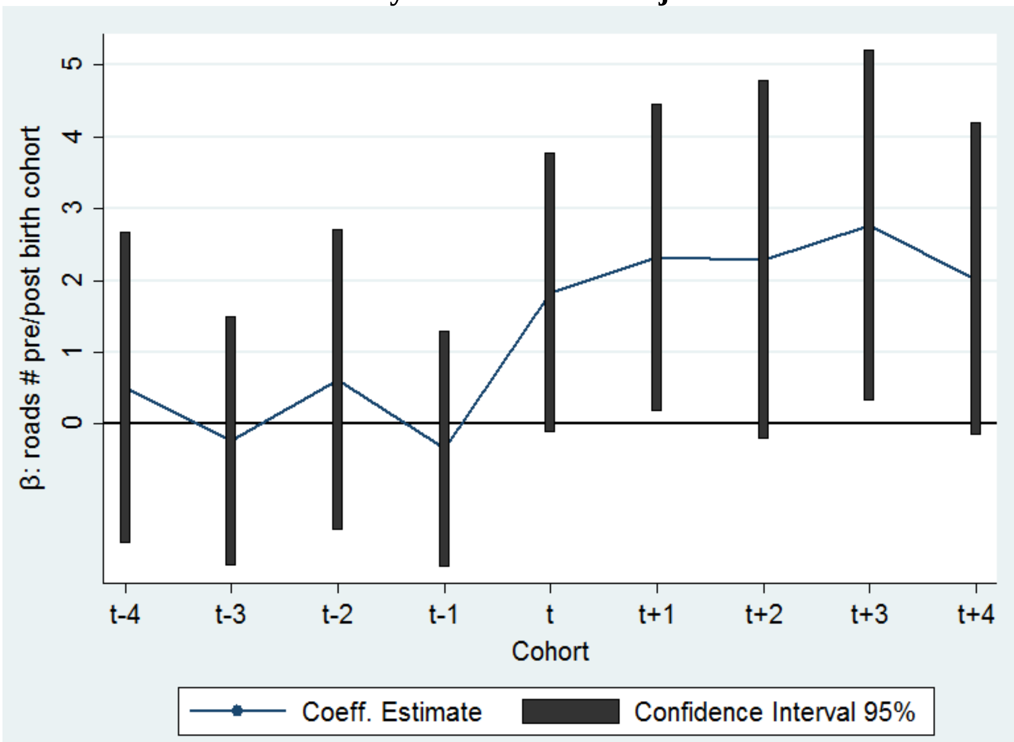
FIGURE IV
Pre-trend analysis: All Roads



Notes: The figure plots the coefficients obtained by a panel regression at mother level of infant mortality on the interaction between roads at time *t* and a full set of birth cohort dummies for the period before and after *t*.

FIGURE V

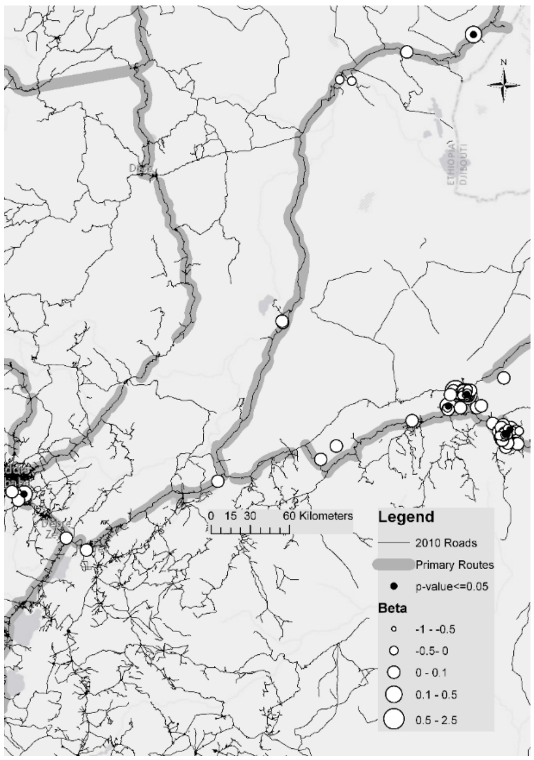
Pre-trend analysis: Somalia and Djibouti Route



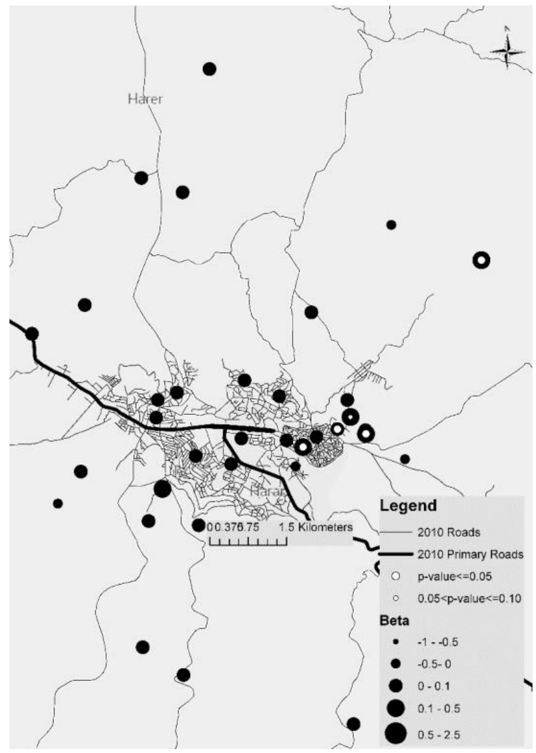
Notes: The figure plots the coefficients obtained by a panel regression at mother level of infant mortality on the interaction between roads at time *t* and a full set of birth cohort dummies for the period before and after *t*.

FIGURE VI
Distribution of the Effect across Clusters on the Djibouti and Somalia Route

Somalia/Djibouti Corridor



Area of Harar only



Notes: The figures plot the size and significance of the coefficients obtained by a pooled OLS regression at the cluster level of infant mortality on birth order and its square, infant sex, mother age at birth and its square, twin status and year of birth fixed effects.

Tables

TABLE I
Infant Mortality and Road Change: Average Effect over Different Birth-Cohorts

	(1) All	(2) Somalia/Djibouti	(3) Eritrea/Sudan	(4) Kenya
Panel A				
Roads5km	0.732	3.020***	3.614	-1.306
	(0.620)	(0.886)	(2.203)	(1.629)
Treated Clusters	153	40	26	17
R-squared	0.027	0.032	0.071	0.029
Panel B				
Roads30km	0.025	-0.245	-0.529	-0.390
	(0.174)	(0.546)	(0.458)	(0.466)
Treated Clusters	423	61	62	35
R-squared	0.027	0.029	0.070	0.029
Number of Clusters	596	77	72	38
Individual Controls	Yes	Yes	Yes	Yes
Mothers FE	Yes	Yes	Yes	Yes
Year Birth FE	Yes	Yes	Yes	Yes
N	24744	3059	2140	1526

Standard errors at the cluster level are reported in parentheses. Dependent variable is *Infant_mortality* which is a dummy equal to one if a child dies under the age of one. *Roads5km* measures the number of road segments within 5 km. This variable corresponds to the number of roads within 5km in 2000 for the births between 2000 and 2004, while corresponds to the number of roads in 2005 for births occurring from 2005 onwards. Panel B displays the number of road segments within 10 km and 30 km from the centre of the cluster. Controls include: gender, twin status, birth order and its square, mother age at birth and its square and luminosity at the cluster level. Mother fixed effects and year of birth fixed effects are included in every column. *Significant at 10%, **significant at 5%, ***significant at 1%.

TABLE II
Initial Conditions and Road Change: Cluster-Level Analysis

	(1) All	(2) Somalia/Djibouti	(3) Eritrea/Sudan	(4) Kenya
Infant_mortality	0.032	0.452	0.278	-0.798
	(0.242)	(1.011)	(0.582)	(1.005)
Luminosity_2000	0.022	0.016	0.001	0.235**
	(0.027)	(0.046)	(0.061)	(0.099)
Electricity	0.144	-0.508	0.281	-1.267
	(0.244)	(0.410)	(0.308)	(0.839)
Rural	-0.126	-0.815	-0.038	-0.138
	(0.161)	(0.507)	(0.435)	(0.707)
Mother_edu	0.023	0.000	0.013	0.069
	(0.022)	(0.045)	(0.031)	(0.073)
Region Fixed Effects	Yes	Yes	Yes	Yes
R-squared	0.275	0.177	0.050	0.493
N	539	60	70	67

Standard errors at the cluster level are reported in parentheses. Dependent variable is the change in roads over the period 2000-2005. The independent variables are averages at the cluster level and refer to the pre-change period 1997-1999, with the exception of *Luminosity_2000* which is the light density at night time of the cluster in 2000. *Infant_mortality* is a dummy equal to one if a child dies under the age of one. Other initial characteristics include the average presence of electricity in the household, the proportion of rural households in the cluster and the average education of the mothers in the cluster. Region fixed effects are included in every column. *Significant at 10%, **significant at 5%, ***significant at 1%.

TABLE III

Infant Mortality and Road Change: Distance to a Source of Water

	(1) All	(2) Somalia/Djibouti	(3) Eritrea/Sudan	(4) Kenya
Panel A				
Roads5km	-0.428	0.541	-0.018	-1.779
	(0.725)	(0.865)	(2.702)	(1.557)
Roads5km#Water	1.510	2.733***	4.472	0.448
	(1.005)	(0.740)	(3.667)	(2.577)
Treated Clusters	153	40	26	17
R-squared	0.161	0.164	0.189	0.221
Panel B				
Roads30km	0.002	-0.855*	-0.695	-0.354
	(0.220)	(0.448)	(0.577)	(0.490)
Roads30km#Water	-0.023	1.454**	0.423	-0.540
	(0.253)	(0.659)	(0.538)	(0.476)
Treated Clusters	423	61	62	35
R-squared	0.161	0.162	0.188	0.221
Number of Clusters	596	77	72	38
Individual Controls	Yes	Yes	Yes	Yes
Mothers FE	Yes	Yes	Yes	Yes
Year Birth FE	Yes	Yes	Yes	Yes
N	24744	3059	2140	1526

Standard errors at the cluster level are reported in parentheses. Dependent variable is *Infant_mortality* which is a dummy equal to one if a child dies under the age of one. *Roads5km* measures the number of road segments within 5 km. This variable corresponds to the number of roads within 5km in 2000 for the births between 2000 and 2004, while corresponds to the number of roads in 2005 for births occurring from 2005 onwards. Panel B displays the number of road segments within 10 km and 30 km from the centre of the cluster. The variable *Roads5km#Water* is the interaction between *Roads5km* and the dummy *Water* which is =1 if the distance between the centre of the cluster and a source of water (river or lake) is lower than the median distance calculated over the entire sample. Controls include: gender, twin status, birth order and its square, mother age at birth and its square and luminosity at the cluster level. Mother fixed effects and year of birth fixed effects are included in every column. *Significant at 10%, **significant at 5%, ***significant at 1%.

TABLE IV

Haemoglobin Level and Road Change: Children 2-5 Years Old

	(1) All	(2) Somalia/Djibouti	(3) Eritrea/Sudan	(4) Kenya
Panel A				
$Roads5km_{t-5}$	-0.054**	-0.194***	-0.107	-0.036
	(0.027)	(0.074)	(0.074)	(0.075)
R-squared	0.145	0.247	0.207	0.144
Panel B				
$Roads30km_{t-5}$	-0.005	-0.024	-0.003	-0.014
	(0.006)	(0.020)	(0.016)	(0.021)
R-squared	0.144	0.242	0.204	0.145
Number of Clusters	1022	138	129	75
HH Controls	Yes	Yes	Yes	Yes
Cluster Controls	Yes	Yes	Yes	Yes
Region FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
N	5441	642	504	387

Standard errors at the cluster level are reported in parentheses. Dependent variable is haemoglobin level. $Roads5km_{t-5}$ measures the number of road segments within 5 km. This variable corresponds to the number of roads within 5km in 2000 for children aged 2-5 years old interviewed in 2005, while corresponds to the number of roads in 2005 for children aged 2-5 years old interviewed in 2010. In the same way, $Roads30km_{t-5}$ in Panel B displays the number of road segments within 10 km and 30 km from the centre of the cluster. Individual controls include: gender, birth order, age and its square. Household (HH) controls include: time to get water, indicator variable for living at and above 1500 meters above the sea level, a dummy for being in a rural area, household size, wealth and electricity, mother's age and mother's years of education. Cluster Controls include: indicator dummies for being along a major route from Somalia, Djibouti, Eritrea, Kenya and Sudan, respectively; economic conditions captured by the luminosity, distance from the border, distance from a source of water, an indicator variable equal to one if the distance from the closest road has decreased over the period 2000-2005, a dummy equal to one if the closest road is a primary road. Region and year fixed effects are included in every column. * Significant at 10%, ** significant at 5%, *** significant at 1%.

TABLE V

Severe Anaemia and Road Change: Children 2-5 Years Old

	(1) All	(2) Somalia/Djibouti	(3) Eritrea/Sudan	(4) Kenya
Panel A				
$Roads5km_{t-5}$	0.413	3.272**	0.631	-0.403
	(0.316)	(1.284)	(0.712)	(0.785)
R-squared	0.044	0.144	0.093	0.081
Panel B				
$Roads30km_{t-5}$	-0.004	-0.422	0.033	-0.027
	(0.057)	(0.444)	(0.185)	(0.243)
R-squared	0.046	0.148	0.086	0.090
Number of Clusters	1022	138	129	75
HH Controls	Yes	Yes	Yes	Yes
Cluster Controls	Yes	Yes	Yes	Yes
Region FE	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes
N	5441	642	504	387

Standard errors at the cluster level are reported in parentheses. Dependent variable is a dummy equal to one if the interviewed child suffers from severe anaemia. $Roads5km_{t-5}$ measures the number of road segments within 5 km. This variable corresponds to the number of roads within 5km in 2000 for children aged 2-5 years old interviewed in 2005, while corresponds to the number of roads in 2005 for children aged 2-5 years old interviewed in 2010. In the same way, $Roads30km_{t-5}$ in Panel B displays the number of road segments within 10 km and 30 km from the centre of the cluster. Individual controls include: gender, birth order, age and its square. Household (HH) controls include: time to get water, indicator variable for living at and above 1500 meters above the sea level, a dummy for being in a rural area, household size, wealth and electricity, mother's age and mother's years of education. Cluster Controls include: indicator dummies for being along a major route from Somalia, Djibouti, Eritrea, Kenya and Sudan, respectively; economic conditions captured by the luminosity, distance from the border, distance from a source of water, an indicator variable equal to one if the distance from the closest road has decreased over the period 2000-2005, a dummy equal to one if the closest road is a primary road. Region and year fixed effects are included in every column. * Significant at 10%, ** significant at 5%, *** significant at 1%.

TABLE VI_a

Alternative Health Outcomes and Road Change: Children 0-5 Years Old

	(1) All	(2) Somalia/Djibouti	(3) Eritrea/Sudan	(4) Kenya
Panel A Respiratory				
$Roads5km_{t-5}$	-0.257	0.429	-1.121	-1.876
	(0.386)	(0.877)	(0.679)	(0.943)
R-squared	0.020	0.047	0.052	0.068
N	10894	1412	1007	735
Panel B Fever				
$Roads5km_{t-5}$	-0.055	0.368	-0.876	-1.430
	(0.484)	(1.047)	(1.230)	(1.363)
R-squared	0.025	0.037	0.047	0.074
N	10858	1405	1006	731
Panel C Diarrhoea				
$Roads5km_{t-5}$	0.216	1.827	0.184	-0.063
	(0.426)	(1.184)	(1.002)	(1.188)
R-squared	0.045	0.063	0.046	0.074
N	10866	1409	1005	733
Number of Clusters	1088	153	139	76
Individual Controls	Yes	Yes	Yes	Yes
HH Controls	Yes	Yes	Yes	Yes
Cluster Controls	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Region FE	Yes	Yes	Yes	Yes

Standard errors at the cluster level are reported in parentheses. The dependent variables fever, diarrhoea and respiratory disease, are dummy equal to one if the child has experienced fever in the last two weeks, diarrhoea recently and suffer from short, rapid breaths respectively. $Roads5km_{t-5}$ measures the number of road segments within 5 km. This variable corresponds to the number of roads within 5km in 2000 for under-fives interviewed in 2005, while corresponds to the number of roads in 2005 for under-fives interviewed in 2010. Individual controls include: birth order, gender, age and its square. Household (HH) controls include: time to get water, indicator variable for living at and above 1500 meters above the sea level, a dummy for being in a rural area, household size, wealth and electricity, mother's years of education and mother age. Cluster controls include: indicator dummies for being along a major route from Somalia, Djibouti, Eritrea, Kenya and Sudan, respectively; economic conditions captured by luminosity, distance from the border, distance from a source of water, an indicator variable equal to one if the distance from the closest road has decreased over the period 2000-2005, a dummy equal to one if the closest road is a primary road. Region and year fixed effects are included in every column. * Significant at 10%, ** significant at 5%, *** significant at 1%.

TABLE VI_b

Alternative Health Outcomes and Road Change: Children 0-5 Years Old

	(1) All	(2) Somalia/Djibouti	(3) Eritrea/Sudan	(4) Kenya
Panel A				
Stunting				
Roads5km$_{t-5}$	-0.377	1.498	0.416	-0.271
	(0.514)	(0.966)	(1.038)	(2.037)
R-squared	0.081	0.103	0.085	0.123
N	10894	1412	1007	735
Panel B				
Size at Birth				
Roads5km$_{t-5}$	0.013	-0.550	-0.035	0.652
	(0.492)	(1.286)	(1.404)	(1.723)
R-squared	0.045	0.028	0.043	0.068
N	10866	1404	1006	734
Number of Clusters	1088	153	139	76
Individual Controls	Yes	Yes	Yes	Yes
HH Controls	Yes	Yes	Yes	Yes
Cluster Controls	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Region FE	Yes	Yes	Yes	Yes

Standard errors at the cluster level are reported in parentheses. The dependent variable Stunting is a dummy equal to one if a child is defined as severely malnourished according to the Z-score classification. The dependent variable Size at Birth is a dummy equal to one if the size of the child at birth is smaller than the average or very small. *Roads5km$_{t-5}$* measures the number of road segments within 5 km. This variable corresponds to the number of roads within 5km in 2000 for under-fives interviewed in 2005, while corresponds to the number of roads in 2005 for under-fives interviewed in 2010. Individual controls include: birth order, gender, age and its square. Household (HH) controls include: time to get water, indicator variable for living at and above 1500 meters above the sea level, a dummy for being in a rural area, household size, wealth and electricity, mother's years of education and mother age. Cluster controls include: indicator dummies for being along a major route from Somalia, Djibouti, Eritrea, Kenya and Sudan, respectively; economic conditions captured by luminosity, distance from the border, distance from a source of water, an indicator variable equal to one if the distance from the closest road has decreased over the period 2000-2005, a dummy equal to one if the closest road is a primary road. Region and year fixed effects are included in every column. * Significant at 10%, ** significant at 5%, *** significant at 1%.