CGR Working Paper Series

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Toxic Roads: Unearthing Hazardous Waste Dumping

CGR Working Paper 82

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Abstract

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TOXIC ROADS: UNEARTHING HAZARDOUS WASTE DUMPING*

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July 2017

ABSTRACT

Illegal disposal of toxic waste has become an issue of concern in both developing and developed countries. Recycling hazardous waste entails very high costs, which might give strong incentives to dispose toxic material in an illegal way. This paper adopts an innovative strategy to identify where toxic waste might have been illicitly dumped. The strategy relies on a crucial premise: road constructions provide an ideal setting in which the burial of hazardous waste may take place. Guided by the medical literature, we investigate the health outcomes of individuals living along recently constructed roads in Ethiopia. We construct a unique dataset, which includes the extensive Demographic and Health Survey, together with georeferenced data on roads, villages and economic development, covering a 10-year period. We find that an additional road within a 5 kilometres radius is associated with an increase in infant mortality by 3 percentage points. Moreover, we provide evidence that young children living near a recently built road show a lower level of haemoglobin and are more likely to suffer from severe anaemia. A series of robustness checks confirms the above findings and excludes other potential confounding factors.

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*Caterina Gennaioli wishes to thank the UK Economic and Social Research Council through the Centre for Climate Change Economics and Policy for financial support, while Gaia Narciso acknowledges funding from Trinity College Dublin Arts and Social Sciences Benefactions. We wish to thank Nicola Gennaioli, Martina Kirchberger, Margaryta Klymak, Jesse Shapiro, Andrea Tesei and seminar participants at the School of Economics and Finance (Queen Mary), School of Business and Management (Queen Mary), 2017 CSAE Conference (Oxford), the Centre for Global Development (London), Centre for Development, Environment and Policy at SOAS, Trinity College Dublin, Grantham Research Institute (London School of Economics) and the Workshop on the Economics of Organized Crime (University of York) for very helpful comments. Shasha Li, Barra McCarthy, Gaspare Tortorici and Bryan Vadheim provided excellent research assistance.

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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 hazardous waste[1] is an important component of the problem and has become an issue of concern in both developing and developed countries.[2] Recycling toxic waste in compliance with existing regulations entails very high costs, which give a strong incentive to companies and individuals to dispose of hazardous material in an illegal way. According to Baird et al. (2014), illegal disposal of waste entails significant savings compared to its legal disposal. The profitability of illegal hazardous 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 (Rucevska et al., 2015), where it is much cheaper to dispose of toxic waste[4], and which have become the ideal destinations of loads of hazardous waste produced in developed countries. The illegal transnational flow of toxic waste is now recognized to be one of the most significant forms of transnational crime operated by criminal organizations worldwide (UNEP, 2015). A report by the World Bank (2010) highlights how illicit

[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 toxic 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 hazardous waste.

[4] Some studies provide specific numbers. 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.

disposing of toxic waste often consists of burying the hazardous waste underground. In other instances, police investigations have uncovered the sinking of ships carrying toxic waste (The Guardian, 2000b). The health and economic consequences on the local population are potentially devastating. In relation to exposure to toxic waste, Currie et al. (2011) shows that superfund clean-ups in New York decreased the incidence of congenital anomalies by 20-25%. Locating and assessing the distribution of 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. Nevertheless the available information on illegal dumping of hazardous waste dumping 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 toxic waste might have been dumped. By focusing on specific health outcomes, we measure the extent of health hazard associated with toxic waste exposure, and we identify where toxic waste may have been buried. 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 toxic waste exposure, as outlined by the medical literature.

Our strategy relies on a crucial premise: road constructions provide an ideal setting in which the burial of hazardous waste may take place. First, the embankments and the construction sites set up during the digging phase of road construction provide a place suitable for illegal waste dumping. Second, newly built roads make previously remote areas more accessible, potentially also for loads of toxic waste. The use of road construction sites for toxic waste disposal is indeed supported by evidence from both developed and developing countries.[5] This is the case of Italy

[5] For evidence on Italy (among others): Der Spiegel International (2014), Il Fatto Quotidiano (2011), The New York Times (2014). For evidence on Somalia (among others): Greenpeace (2010), The Guardian (2009a).

and what it is called the “Triangle of Death”, a vast area near Naples which has been the dump of toxic and industrial waste over the last few years. More recently, reports have emerged regarding the illicit burying of hazardous waste during the construction of the Brescia-Milano highway (La Repubblica, 2014). Dumping of toxic waste does not only happen under road construction sites, but also in the proximity of newly built roads, for example in places which become more accessible. According to an Environmental Assessment of a new road project in Ethiopia, funded by the African Development Fund, “*The major issues that need to be monitored during and after construction include […] potential increase in dumping of hazardous wastes on farmland and settlement areas*” (African Development Fund, 2011). Toxic waste sites are recognized as a major global health, it is therefore of uttermost importance to locate and study the distribution of hazardous waste.

Toxic waste has a number of negative effects on the health status of exposed individuals. The medical literature links specific health conditions, e.g. lower fertility, birth defects, anaemia, lower haemoglobin, to the potential effects of toxic waste exposure (Azmi et al. 2009, Khan et al. 2013, Stillerman et al. 2008, WHO 2010). Were toxic waste dumped during road construction, the health status of individuals living close to newly built roads would worsen. 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 nearby, in particular: infant mortality, haemoglobin level and severe anaemia of children under five years old.

The focus of our study is Ethiopia. A report by the United Nation Office on Drugs and Crime (UNODC, 2009) identifies Eastern African countries, including Somalia, Ethiopia and Eritrea, to be particularly under threat of toxic waste dumping and trafficking. Some of the contributing factors highlighted in the study are the weak institutional setting prevalent in the region, the widespread corruption and the geographical location. In particular the long coastline and penetrable borders, together with potential corruption episodes at the border (UNODC 2009 and AfDB 2012), render the access and the transit of illicit goods easy. We expect the effect of road constructions on health to be significant in the areas close to the major routes connecting Ethiopia to the main ports of access to the sea, mainly Somalia and Djibouti, which the anecdotal evidence associates with toxic waste trajectories (UNEP 2015, UNODC 2009, Greenpeace 2010). Indeed, 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*".

We focus on the Road Sector Development Program (RSDP), a major large-scale development program implemented in Ethiopia between 1997 and 2010. This program, 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, which took place between 2000 and 2010, 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), which contains several indicators of health for adults and children. In particular, we focus on the level of haemoglobin and severe anaemia of children under five, and on infant mortality. We then use georeferenced data on the Ethiopian roads network for the years 2000, 2005 and 2010, and we add data on light intensity at night-time to account for local economic development. Road maps are available for three points in time, hence allowing us to identify two changes, the first one occurring between 2000 and 2005 and the second between 2005 and 2010. 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. In this way we avoid to study the effect of roads not yet constructed and we isolate the effect of roads whose construction was completed.

The results are striking. 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. 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 these results hold along two main trajectories, which connect Ethiopia to Djibouti and to Somalia. These findings are consistent with the anecdotal evidence on the likely routes followed by toxic waste (UNODC 2009, Greenpeace 2010).

The identification of the effects we find is prone to be affected by several confounding factors and endogeneity problems. 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 toxic waste. To deal with these issues, we present a series of specifications and robustness checks, which further support our findings. First, we control for the role of urbanization; second, we provide evidence of the lack of relationship between road constructions and other alternative diseases not linked to exposure to toxins; third, 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. Our results are robust to these and other alternative specifications and are consistent with toxic waste being dumped along road constructions.

This paper provides ground-breaking evidence on the presence of toxic waste dumped during road constructions along the main routes connecting Ethiopia to Somalia and Djibouti. Our findings are of high policy relevance, suggesting that international organizations dealing with toxic waste should intensify their monitoring effort during 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 construction 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 looking 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. The authors consider births occurring within 5 kilometres of a superfund site between 1989 and 2003. They find that superfund clean-ups decrease the incidence of congenital anomalies by 20-25%. 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. 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. He and Perloff (2016) provide evidence of a non-monotonic relationship between water pollution and infant deaths: moderate levels of pollution are found to be the most dangerous.

Unlike previous studies, we could not use available data to measure directly the presence of toxic waste, as dumping of toxic waste is illegal and, by definition, it is 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).[6]

In the rest of the paper, Section II provides background information on toxic waste, and presents the Ethiopian context. 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 reports a series of robustness checks. Section VI presents further evidence and Section VII concludes.

II. INSTITUTIONAL BACKGROUND

II.A. Toxic Waste: Definition and Trends

Toxic waste can take many different forms, such as industrial waste, electronic and electrical waste (e-waste), or persistent organic pollutants.[7] In general, industrial waste refers to industrial by-products, such as incinerator ash, coolants and insulating fluids. Hazardous waste can also

[6] See also Olken and Pande (2012) for a review of these measurement methods in the context of corruption.

[7] 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).

originate from tanners, pharmaceutical companies or nuclear energy production. Persistent Organic Pollutants, *i.e.* pesticides, represent another instance of highly toxic material, which needs a high level of sophistication for the correct disposal.[8] The Food and Agriculture Organization (FAO) has compiled an inventory of stockpiles of obsolete pesticides for a large set of countries. The total existing stockpiles are estimated to be nearly 500 metric ton, often kept in the open, or in sub-standard storage facilities, or buried (FAO, 2001).[9]

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 disposal established a system of tracking and regulating the movement of hazardous waste. According to this system, senders should notify exporting, transit and destination countries of any hazardous waste shipments involving their territory. The 1989 Basel Convention criminalized trafficking of hazardous waste following the principle that waste should be managed as close as possible to the place where it was generated. The Basel Convention, which failed to stop transboundary movements of waste to African countries, was followed by the Bamako Convention. This agreement was ratified in 1995 and entered into force in 1998, banned the 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*".

[8] In 2001 the Stockholm convention banned the worst toxic chemicals.

[9] The FAO recommends that obsolete pesticides should be returned to the country of origin and effectively returned to the vendor. However, the cost of disposal is estimated around US $ 3,000 per tonne, which would amount to a total of US$ 1.5 billion (FAO, 2001).

II.B. The Ethiopian Context

Situated in the Horn of Africa, Ethiopia is a landlocked country. It is the second most populous country in Sub-Saharan Africa, with an estimated population in 2010 of 83 million people. 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.

Ethiopia represents an interesting case for two reasons. First, investigative reports indicate Ethiopia as a potential destination of the toxic waste traffic originating from developed countries (UNEP 2015, UNODC 2009, Legambiente 2011).[10] Second, Ethiopia has accumulated significant stockpiles of expired pesticides over the past decades due to poor pesticide management, donations in excess of need and the imposition of bans on the worst toxic chemicals. Indeed the absence of appropriate facilities to store the pesticides contributed to their accumulation all over the country, which leads to significant environmental and public health risk. Poor storage conditions, poor management of the stocks as well as a lack of monitoring and staff training have all affected the amount of stockpiles.[11]

Given the extent of the problem, the Ethiopian government, with the support of donors and the FAO, has initiated a series of pesticides' inventories.[12] It was estimated that there were at least 2,600 tons of obsolete pesticides in 2003. Part of these stockpiles was sent to Finland for treatment.[13] Due to budget limitations, the project could only conduct inventories of the known

[10] According to a Greenpeace report (2010) on toxic ships, a ship, the Lynx, sailed from the port of Marina di Carrara with a load of more than 2,000 tons of industrial waste. Its original destination was Djibouti, although, according to the report, Djibouti never meant to be the end of the export route. Djibouti is considered an important logistic hub for goods delivery to Somalia and Ethiopia. The Greenpeace report (2010) suggest that t waste could have followed the same delivery paths.

[11] Pesticides have a limited shelf life, which greatly shortens if not properly stored.

[12] United Nations Environment Programme (UNEP) cites Ethiopia as being one of the countries with the highest priorities for increasing technical, policy and institutional capacity and understanding for managing waste (UNEP, Ethiopia National Report, 2012).

[13] This project, supported by donors (in particular USAID and Sweden), is conducted by the World Bank.

situation. Therefore, buried pesticides and contaminated soil were not part of the project. Throughout the paper we argue that hazardous waste of this type may have been buried during road construction in Ethiopia.

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.[14] 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 2000-2010, which was exactly when the country held many open building sites.

III. DATA

According to the medical literature, three 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

[14] 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.

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 10km of the plant. Pesticide poisoning has also been found to lead to low 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.

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 the individual levels.[15] 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.[16] Therefore, haemoglobin levels are adjusted to take into account altitude and an indicator of severe anaemia is constructed accordingly.

Road data for 2000 and 2005 come from the Geographic Information Support Team (GIST) Repository at the University of Georgia, a USAID-funded global archive of spatial data. Road data for 2010 arise from Open Street Map a geospatial road information system with global map coverage. 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'

[15] 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.
[16] See Windsor et al. (2007) for a review of the medical literature.

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 toxic waste for two reasons; on the one hand, toxic waste can be buried under the newly built roads during construction, on the other hand, some remote areas might become more accessible also for loads of toxic waste. In both cases, an additional road segment could lead to a higher exposure to toxic 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.[17]

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 introduces a measurement error in our estimation, which would bias our estimates. The direction of the bias is undetermined. In some instances the displacement would move households away from the road change they actually experience, which would bias our results downwards. In other cases the displacement would move households closer to a road change that we observe, which would bias our results upwards.[18] The analysis performed in the paper would be biased only in the event that the displacement systematically moves clusters from areas with small roads changes to areas with large roads changes. In addition this should

[17] For simplicity, in the paper we will use the expression "number of roads" instead of "number of roads segments".
[18] The scenario of most concern would arise when the displacement of the cluster is performed at its maximum, i.e. 5 km, as it would attribute the change in roads that we observe to households that are located further away. This possibility takes place only when the change in roads that we observe is located outside the 5 km radius from the centre of the actual cluster, but within the 5 km circle from the centre of the displaced cluster. In this scenario, the maximum bias would arise by placing those households located 15 km away at a distance of 10 km.

happen only along specific routes within Ethiopia. This possibility is unlikely. 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.

We are able to identify two changes of the road system, the first occurring between 2000 and 2005 and the second between 2005 and 2010. 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. In this way we avoid to study 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.

Figure I displays the expansion of the road network occurring between 2000-2005 and 2005-2010, respectively, according to the road sector development program. Figure II shows how the expansion in the two periods varies by zone.[19] The highlighted routes in Figure I are the main trajectories that connect the capital Addis-Ababa to the neighbouring countries. Note that the extension of the road network between 2005 and 2010 seems to be much larger compared to the one reported for the period 2000-2005. In Figure II this is evident when looking at the difference between increases in the average number of roads over the two periods. This can be due to a large expansion of the road network over the period 2005-2010 but also to the fact that the data source for the 2010 map is different and might have a greater level of detail with respect to the previous ones. For this reason, we mainly use the change in road construction between 2000 and 2005 in our analysis. It is worth noting that the results based on the more recent road expansion support our findings as well.

[19] Third-level administrative divisions in Ethiopia.

[Figure I here]

[Figure II here]

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. 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.

The dataset is enriched with a number of control variables. We include clusters' light intensity at night-time which indicates the average luminosity across pixels that falls within the cluster. This variable comes from the Operational Linescanner System on the Defense Meteorological Satellite Program and allows us to control for clusters' economic conditions.[20]

[20] 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.

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)[21] 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. Descriptive statistics and relative sources are reported in Table A.1. in the Appendix.

IV. ROADS AND INFANT MORTALITY

IV.A. Infant Mortality

Road constructions provide an ideal setting in which the burial of hazardous waste may take place, as discussed in Section II.

As discussed, toxic waste has a number of negative effects on the health status of exposed individuals. Therefore if toxic waste were dumped during road construction, this would especially affect the health status of individuals living close to the new roads. In order to identify where hazardous 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. In fact, the medical literature, discussed in the Introduction, links these specific health measures directly to the potential effects of toxic waste exposure. 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.

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

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

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 follows:

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

The dependent variable 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. Our variable of interest 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, while X_{ct} indicates the night-light intensity and accounts for the level of economic development of each cluster.

[Table I 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 of 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 Kenya.[22] Results in Table 1 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. The size of the effect is large and corresponds to 35% of the sample mean.

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.

[22] 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.

The specification outlined in equation (1) captures the average effect over different birth cohorts. We can further disentangle the effect of roads by birth cohort, as it follows:

$$Y_{imct} = c + \sum_{j=0}^{4} \beta_j \, roads_{c\tau} * cohort_{(\tau+j)} + \boldsymbol{Z'_{imt}\theta} + \boldsymbol{I'_{it}\pi} + \delta X_{ct} + \eta_t + \mu_m + \varepsilon_{imct} \quad (2)$$

Where t=2000, 2001,…, 2010 and $\tau = \begin{cases} 2000 \; if \; t < 2005 \\ 2005 \; if \; t \geq 2005 \end{cases}$

The dependent variable takes the value of 1 if child *i* born in year *t* from mother *m* in cluster *c* died before reaching the age of 1 and takes the value of 0 otherwise. The variable $roads_{c\tau}$ measures the number of roads within 5 kilometres, in cluster *c* as measured at time τ, where τ can take two values, 2000 and 2005. We include child's characteristics ($\boldsymbol{I_{it}}$), mother's characteristics ($\boldsymbol{Z_{imt}}$), economic development at the cluster level (X_{ct}), birth cohort fixed effects (η_t) and mother fixed effects (μ_m). The coefficient of interest, β_j, captures the change in the probability of an infant death if a mother gives birth *j* years after the observed road constructions.

Table II presents the results of this specification. As before, we find no effect when analysing the entire sample. In line with the previous results, roads have a positive and statistically significant impact on the probability of infant mortality along the corridors connecting Addis-Ababa to Somalia and Djibouti (column 2). The estimated impact is greater for children born 2 to 3 years after the reported road construction. We do find some statistically significant impact of road construction on the route towards Eritrea/Sudan, however these findings disappear once we exclude from these routes, the roads that are in common with the Djibouti corridor.[23] Table A.2.

[23] Some of the main routes coming from Eritrea are in common with Djibouti and Somalia. In particular we observe that around 20% of the clusters located along the Eritrea corridor are also located along the Djibouti corridor. Results

in the Appendix presents the results of the placebo specification, where the number of roads between 10 kilometres and 30 kilometres is used as the main independent variable. In line with our expectations, we find no impact of roads being built further away on infant mortality.

[Table II here]

These findings seem to corroborate our hypothesis on the routes likely followed by toxic waste, i.e. the ones leading to the main ports. In particular we find evidence on higher infant mortality along the Somalia/Djibouti corridor. It is not surprising that we find a less robust effect on the Eritrea corridor, as the entry 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.

IV.B. Endogeneity

Cluster-Level Analysis

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 study whether the change in

of the exercise where we exclude the clusters that are located along the main Eritrean routes in common with Djibouti are available upon request.

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.[24] 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 III reports the results of this estimation conducted at 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.

[Table III here]

Pre-Trends in Infant Mortality

The results presented in Table III seem to exclude reverse causality in the relationship between lagged infant mortality rate and road constructions at cluster level. However it might be possible

[24] 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.

that for some unobservable reasons infant mortality was already raising in the treated clusters before the construction of new roads had actually taken place. To address this issue we test for the presence of pre-trends in infant mortality, comparing treated and untreated clusters before the treatment. The treated clusters are the ones which experience a positive increase in the number of roads between 2000 and 2005, while untreated clusters are the ones with a zero increase in roads between 2000 and 2005. The graphs reported below plot the coefficients of the regression of infant mortality on the interaction between dummies for birth cohorts in the period 1995-2000 and the intensity of the treatment they experience afterwards (i.e. change in roads between 2000 and 2005). The first graph refers to the overall sample, while the second reports the results when the sample is restricted to the Somalia/Djibouti corridor.

[Figure IV here]

[Figure V here]

The coefficient estimates in Figure IV and Figure V are statistically insignificant and close to zero, showing that the pattern of infant mortality is similar in treated and untreated clusters in the pre-treatment period, 1995-2000. This evidence rules out the presence of an existing trend in infant mortality before the road constructions takes place.

Falsification Test: Past-Future Roads

As a further step in the analysis of the timing of the effect, we analyse the relationship between infant mortality and road constructions, at cohort level, from four years before the observed road change to four years afterwards. We introduce a specification similar to equation (2), which focuses on both the pre- and post-road construction periods, as it follows:

$$Y_{imct} = c + \sum_{j=-4}^{4} \beta_j \, roads_{c\tau} * cohort_{(\tau+j)} + \boldsymbol{Z'_{imt}\theta} + \boldsymbol{I'_{it}\pi} + \delta X_{ct} + \eta_t + \mu_m + \varepsilon_{imct} \quad (3)$$

Interestingly 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).

Figures VI and Figure VII report the estimated β coefficients and relative confidence intervals at 95% level of equation (3), for the overall sample and for the sample restricted to the Somalia/Djibouti corridor.

[Figure VI here]

[Figure VII here]

The two graphs provide outright evidence that only completed roads lead to an increase in infant mortality, while future, not yet constructed, roads and roads supposedly under construction have a zero effect on the probability of infant mortality.

IV.C. Heterogeneous Effects

The aim of this section is to advance the understanding of the phenomenon of toxic 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 hazardous waste sites are found to contain several toxic chemicals.[25] Unfortunately we were not able to collect and analyse samples of soil or water in the field. Nonetheless we could 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 IV 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

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

household to a source of water. 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 IV further corroborates the hypothesis of the presence of toxic waste dumping along that Somalia and Djibouti route.

[Table IV here]

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[26] at the cluster level using all birth cohorts between 2000 and 2010, including the relevant controls[27] 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. Figure VIII 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 small circles but those coefficients are not statistically significant. Figure IX shows a similar picture but zoomed around the area of Harar.

[26] We do not have enough power to estimate the model in (1) including mother FE.

[27] Birth order and its square, infant sex, mother age at birth and its square and twin status.

[Figure VIII here]

[Figure IX here]

The figures suggest that the spots where we obtain a 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. The two cities are both very close to the border with Somalia, at around two hours' drive 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 concurrent disrupting 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, migration within Ethiopia follows mostly the rural-urban pattern and most of the clusters (about 80%) in our sample are in rural areas; 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 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 buried toxic waste. 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. The evidence in Tables A.3. in the Appendix confirms that the results are robust to the exclusion of the capital and surroundings.

As a further check we repeat the estimation in (1) excluding all the clusters that are classified as urban and we obtain an even stronger effect.[28] 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 this Section.

[28] Results from this specification are available upon request.

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 of 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 interview through the HemoCue machine that also allows an instantaneous anaemia assessment.[29] We study the effect of road construction on these two health outcomes, using a repeated cross section of children surveyed in 2005 and 2010 respectively. We estimate the following equation:

$$Y_{ihcrt} = \beta_0 + \beta_1 roads_{cr(t-5)} + \boldsymbol{X}'_{\boldsymbol{ihcrt}}\boldsymbol{\gamma} + \boldsymbol{Z}'_{\boldsymbol{hcrt}}\boldsymbol{\eta} + \boldsymbol{K}'_{\boldsymbol{crt}}\boldsymbol{\theta} + \delta_r + v_t + \varepsilon_{rt} + u_{ihcrt} \qquad (4)$$

where the dependent variable is either haemoglobin level or the presence of severe anaemia, for child *i*, belonging to household *h*, living in cluster *c*, in region *r*. The variable of interest,

[29] 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.

$roads5km_{cr(t-5)}$, 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 2010. 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 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 (4) 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 4 as a repeated cross-section.[30] Table V and Table VI report the results. We do not find any statistically significant relationship between roads construction and haemoglobin level when we consider children between 0-5 years old, while Table VI provides evidence of a positive and statistically significant relationship between severe anaemia and road construction along the Somalia/Djibouti corridor.

[30] Table A4 in the Appendix presents the estimation results of equation 4 where the dependent variable is infant mortality. The findings are very similar to the panel estimation presented in Table 1.

[Table V here]

[Table VI here]

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 V and Table VI 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 (4) 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. Results, reported in Table VII and Table VIII show a statistically insignificant relation between road construction and low haemoglobin levels, as well as the incidence of severe anaemia when considering Ethiopia as a whole. 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 higher incidence of severe anaemia and lower haemoglobin level. In particular results in column (2) of Table VII point out that an additional road within 5 kilometres is associated with a 0.17 points lower haemoglobin level, which correspond to 1.6% of the sample mean.

[Table VII here]

[Table VIII here]

The evidence in Table VIII highlights a tremendous effect of road construction on severe anaemia; an additional road within 5 kilometres is associated with an increase of 4 percentage points in the incidence of severe anaemia in children aged 2-5 years old. This corresponds to an increase of 75% 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.[31] 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 routes followed by toxic waste entering the Horn of Africa.

V.C. Alternative Health Outcomes

Our results might 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 (4) for a set of alternative health measures for the sample of children aged 0-5 years old.[32] 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 IX 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.

[31] The results hold when the capital Addis-Ababa is excluded from the sample (see Tables A.5.-A.6. in the Appendix).
[32] 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.

Given the richness of DHS data we are able to run an additional check and estimate specification (4) using an alternative health outcome, specifically respiratory diseases that can be directly linked to pollution.[33] Panel A in Table IX 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, do not suffer from air pollution. Table IX 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.

[Table IX here]

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 the displacement is randomly distributed across clusters and routes. To further address this issue we have performed alternative specifications where we consider changes in roads at different distances from the centre of the clusters. In particular we have studied 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.[34]

[33] The medical literature has extensively proven how pollution increases the incidence of respiratory conditions. See for example Dominici et al. (2006).
[34] Results from these specifications are available upon request.

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 geographical proximity of these countries. As a robustness check we have repeated the analysis presented in the paper, considering all of the routes separately. 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.[35]

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 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.[36] If anything our results should be downward

[35] Results from these specifications are available upon request.
[36] 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.

biased. To investigate this issue we run a series of specifications[37] 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. Results from these specifications show that road construction has a minimum effect on contemporaneous cohorts, while it has the largest and most significant effect on later cohorts.

VII. 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.

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

[37] Results from these specifications are available upon request.

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 certain 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 of 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 other potential confounding factors, such as pollution, migration and issues in relation to reverse causality. 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 toxic 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 toxic 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 illegal 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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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	0.640	3.012***	2.737	-1.286
	(0.648)	(0.895)	(2.195)	(1.688)
Treated Clusters	153	40	26	17
R-squared	0.160	0.157	0.188	0.217
Panel B				
Roads30km	-0.006	-0.344	-0.467	-0.475
	(0.169)	(0.511)	(0.457)	(0.424)
Treated Clusters	423	61	62	35
R-squared	0.160	0.154	0.188	0.217
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

Infant Mortality and Road Change: Individual Effect by Birth-Cohort

	(1) All	(2) Somalia/Djibouti	(3) Eritrea/Sudan	(4) Kenya
$Roads_t \# Cohort_t$	0.521	2.619**	1.225	-2.892
	(0.699)	(1.148)	(2.279)	(2.371)
$Roads_t \# Cohort_{t+1}$	0.132	2.987***	3.969*	-0.853
	(0.695)	(0.982)	(2.282)	(2.190)
$Roads_t \# Cohort_{t+2}$	1.003	2.959**	4.463*	-2.196
	(0.706)	(1.194)	(2.406)	(2.234)
$Roads_t \# Cohort_{t+3}$	0.496	3.652***	4.200*	-1.558
	(0.701)	(1.183)	(2.271)	(1.588)
$Roads_t \# Cohort_{t+4}$	0.697	2.721**	1.398	-0.085
	(0.693)	(1.137)	(2.161)	(2.062)
Treated Clusters	153	40	26	17
R-squared	0.164	0.170	0.198	0.224
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. $Roads_t$ measures the number of road segments within 5 km at time *t*. This variable corresponds to the number of roads within 5km in *t*=2000 for the births between 2000 and 2004, while corresponds to the number of roads in *t*=2005 for births occurring from 2005 onwards. The variable $Roads_t \# Cohort_{t+j}$ is the interaction between $Roads_t$ and a "cohort" dummy (=1 if a child is born in *t+j*). 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 III

Initial Conditions and Road Change: Cluster-Level Analysis

	(1) All	(2) Somalia/Djibouti	(3) Eritrea/Sudan	(4) Kenya
Infant_mortality	0.014	0.280	0.278	-0.798
	(0.243)	(0.993)	(0.582)	(1.005)
Luminosity_2000	0.022	0.017	0.001	0.235**
	(0.027)	(0.047)	(0.061)	(0.099)
Electricity	0.145	-0.500	0.281	-1.267
	(0.244)	(0.411)	(0.308)	(0.839)
Rural	-0.125	-0.810	-0.038	-0.138
	(0.161)	(0.508)	(0.435)	(0.707)
Mother_edu	0.022	-0.003	0.013	0.069
	(0.022)	(0.045)	(0.031)	(0.073)
Region Fixed Effects	Yes	Yes	Yes	Yes
R-squared	0.275	0.175	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 IV

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

	(1) All	(2) Somalia/Djibouti	(3) Eritrea/Sudan	(4) Kenya
Panel A				
Roads5km	-0.383	0.551	-0.049	-1.437
	(0.725)	(0.886)	(2.712)	(1.518)
Roads5km#Water	1.498	2.747***	4.493	0.230
	(1.005)	(0.759)	(3.676)	(2.578)
Treated Clusters	153	40	26	17
R-squared	0.162	0.171	0.189	0.217
Panel B				
Roads30km	-0.012	-0.884**	-0.683	-0.259
	(0.219)	(0.433)	(0.576)	(0.501)
Roads30km#Water	-0.005	1.517**	0.418	-0.556
	(0.251)	(0.655)	(0.538)	(0.479)
Treated Clusters	423	61	62	35
R-squared	0.162	0.170	0.188	0.218
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. 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 V

Haemoglobin Level and Road Change: Children 0-5 Years Old

	(1) All	(2) Somalia/Djibouti	(3) Eritrea/Sudan	(4) Kenya
Panel A				
$Roads5km_{t-5}$	-0.027	-0.095	-0.085	-0.000
	(0.024)	(0.078)	(0.069)	(0.071)
R-squared	0.196	0.282	0.266	0.255
Panel B				
$Roads30km_{t-5}$	-0.002	-0.014	0.004	-0.017
	(0.005)	(0.022)	(0.015)	(0.020)
R-squared	0.196	0.281	0.265	0.256
Number of Clusters	1021	135	128	74
HH Controls	Yes	Yes	Yes	Yes
Cluster Controls	Yes	Yes	Yes	Yes
Region FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Year by Region FE	Yes	Yes	Yes	Yes
N	8098	946	720	552

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 under-fives interviewed in 2005, while corresponds to the number of roads in 2005 for under-fives 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, year and year by region fixed effects are included in every column. * Significant at 10%, ** significant at 5%, *** significant at 1%.

TABLE VI

Severe Anaemia and Road Change: Children 0-5 Years Old

	(1) All	(2) Somalia/Djibouti	(3) Eritrea/Sudan	(4) Kenya
Panel A				
$Roads5km_{t-5}$	0.280	2.792**	1.150	-0.407
	(0.284)	(1.255)	(0.846)	(0.661)
R-squared	0.078	0.185	0.154	0.188
Panel B				
$Roads30km_{t-5}$	-0.013	-0.193	-0.202	0.032
	(0.058)	(0.480)	(0.209)	(0.185)
R-squared	0.078	0.179	0.153	0.187
Number of Clusters	1021	135	128	74
HH Controls	Yes	Yes	Yes	Yes
Cluster Controls	Yes	Yes	Yes	Yes
Region FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Year by Region FE	Yes	Yes	Yes	Yes
N	8098	946	720	552

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 under-fives interviewed in 2005, while corresponds to the number of roads in 2005 for under-fives 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, year and year by region fixed effects are included in every column. * Significant at 10%, ** significant at 5%, *** significant at 1%.

TABLE VII

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

	(1) All	(2) Somalia/Djibouti	(3) Eritrea/Sudan	(4) Kenya
Panel A				
$Roads5km_{t-5}$	-0.037	-0.170**	-0.097	-0.036
	(0.027)	(0.080)	(0.073)	(0.076)
R-squared	0.175	0.263	0.262	0.203
Panel B				
$Roads30km_{t-5}$	-0.002	-0.010	-0.001	-0.028
	(0.006)	(0.022)	(0.015)	(0.023)
R-squared	0.175	0.259	0.259	0.206
Number of Clusters	981	125	123	72
HH Controls	Yes	Yes	Yes	Yes
Cluster Controls	Yes	Yes	Yes	Yes
Region FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Year by Region FE	Yes	Yes	Yes	Yes
N	5386	636	487	381

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, year and year by region fixed effects are included in every column. * Significant at 10%, ** significant at 5%, *** significant at 1%.

TABLE VIII

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

	(1) All	(2) Somalia/Djibouti	(3) Eritrea/Sudan	(4) Kenya
Panel A				
$Roads5km_{t-5}$	0.267	4.035***	0.643	-0.082
	(0.313)	(1.362)	(0.781)	(0.803)
R-squared	0.070	0.175	0.183	0.261
Panel B				
$Roads30km_{t-5}$	0.001	-0.278	0.072	0.122
	(0.058)	(0.508)	(0.209)	(0.248)
R-squared	0.070	0.163	0.182	0.262
Number of Clusters	981	125	123	72
HH Controls	Yes	Yes	Yes	Yes
Cluster Controls	Yes	Yes	Yes	Yes
Region FE	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes
Year by Region FE	Yes	Yes	Yes	Yes
N	5386	636	487	381

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, year and year by region fixed effects are included in every column. * Significant at 10%, ** significant at 5%, *** significant at 1%.

TABLE IX

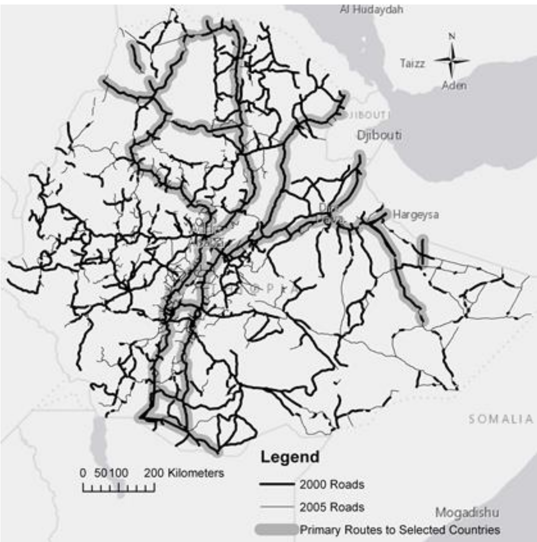
Alternative Health Outcomes and Road Change: Children 0-5 Years Old

	(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%.

FIGURE I
Change in the Road Network

Period: 2000-2005



Period: 2005-2010

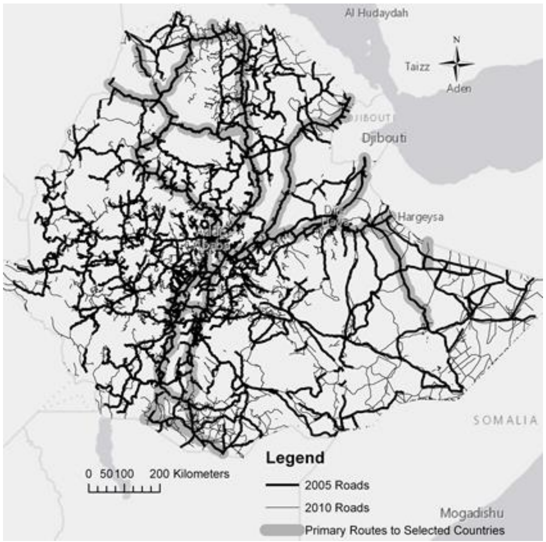
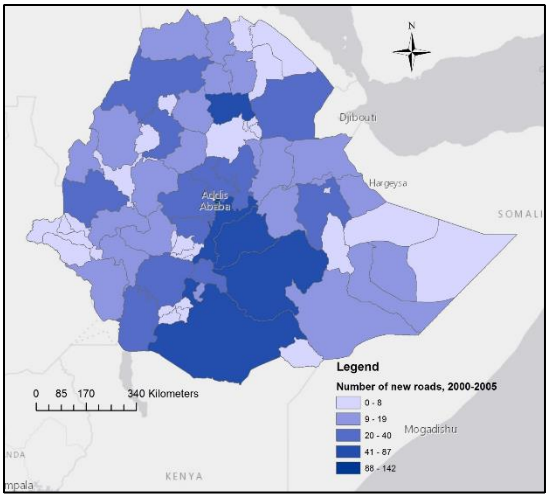


FIGURE II
Change in the Road Network by Zones

Period: 2000-2005



Period: 2005-2010

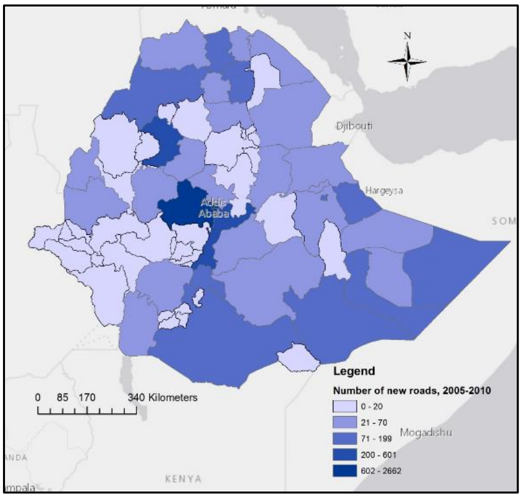


FIGURE III
Increase in the Road Network for a Random Cluster

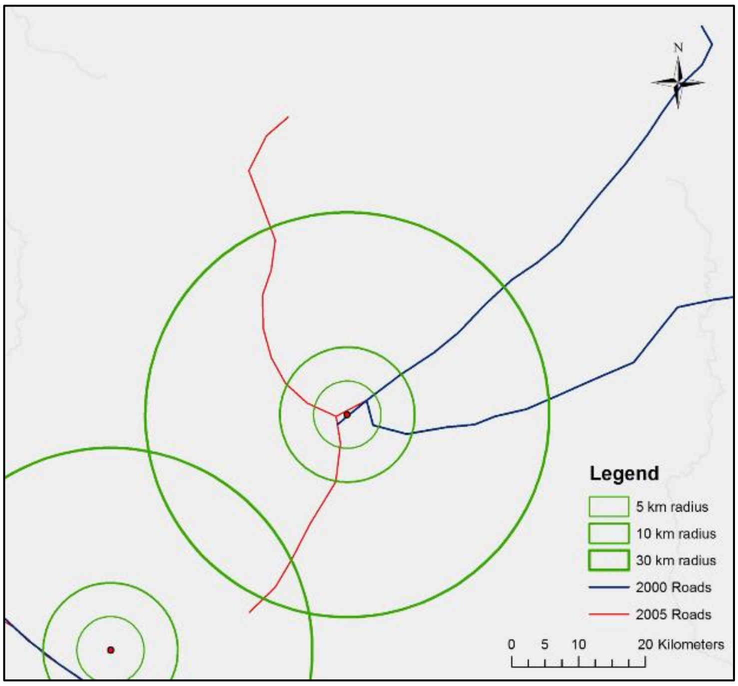
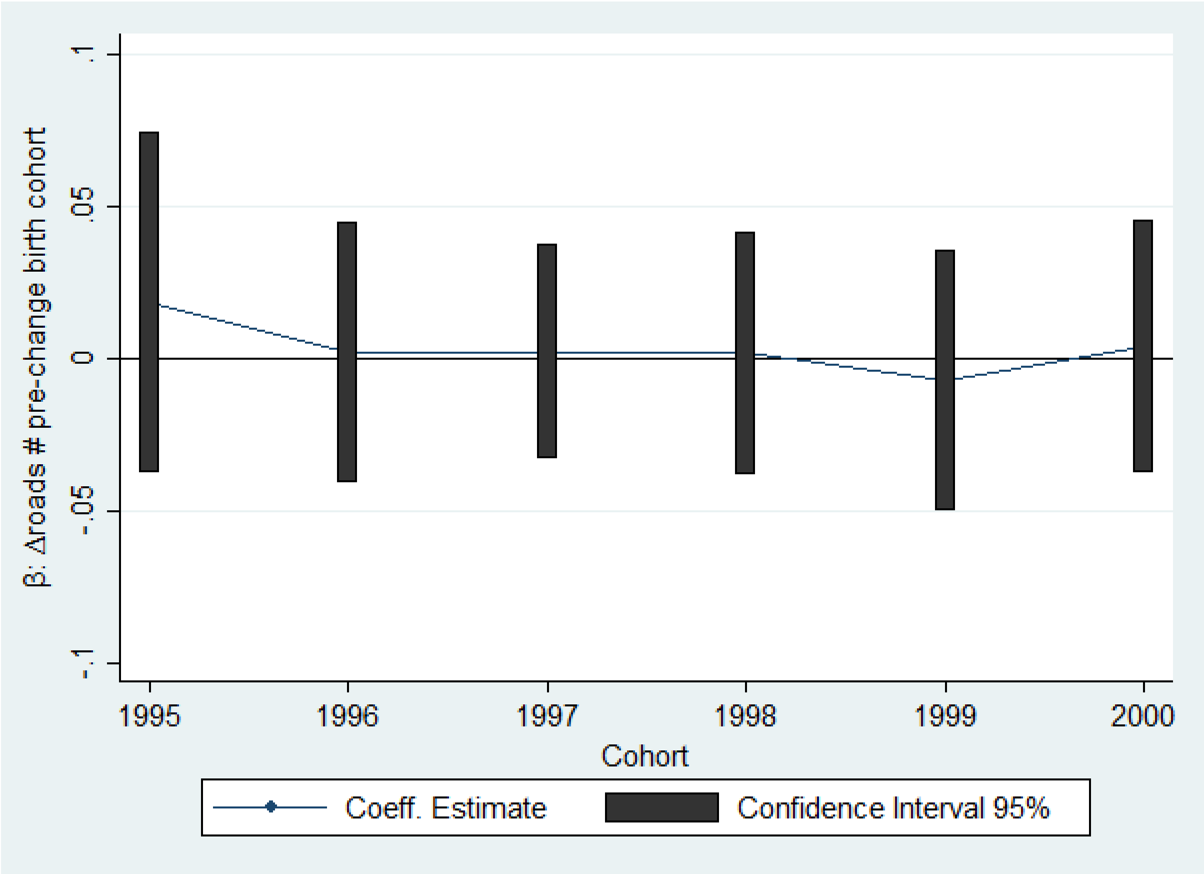
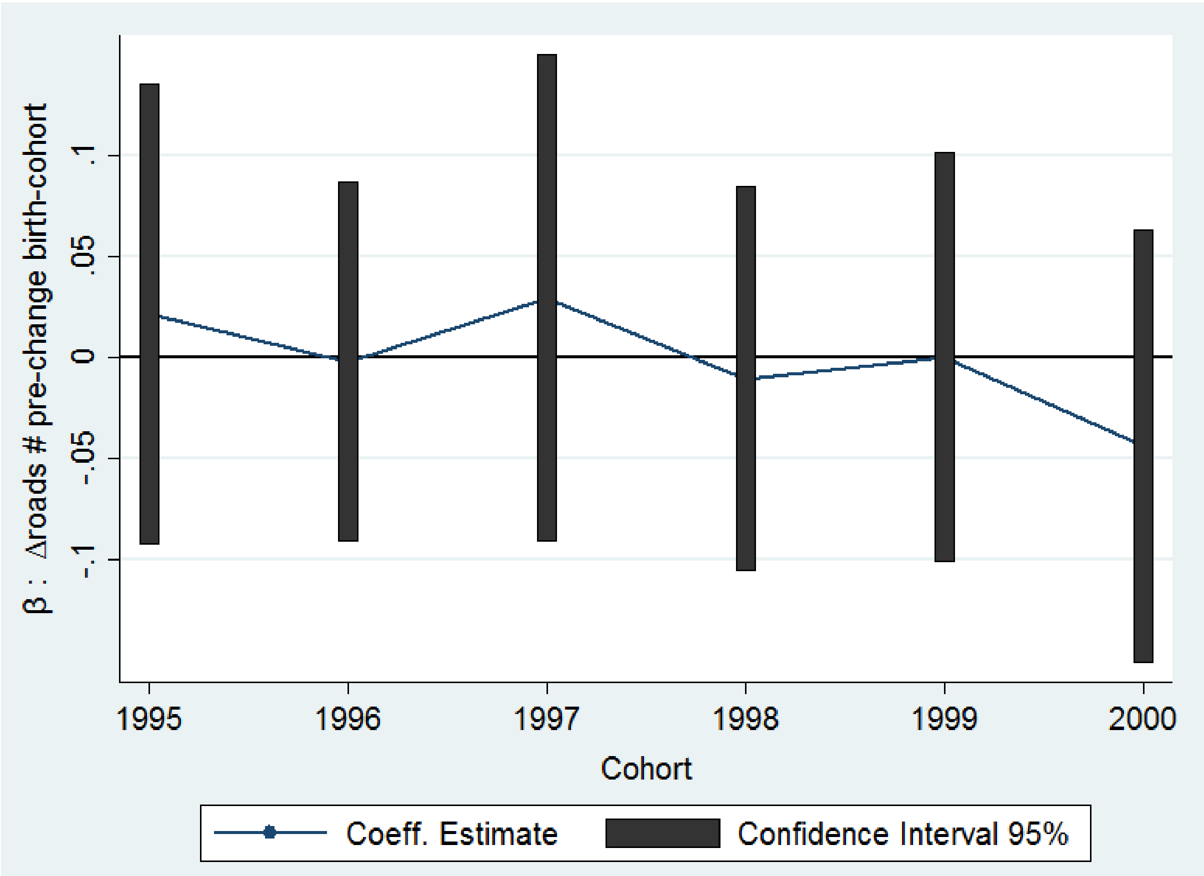


FIGURE IV
Pre-Trends in Infant Mortality: All Roads



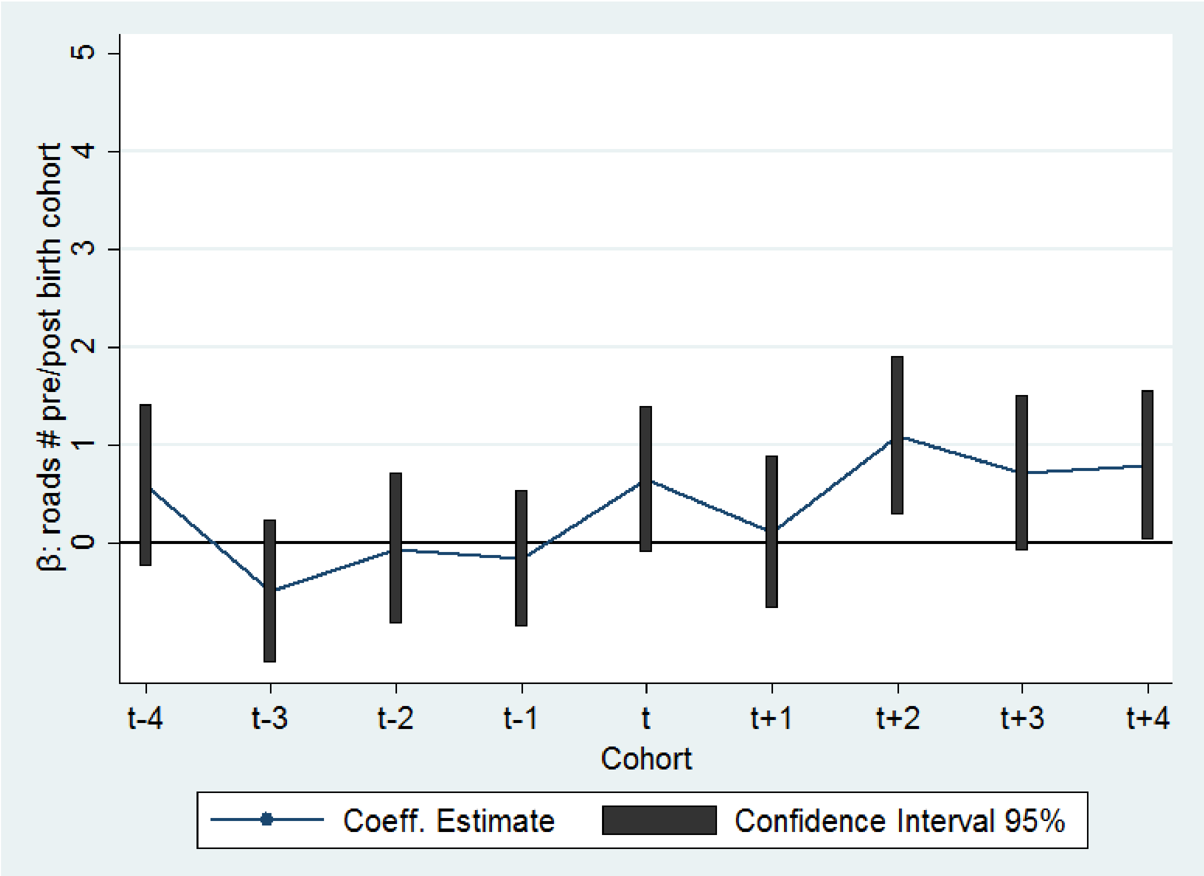
The figure plots the coefficients obtained by a panel regression at mother level of infant mortality on the interaction between the change in roads over the period 2000-2005 and birth cohort dummies for the pre-road change period (1995-2000).

FIGURE V
Pre-Trends in Infant Mortality: Somalia and Djibouti Route



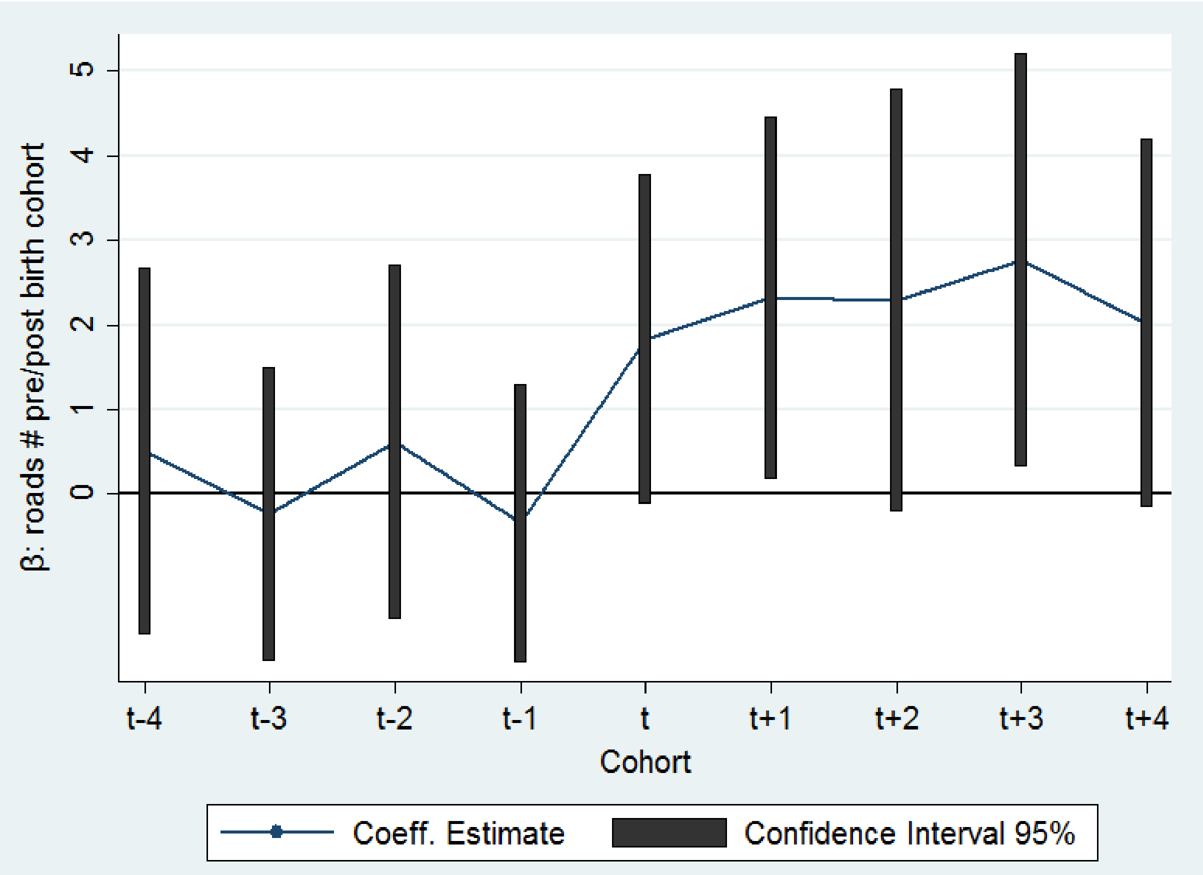
The figure plots the coefficients obtained by a panel regression at mother level of infant mortality on the interaction between the change in roads over the period 2000-2005 and birth cohort dummies for the pre-road change period (1995-2000).

FIGURE VI
Falsification Test: All Roads



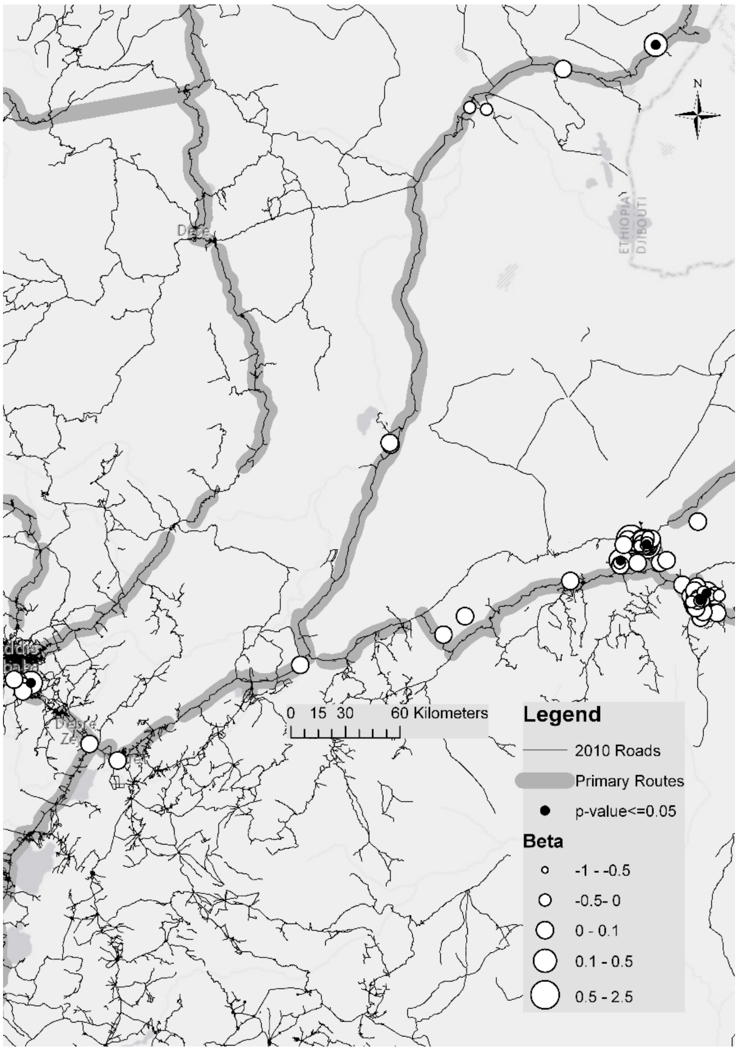
The figure plots the coefficients obtained by a panel regression at mother level of infant mortality on the interaction between roads at time *t* and a full set of birth cohort dummies for the period before and after *t*.

FIGURE VII
Falsification Test: Somalia and Djibouti Route



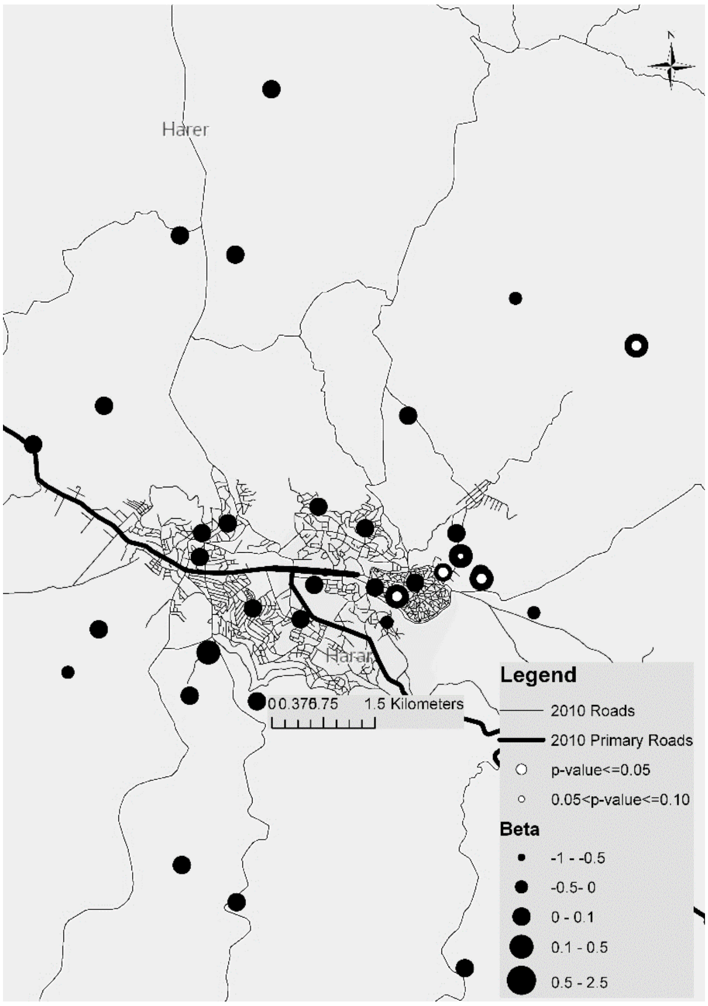
The figure plots the coefficients obtained by a panel regression at mother level of infant mortality on the interaction between roads at time *t* and a full set of birth cohort dummies for the period before and after *t*.

FIGURE VIII
Distribution of the Effect across the Clusters along the Djibouti and Somalia Routes



The figure plots 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.

FIGURE IX
Distribution of the Effect across the Clusters around the Area of Harar



The figure plots 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.

APPENDIX

TABLE A.1.

Descriptive Statistics and Data Sources

Variable	Obs	Mean	Std. Dev.	Min	Max	Source
Infant_mortality	24744	0.085	0.28	0	1	DHS (Births Recode)
Haemoglobin	8508	10.713	1.814	1.8	18.3	DHS (Births Recode)
Severe Anaemia	8508	0.053	0.225	0	1	DHS (Births Recode)
Diarrhoea	10688	0.152	0.359	0	1	DHS (Births Recode)
Fever	10670	0.195	0.396	0	1	DHS (Births Recode)
Respiratory	12940	0.096	0.295	0	1	DHS (Births Recode)
droads5km_1	24744	0.287	0.661	0	4	GIST-USAID, University of Georgia
droads5km_2	24744	36.281	164.144	0	978	GIST-USAID and Open Street Map
droads30km_1	24744	2.418	2.433	0	13	GIST-USAID, University of Georgia
droads30km_2	24744	278.53	1353.589	0	7814	GIST-USAID and Open Street Map
Somalia	24744	0.108	0.31	0	1	GIST-USAID, University of Georgia
Djibouti	24744	0.07	0.256	0	1	GIST-USAID, University of Georgia
Eritrea	24744	0.091	0.288	0	1	GIST-USAID, University of Georgia
Kenya	24744	0.062	0.242	0	1	GIST-USAID, University of Georgia
Sudan	24744	0.016	0.125	0	1	GIST-USAID, University of Georgia
primary road	23871	0.192	0.394	0	1	GIST-USAID, University of Georgia
distance1_d	24744	0.513	0.5	0	1	GIST-USAID, University of Georgia
distance2_d	24744	0.761	0.426	0	1	GIST-USAID, University of Georgia
border_distance	23871	171195.7	113261.1	134.31	446390.9	GIST-USAID, University of Georgia
water_distance	23871	4006.896	5297.212	0.44	64358.8	GIST-USAID, University of Georgia
rural	24744	0.83	0.376	0	1	DHS (Births Recode)
high	24744	0.609	0.488	0	1	DHS (Births Recode)
time_water	24193	60.084	88.13	0	995	DHS (Births Recode)
NTLI	24744	3.86	17.331	0	212.545	Operational Linescan System, Defense Meteorological Satellite Program
electricity	24744	0.183	0.387	0	1	DHS (Births Recode)
wealth	24744	2.726	1.502	1	5	DHS (Births Recode)
HH_size	24744	6.341	2.389	1	22	DHS (Births Recode)
female	24744	0.489	0.5	0	1	DHS (Births Recode)
age (months)	10480	29.127	17.432	0	59	DHS (Births Recode)
birth_order	24744	3.874	2.534	1	17	DHS (Births Recode)
Motherage_birth	24744	25.12	6.56	10	47	DHS (Births Recode)
HH_female	24744	0.197	0.398	0	1	DHS (Births Recode)
non_smoker	24731	0.958	0.201	0	1	DHS (Births Recode)
Mother_age	24744	31.356	6.979	15	49	DHS (Births Recode)
Mother_edu	24744	1.322	2.912	0	17	DHS (Births Recode)

TABLE A.2.

Infant Mortality and Road Change: Individual Effect by Birth-Cohort

	(1) All	(2) Somalia/Djibouti	(3) Eritrea/Sudan	(4) Kenya
$Roads_t\#Cohort_t$	0.006	-0.301	-0.443	-0.533
	(0.172)	(0.460)	(0.431)	(0.377)
$Roads_t\#Cohort_{t+1}$	-0.052	0.011	-0.334	-0.479
	(0.172)	(0.484)	(0.435)	(0.397)
$Roads_t\#Cohort_{t+2}$	0.078	-0.105	-0.770*	-0.366
	(0.177)	(0.534)	(0.435)	(0.437)
$Roads_t\#Cohort_{t+3}$	-0.122	-0.096	-0.224	-0.447
	(0.178)	(0.544)	(0.415)	(0.321)
$Roads_t\#Cohort_{t+4}$	-0.002	-0.207	-0.470	-0.087
	(0.172)	(0.489)	(0.502)	(0.424)
Treated Clusters	423	61	62	35
R-squared	0.161	0.158	0.190	0.220
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. $Roads_t$ measures the number of road segments between 10km and 30 km at time *t*. This variable corresponds to the number of roads between 10km and 30km in *t*=2000 for the births between 2000 and 2004, while corresponds to the number of roads in *t*=2005 for births occurring from 2005 onwards. The variable $Roads_t\#Cohort_{t+j}$ is the interaction between $Roads_t$ and a "cohort" dummy (=1 if a child is born in *t+j*). 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 A.3.

Infant Mortality and Road Change: Average Effect over Different Birth-Cohorts Excluding the Capital Addis-Ababa

	(1) All	(2) Somalia/Djibouti	(3) Eritrea/Sudan	(4) Kenya
Panel A				
Roads5km	0.675	3.083***	4.810*	-4.770**
	(0.723)	(0.898)	(2.639)	(2.025)
Treated Clusters	121	36	12	11
R-squared	0.159	0.155	0.183	0.197
Panel B				
Roads30km	0.032	-0.339	-0.423	-0.563
	(0.177)	(0.633)	(0.587)	(0.480)
Treated Clusters	369	56	38	26
R-squared	0.159	0.152	0.182	0.195
Number of Clusters	542	72	48	29
Individual Controls	Yes	Yes	Yes	Yes
Mothers FE	Yes	Yes	Yes	Yes
Year Birth FE	Yes	Yes	Yes	Yes
N	23892	2946	1755	1354

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 A.4.

Infant Mortality and Road Change: Repeated Cross-Section

	(1) All	(2) Somalia/Djibouti	(3) Eritrea/Sudan	(4) Kenya
Panel A				
$Roads5km_{t-5}$	0.111	1.413**	0.637	0.021
	(0.184)	(0.561)	(0.464)	(0.530)
R-squared	0.051	0.072	0.080	0.081
Panel B				
$Roads30km_{t-5}$	-0.009	-0.003	0.068	0.193
	(0.048)	(0.185)	(0.110)	(0.122)
R-squared	0.051	0.070	0.079	0.082
Number of Clusters	571	77	72	38
HH Controls	Yes	Yes	Yes	Yes
Cluster Controls	Yes	Yes	Yes	Yes
Region FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Year by Region FE	Yes	Yes	Yes	Yes
N	23724	3038	2104	1918

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. $Roads5km_{t-5}$ measures the number of road segments within 5 km. This variable corresponds to the number of roads within 5km in 2000 for children born between 2000 and 2004, while corresponds to the number of roads in 2005 for children born between 2005 and 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: infant sex, birth order and its square, 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 at birth and its square, smoking status 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, year and year by region fixed effects are included in every column. * Significant at 10%, ** significant at 5%, *** significant at 1%.

TABLE A.5.

Haemoglobin Level and Road Change: Children 2-5 Years Old Excluding the Capital Addis-Ababa

	(1) All	(2) Somalia/Djibouti	(3) Eritrea/Sudan	(4) Kenya
Panel A				
$Roads5km_{t-5}$	-0.032	-0.163**	-0.155	0.006
	(0.029)	(0.080)	(0.096)	(0.084)
R-squared	0.174	0.252	0.255	0.174
Panel B				
$Roads30km_{t-5}$	-0.003	-0.010	-0.001	-0.040
	(0.006)	(0.023)	(0.018)	(0.026)
R-squared	0.174	0.248	0.249	0.181
Number of Clusters	907	119	90	60
HH Controls	Yes	Yes	Yes	Yes
Cluster Controls	Yes	Yes	Yes	Yes
Region FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Year by Region FE	Yes	Yes	Yes	Yes
N	5218	614	413	343

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, year and year by region fixed effects are included in every column. * Significant at 10%, ** significant at 5%, *** significant at 1%.

TABLE A.6.

Severe Anaemia and Road Change: Children 2-5 Years Old Excluding the Capital Addis-Ababa

	(1) All	(2) Somalia/Djibouti	(3) Eritrea/Sudan	(4) Kenya
Panel A				
$Roads5km_{t-5}$	0.222	4.059***	1.283	-0.258
	(0.332)	(1.366)	(0.966)	(0.949)
R-squared	0.071	0.172	0.175	0.105
Panel B				
$Roads30km_{t-5}$	0.001	-0.277	0.008	0.183
	(0.058)	(0.511)	(0.249)	(0.286)
R-squared	0.071	0.160	0.172	0.107
Number of Clusters	907	119	90	60
HH Controls	Yes	Yes	Yes	Yes
Cluster Controls	Yes	Yes	Yes	Yes
Region FE	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes
Year by Region FE	Yes	Yes	Yes	Yes
N	5218	614	413	343

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, year and year by region fixed effects are included in every column. * Significant at 10%, ** significant at 5%, *** significant at 1%.