Dam Operations and Infant Mortality in Africa*

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Abstract

This paper investigates the impact of dams on infant mortality in Africa. It exploits variation in child exposure to dams at birth across both regions and birth cohorts. The paper uses a compiled sample of 912,080 children from DHS surveys in 17 African countries. Only children of non-migrant mothers from this sample are used in the main analysis to minimise sample selection bias from endogenous parental migration. We account for the fact that dam impacts are determined by relative locations of households and dams along the river network. Our results indicate that each dam in the neighbouring upstream river basin from a child reduces the probability of her death during age 0-12 months by 3.84-4.60% on average. This is due to households being close enough to access dam irrigation services that are provided immediately downriver from the dam, and which reduce vulnerability to rainfall shocks in agricultural production. In contrast, upstream dams in river basins farther upriver from the child increase infant mortality risk by 2.18-2.36%. This is because dams reduce water levels downriver, and households cannot access compensating irrigation services from dams that are too far upstream. The decline in water level is very detrimental to floodplain recession agriculture, on which much of Africa depends. Regulated discharges of water from these upstream dams to reduce amplitude of rainfall shocks downriver also do not compensate for the detriments of declining water levels. Within-basin dams marginally increase infant mortality by 0.74-0.79% for children born in floodplain regions, by disrupting the river inundation cycle and possibly increasing incidence of waterborne diseases in the same river basin. Downstream dams have no apparent impact on infant mortality.

JEL classification: I18, J13, O22, O55

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"It completely regulates flooding in the Omo, which has been a major problem."

-Ethiopia Prime Minister Zenawi, on Gibe III dam planned for the Omo River, 2009.

"We will suffer because there will be no more floods. I don't think the government likes the Omo tribes. They are going to destroy us."

-Mursi tribe elder, on Gibe III dam being built upstream, Ethiopia, 2009.

1 Introduction

The debate on the welfare effects of large dams has become increasingly vocal in recent years. Many developing countries have undertaken very large investments in dam construction to increase irrigation and hydroelectricity generation capacity, to the extent that dams have been placed on nearly half the world's rivers (Duflo and Pande, 2007). Dam construction has undoubtedly played an important role in economic development, with 30-40% of the irrigated area and 19% of the total electricity generation in the world being dependent on dam operation (World Commission on Dams, 2000). However the effects of dam construction have often been visibly harmful, and often extremely severe. Documented consequences include flooding beyond the reservoir, increased saline content in the soil, and detrimental changes in cropping patterns forced by altered river flow patterns. Declining water levels and changing currents due to upstream dams can also permanently alter the river ecosystem, as well as the livelihoods of communities who rely on this ecosystem and the natural flow of the river. Whether these various dam effects have a direct impact on infant survival is a question that is yet to be answered. Ideally the answer to this question should be a fundamental underpinning of the dam-building process. This paper investigates whether dam operations have indeed had an impact on infant mortality in Africa; the continent that is currently undergoing a surge in dam construction and where the policy implications of this analysis are highly relevant.

To the best of our knowledge this is the first paper that attempts to identify the impact of dams on infant mortality. The findings of our analysis are meant to improve on what is already known on the welfare effects of dams by investigating this question for a very large sample of children across several countries in Africa. If dam operations have any significant effects on infant mortality, then our sample alone would account for more than half a million children who potentially experience these effects. We additionally separate the impacts of dams in neighbouring regions to households from the effect of dams in regions farther away along the river, which is another contribution to the existing literature. Disaggregating dam impacts based on distance is important, as the effect of dams on river water levels and amplitude of rainfall shocks changes from within the extent of the dam irrigation network to outside this extent farther downriver. This is also the first paper we are aware of that uses estimations at the level of the individual child to assess the impact of dams on a welfare outcome.

Our empirical analysis faces some fairly weighty confounding factors. The first issue is that regions selected for dam construction are likely to be very different from those not chosen, as dams require moderate to steep river gradients to operate. There are also political and other regional factors besides geography that determine dam placement. Hence even though we have significant regional variation in intensity of dam construction, a simple comparison of infant mortality probability between these regions will lead to biased estimates of dam impacts. To address this we exploit the fact that there is variation in child exposure to dams at birth both across regions, and over time due to variation in the timing of dam construction and child birth. This allows us to use a difference-in-difference (DID) estimation using this variation across both regions and time in exposure to dams at birth to ascertain dam impacts on infant mortality.

The second major issue is that of selective migration bias. The enmasse displacement of people due to dams as well as voluntary migration potentially leads to highly selected samples of mothers in each region, making it potentially difficult to separate dam effects from unobserved maternal characteristics that influence both the decision to migrate to particular regions and the probability of infant survival. To deal with this concern we identify women interviewed in our sample who have never migrated, and carry out our main analysis only for children born to these non-migrant mothers. This reduces sample selection bias from parental migration out of areas harmfully affected by dams into areas that are benefited. Non-migrants are more comparable between different categories of dam exposure as they are present over time in the same place while dams are constructed. Given that households are welfare-maximisers, we can reasonably expect that non-migrants choose to stay at their current place of residence as it maximises the net gains from all harmful and beneficial impacts of dams subject to available household resources. However non-migrant mothers may also choose to remain where they reside based on other unobservable factors that are potentially correlated with dam coverage. We therefore check our results carefully for omitted variable bias using several robustness checks. The first of these shows that there are negligible impacts on a child's infant mortality risk of dams built when the child is aged 10 years or older. The second set of checks are placebo regressions using dams located very far away from children as the source of exposure rather than dams that are closer, and ensuring that estimated impacts shrink as a result. To additionally check for bias from omitted geographical factors within the river basin, we implement an additional check that exploits dam dependence on river gradients to construct regional propensity scores for dam placement. We then include the propensity score as a regressor in our specifications to ensure no geographical omitted unobservables are driving the results.

Since dam effects vary depending on where households are located along the river network relative to the dam, we define whether dams are upstream, downstream, or in the same vicinity as households by using river drainage basins. The entire African continent can be broken down into these river basins, and each basin is coded so that we can identify whether it is upstream or downstream along the river network from every other basin. We identify which river basins households and dams lie in, and then define whether dams are upstream, downstream, or in the same basin as households using the basin river linkages. We then exploit the regional variation in our sample to separately identify the effects of upstream, downstream, and within-basin dams on infant mortality. As an extension to the analysis we search for differential dam impacts among children born in floodplain regions, as floodplain recession agriculture is widely prevalent in Africa.

The results for children of non-migrants indicate that each dam in the neighbouring upstream river basin reduces infant mortality by 3.84-4.60%, conditional on other forms of dam exposure at birth. In contrast, upstream dams farther up the river increase infant mortality by 2.18-2.36% on average. This is in contrast to Duflo and Pande (2007) which finds that all upstream dams improve agricultural productivity and reduce poverty in districts lying downriver in India. However it does not separate the effects of neighbouring upstream dams from upstream dams farther upriver. Doing this is important in Africa, where unlike in India there is widespread reliance on floodplain recession agriculture. Dams provide irrigation services within a designated command area immediately downstream by redirecting river flow, which increases access to water and reduces vulnerability to rainfall shocks without reducing mean water levels in this area. Beyond the command area however, dams significantly reduce the amount of water that flows downriver. At the same time they also reduce the variance in rainfall shocks downriver via regulated discharges in periods of water shortage. However the height of the water level seems to be more important for African agriculture than the variance, which is reflected by our results in that infant mortality increases due to upstream dams farther upriver that reduce water levels but are too far away to provide compensating irrigation services. On the other hand households benefit from neighbouring upstream dams, as they are close enough to take advantage of command area irrigation services that reduce the amplitude of rainfall shocks with unchanged mean water levels. Strobl and Strobl (2009) find that all upstream dams increase agricultural productivity in Africa, but they also do not separate the impact of neighbouring upstream dams from that of upstream dams in river basins farther away. We find that within-basin dams increase infant mortality risk by 0.74-0.79% for children born in floodplains. This is consistent with the results of both Duflo and Pande (2007) and Strobl and Strobl (2009), which find that dams increase vulnerability to rainfall shocks in the region where they are built. We could additionally also be capturing increased incidence of waterborne disease caused by dams in the same basin in floodplain regions. Downstream dams do not appear to have any effect on infant mortality.

The rest of the paper is organised as follows. Section 2 presents background information on dams and previous analyses concerning their effects in the African continent and other parts of the world. In Section 3 we describe the data used for our estimations, and outline our empirical strategy for identification of any possible dam effects on infant mortality. The results of these estimations are shown and summarised in Section 4, and results from various robustness checks are also presented. Finally in Section 5 we summarise and discuss the implications of our results separately for children born to non-migrant and migrant mothers, and also do so based on whether they are born in floodplain or non-floodplain regions.

2 Background

In this section we summarise the geographical and humanitarian effects generated by dams. We then place these effects in the context of Africa, and outline our use of river basins in constructing our null hypotheses about dam impacts on infant mortality.

2.1 Dams and Welfare

Dams have varying and complex impacts on their surrounding areas and the resident population depending on whether these areas are upstream, downstream, or in the immediate vicinity of them, and how far along the river away from the dam these areas are. Illustrating the importance of dams is not a difficult task. Approximately a third of the entire world's irrigated lands rely on dams as mentioned previously. Dams are also estimated to contribute about 12-16% of world food production. Other purposes for which dams are built include hydroelectricity production, flood control, and water supply. Hydropower generated by dams accounts for more than 50% of the national electricity supply in 63 countries (World Commission on Dams, 2000). While there are no studies on the welfare impacts of hydropower generated by dams, hydroelectric dams are usually coupled with irrigation infrastructure built as part of the structure. Their effect on agricultural productivity is therefore assumed to be the same as irrigation dams in Strobl and Strobl (2009), and we do the same for our analysis.

The distributional effects of dam construction, and its effects on agricultural productivity have been investigated previously (Duflo and Pande, 2007; Strobl and Strobl, 2009). The evidence indicates that upstream dams significantly increase agricultural productivity, by providing dam irrigation services in the command area immediately downriver and by regulating water flow to counteract rainfall shocks downriver. Duflo and Pande (2007) also find a decline in poverty incidence among households living downstream from dams in India. However the impact of dams on agriculture is likely to differ depending on the nature of cultivation techniques employed. Farming in Africa is typically based in floodplain recession agriculture, which relies on the cyclical flooding of rivers every year to deposit fertile silts. Dams reduce water levels downriver beyond their irrigation command areas, and can therefore significantly reduce the height of river floodwaters that deposit these silts. This is potentially very detrimental for floodplain agriculture in areas downriver beyond the irrigation command area of the dam, and there is evidence that households dependent on agriculture in these areas also suffer as a result. In North-West Nigeria for instance, the Balokori Dam reduced flood levels by 50%, leading irrigated area to decline by 53% and a quarter of households to abandon dry-season agriculture as a way of life. Similar detrimental impacts on floodplain agriculture have been seen in Niger, Chad, Sudan, Senegal, and Mali (Adams, 2000). While regulated discharges of water from upstream dams can be used to smooth the impact of rainfall shocks downriver, it is unlikely to compensate for the decline in the height of floodwater these dams cause. Many households in Africa also depend on fisheries for their livelihood, and the reduction in water level caused by upstream dams can disrupt the freshwater ecosystem that allows these fisheries to operate. For these reasons upstream dams in Africa are likely to be detrimental to household welfare in regions downriver beyond their command areas, unlike in India.

The irrigation network provided by dams within the command area however greatly reduces the effective variance in rainfall shocks experienced by households who are close enough to use it. The increased irrigation also compensates for the reduction in floodwaters, leaving the mean water levels in the command area effectively constant. Hence the net effect on welfare for households who reside close enough downriver from the dam to access the command area is purely beneficial, as agricultural productivity is protected against rainfall fluctuations within this area.

Creating the dam reservoir requires flooding thousand of square kilometers with harsh consequences to people's homes and livelihoods. The reservoir drains a proportionate fraction of its surrounding land known as the catchment area of the dam. A common outcome of the reservoir in this catchment area is increased salinisation and waterlogging of the soil due to rising groundwater levels. This greatly reduces the productivity of the land near the reservoir; a result that has been shown in the literature (McCully, 2001; World Bank, 1997). There is also evidence in the medical literature of increased malaria incidence among children living near dam reservoirs in Africa (Ghebreyesus et. al., 1999; Lautze et. al., 2007; Yewhalaw et. al., 2009). While there may be benefits from increased economic activity around the dam while it is being constructed, they are unlikely to outweigh these long term detriments. The health and welfare impact of dams on households in the catchment area is therefore in all likelihood harmful.

The dam impacts described above are depicted in Figure 1a, where Dam A is an example dam on a river flowing East to West. If we could accurately pinpoint dam catchment and command areas, as well as household locations, our analysis would be made easier. Unfortunately such information on catchment and command areas is unavailable, and the households we use in our analysis can only be located within a ten kilometre radius. We therefore instead use data on river drainage basins, for which upstream and downstream linkages can be determined, and construct our null hypotheses on the different forms of dam exposure based on which of these river basins dams and households are located in. The data on river drainage basins comes from the HYDRO1K dataset released by the US Geological Survey. The drainage basins are defined at six different levels according to size, with level 1 being the largest and level 6 the smallest. The level 6 basins are nested within the level 5 basins, the level 5 basins within the level 4 basins, and so on up to level 1. At the smallest level of regional subdivision, there are 7,131 level 6 basins in the continent with an average area of approximately 4,200 square kilometres. Mean basin area increases dramatically to about 18,350 square kilometres from level 6 to level 5, and further to about 148,160 square kilometres at level 4. We exploit this variation in basin size between levels for our robustness checks.

Figure 1b uses quadrants as theoretical representations of these river basins to illustrate the possible dam impacts on infant mortality based on household locations, which are also depicted. In quadrant I, where Dam A is built, infant mortality is likely to decline among children born in the part of the command area that lies within the quadrant. On the other hand it will probably increase among children born within the catchment area. Children born in quadrant I but away from both areas should be unaffected by Dam A. Children born in quadrant II will experience lower infant mortality risk if their parental households are located in the command area of Dam A built in the neighbouring upstream quadrant I. Those born outside the command area in quadrant II will be harmfully affected by the decline in river water level, and consequently face higher infant mortality risk. In quadrant III, the upstream dam in quadrant I is too far upriver to compensate for declining water levels with command area irrigation. Any gains from regulated discharges of water from the dam will probably not outweigh the detriments of the reduced height of floodwaters. Children born in quadrant III will therefore experience higher infant mortality due to Dam A. Those born in quadrant IV are unconnected to the dam by river flow, and should therefore be unaffected.

We translate these numerous dam impacts on households in the same or connected river basins into null hypotheses, which are outlined briefly in Table 1. The first column of the table describes each category of dam exposure we will examine, based on the relative locations of the river basins dams and households are located in along the river. The second column shows which households in Figure 1b are being referred to for each null hypothesis by quadrant of residence, assuming Dam A is the treatment dam in each category of exposure. The third and fourth columns list the benefits and detriments of dams in each category on households. The final column describes the anticipated net effect of these counteracting benefits and detriments on infant mortality within the household. Households in quadrant I, in the same basin as a dam, can either benefit or suffer due to the dam depending on whether they are located in the catchment or the command area. There are also households in quadrant I who are unaffected. The net effect of dams on infant mortality in the same basin in quadrant I is therefore ambiguous. We assume that catchment areas are contained within the basin where the dam is built, which is reasonable given that the large mean area of level 6 river basins we use for the analysis. The net impact of neighbouring upstream dams in quadrant I on infant mortality in quadrant II is similarly ambiguous, as it is determined by whether or not households are located in command areas. The impact on infant mortality in quadrant III of upstream dams farther away in quadrant I is predicted to be harmful. Downstream dams have no impact in theory or in previous research on welfare outcomes in the African context, and as such we expect them to have no impact. However this has not yet been empirically tested in the literature. We therefore include neighbouring and distant downstream dams in the analysis to control for any confounding influences they may have on the other categories of dam exposure, and to ensure our estimates are in line with what is expected from the theory.

2.2 Dams in Africa

Africa is often referred to as the "under-dammed continent". This is because only 5.5% of the continent's renewable water resources are used (compared to 20.4% in Asia) despite it being the driest and least electrified continent in the world. The potential for better exploitation of these water resources is greatest in Sub-Saharan Africa, where only 3.5% of total cultivated area is irrigated (FAO, 2007). There was a spate of dam building across the continent in the latter half of the twentieth century to meet increasing demand for irrigation and industrial water supply. According to the International Commission on Large Dams (ICOLD), Africa accounted for more than 1,200 large dams at the beginning of the millennium, as well as a host of other reservoirs that are not recorded (ICOLD, 1998). Lack of investment in water infrastructure has nevertheless still left much of the available water resources unused. As a result there is large variation in the number of dams present across different parts of the continent, which we exploit for our empirical analysis.

We use the geo-referenced database on African dams released by the Aquastat programme of the Food and Agriculture Organisation (FAO) in 2006 to identify the geographic locations of dams across the continent of Africa. The FAO used the World Register of Dams, national reports and experts, and the internet to compile the database, which includes both large dams as defined by ICOLD and all other dams for which locations were found. The database also contains the year in which dams were completed or began operation; information we exploit in our analysis to compare children born after the dams are completed to children born before in the same region. We filled in missing values for year of construction in the database to the best of our ability using updated ICOLD data (ICOLD, 2003) and internet searches. Of the 1,040 dams in the database for which geographical coordinates are available, we are able to obtain the year of completion or start of operations for 967. The regional variation in dam construction is visible in Figure 2, which depicts African dam locations from our data as well as the continent broken down into level 6 river basins. The earliest constructed dam in the dataset was built in 1691, and the last in 2008.[1] The frequency of dams built annually in Africa from the year 1900 according to our dataset is shown in Figure 3.

Recent years have seen a resurgence in large-scale dam projects being commissioned across Africa. The major motivation behind the spurt of new dam construction is the continent-wide high demand for electricity. The amount of hydropower under construction in Africa increased by 53% from 2004 to 2006 (Wachter, 2007). Countries with a high hydropower generation capacity such as Ethiopia and the Democratic Republic of Congo have begun building dams of vast proportions to meet their own power needs, and also to export electricity to neighbouring countries.[2] Several of these projects have received substantial financial support from the World Bank and other development finance institutions. Many new large dams, such as the Gibe III in Ethiopia and the Merowe dam in Sudan, are also being financed by Chinese private firms and large banks (Economist, 2010; Hydroworld, 2010). The growing number of projects and the level of financial support from international sources shows a great deal of confidence in dams as an investment in the future of Africa, but the impact on welfare these new projects will have forms an important part of the return to this investment.

3 Empirical Strategy

In this section we discuss the household data we use for our analysis, and how we implement our estimations. We then outline the specifications and econometric procedures we use on

[1]Six of these dams are still under construction or not operational. We use them in our analysis as dams present but not operational before children in connected river basins are born.

[2]The Grand Inga dam on the Congo river will cost approximately $80 billion to build, and is estimated to be capable of providing power to 500 million households on its own (World Bank, 2009). It is planned to generate twice the amount of power currently generated by the largest hydropower generating dam in the world; the Three Gorges dam in China.

the data, and discuss the results in the next section.

3.1 Household and Infant Mortality Data

Our data on children and households comes from the Demographic and Health Survey (DHS) that is carried out across several countries in Africa at different points in time. Clusters of households are randomly selected across each country to participate in the survey, and all women aged 15-49 years are interviewed in each household. A detailed fertility history is collected from each interviewee along with information on maternal and child health indicators, child mortality outcomes, household members, personal background, and wealth indicators. For several of these surveys, the latitude and longitude of the location of each cluster of selected households is recorded, and can be accurately pinpointed within a ten kilometre radius. We use every wave of the DHS survey carried out in an African country for which this geographic data is available. This gives a sample of women and children from 32 waves of DHS surveys in Burkina Faso, Cameroon, Cote d'Ivoire, the Democratic Republic of Congo, Egypt, Ethiopia, Ghana, Kenya, Morocco, Madagascar, Malawi, Nigeria, Namibia, Swaziland, Tanzania, Zambia, and Zimbabwe whose geographic locations we can identify for our analysis. The clusters of women interviewed in the Cameroon DHS survey in 2004 are shown in Figure 4, along with the locations of dams in the country and the division of the terrain into level 6 river basins. The size of the entire pooled sample from all the surveys is 231,169 women and 912,080 children. The fraction of children born each year that die aged 0-12 months in the final pooled sample for birth cohorts born from 1960 onwards is shown in Figure 5. [3] There is a clear downward trend in the infant mortality rate over time, although some of this is driven by differing survey years across countries.

The DHS waves we use and the total frequency of women and children from each country are reported in Table 3. In Table 4 we also report the number of children of non-migrants that are exposed to at least one dam at birth, broken down by category of dam exposure and time period of the child's birth. Within-basin dams are by far the most prevalent form of dam exposure at birth. There are however enough children born into each category of dam exposure, and enough variation within each category over birth cohorts, to carry out our analysis. The number of dams children are exposed to at birth within each category is reported in Table 5.

[3] 70% of the 134,143 children who die aged five or below in our sample are 0-12 months old at the time of their death.

Upon taking a closer look at various characteristics of the women surveyed we find fairly large differences between them by different kinds of dam exposure. For instance Table 6 shows that women with at least one dam upstream are much less likely to live in a house with a sand or earth floor, or be poor enough to be within the poorest two quintiles of the women surveyed in the same DHS wave than those without a dam upstream. Women with at least one dam in the same river basin as where they reside are also very different from those without such a dam according to Table **??**, being much less likely to belong to the poorest two quintiles or have a sand or earth floor. We have reason to believe that some of these differences will be driven by geographical variation, and some of them will also be causal impacts of exposure to dams. Women are similarly not balanced in observable characteristics by downstream dam coverage, even though downstream dams have no impact on welfare in theory. Hence these differences are likely illustrating the importance of geography. Noticeably there is no significant difference between the proportion of women with at least one dam downstream and the proportion without a dam downstream belonging to the poorest two quintiles in their DHS survey sample. The differences in these and other wealth-related proportions found by upstream and within-basin dam coverage are therefore possibly reflecting actual dam effects.

3.2 Empirical Strategy

There are two major issues intrinsic to dam construction and the resulting consequences that complicate the empirical investigation. The first is that river basins where dams are constructed are geographically different from those where they are not. As explained in Duflo and Pande (2007), dam operations require rivers flowing at different gradients depending on the purpose of the dam. According to the dam engineering literature, irrigation dams require a gentle river slope to create a long reservoir in proportion to the height of the dam and to allow the water to reach the irrigated area via gravity (Golze, 1977; Cech, 2003). If the river gradient is too steep the water flow will erode the canals that transport water to the command area. In contrast, hydroelectric dams require a steep river gradient so that fast-flowing water can power the electricity-generating turbines (Warnick, 1984; Cech, 2003). Therefore river basins with river gradient conditions and geography suitable for dam construction will most likely differ from other basins in agricultural conditions, average elevation, temperature, and other factors that influence regional infant mortality rates. There are also undoubtedly region-specific political elements that influence the negotiations, contracts, and agreements that determine where dams are going to be constructed. These elements in all probability are closely linked to economic factors at a more disaggregated level within each country, which determine both regional dam placement and infant mortality rates. An OLS regression of infant mortality rate or child survival probability on the number of dams exposed to will therefore lead to biased estimates.

We implement a DID estimation to deal with the above concern. Specifically we examine different levels of exposure to dams for children born in the same river basin, which are determined by the river basin where the child was born, the year the dam was constructed, and her year of birth. The geographical factors that influence dam construction are nearly constant over time, and the concentration of dams in a river basin is a good indication of how effective the other influences behind dam placement are in the region. We can therefore consider children born in the same river basin to be subject to the same elements that determine selection into the different kinds of exposure to dams, and use the variation in dam construction over time as well as child birth cohorts in our sample to examine the impact of this exposure on these children based on how many dams were operating upstream, downstream, or in the same river basin at the time of their birth. The children's years of birth in the sample range from 1953 to 2008, covering more than 50 years. This period coincides very closely with the years when dams were constructed most rapidly across Africa, which was approximately 1950 to 1995. There is therefore a lot of variation in the intensity of children's exposure to dams that we can exploit for our analysis.

The second serious concern for our empirical estimations is that households often migrate in large numbers due to the effects of dams on the geography in their place of residence. This migration, whether forced or voluntary, can lead to biased estimates of dam impacts if households select themselves endogenously into regions that benefit from dams based on unobservable characteristics. To deal with this econometric concern, we carry out estimations only for children of non-migrant women as discussed in the introduction. This sample also makes our estimations prone to different sources of bias, so we present a series of robustness checks to examine if our coefficients are affected by these possible sources. We identify non-migrant mothers using the information on the number of years each woman interviewed has lived in her current place of residence. If the answer to the question is "always", the woman is classified as a non-migrant. This process gives us a sample of 103,211 non-migrant women and 415,548 children born to non-migrant mothers.

Our outcome of interest is whether a child dies aged 0-12 months. The central econometric approach we use to find any impact of dams on this outcome is a linear probability model (LPM). The LPM is attractive due to its simplicity, but the linear specification may lead to probability estimates lying outside the unit interval. We perform checks to make sure that enough of the predicted probabilities from the model lie between 0 and 1. We can also correct for the individual-specific heteroscedasticity built into the error structure of the LPM by using robust standard errors. To illustrate our DID procedure using the LPM specification, consider the following regression:

$$y_{ij} = \alpha + \beta_1 UDAMS^B_{ij} + \beta_2 WDAMS^B_{ij} + \beta_3 DDAMS^B_{ij} + \gamma X_{ij} + \theta_j + t_i + \epsilon_{ij} \quad (1)$$

where the dependent variable y_{ij} is a dummy variable taking the value 1 if child i born in river drainage basin j died when aged 12 months or younger. Regressors $UDAMS^B_{ij}$, $WDAMS^B_{ij}$, and $DDAMS^B_{ij}$ represent respectively the total number of upstream, within-basin, and downstream dams built before the child's birth year t_i for basin j. X_{ij} is a vector of other regressors that affect child survival probability. θ_j is a basin fixed effect that we include in the specification to control for unobserved time-invariant regional factors that influence infant mortality. t_i is a birth year fixed effect for child i to control for time trends in infant mortality probabilities. ϵ_{ij} is an idiosyncratic error term. If we believed that an OLS regression would yield unbiased results, then the estimated beta coefficients from this regression would capture the effects of upstream, downstream, and within-basin dams on infant mortality probability. However, as discussed earlier, neighbouring upstream and neighbouring downstream dams could have differential effects from upstream and downstream dams farther away. We could therefore expand (1) to the following,

$$\begin{aligned} y_{ij} = \alpha &+ \beta_1 UDAMS^B_{ij} + \beta_2 WDAMS^B_{ij} + \beta_3 DDAMS^B_{ij} \\ &+ \beta_4 UDAMS\_NBR^B_{ij} + \beta_5 DDAMS\_NBR^B_{ij} \\ &+ \gamma X_{ij} + \theta_j + t_i + \epsilon_{ij} \end{aligned} \quad (2)$$

where we now include $UDAMS\_NBR^B_{ij}$ and $DDAMS\_NBR^B_{ij}$, which represent respectively the number of neighbouring upstream and neighbouring downstream dams from basin j that were built before the birth year of child i. Including these dam counts alongside the total number of upstream and downstream dams built by year t_i will allows us to separately identify any differential effects they may have from dams that are further away. However, estimating (1) and (2) using OLS would lead to biased results due to omitted regional variables that determine the number of dams built in any river basin, and also household level unobservables that determine both migration status and infant mortality risk. To deal with regional omitted variables that determine"selection" into differing intensities of dam exposure, we further alter (2) to the following,

$$\begin{aligned} y_{ij} \;=\; \alpha \;&+\; \beta_1 \, UDAMS^B_{ij} \;+\; \beta_2 \, WDAMS^B_{ij} \;+\; \beta_3 \, DDAMS^B_{ij} \\ &+\; \beta_4 \, UDAMS\_NBR^B_{ij} \;+\; \beta_5 \, DDAMS\_NBR^B_{ij} \\ &+\; \delta_1 \, UDAMS_j \;+\; \delta_2 \, WDAMS_j \;+\; \delta_3 \, DDAMS_j \\ &+\; \delta_4 \, UDAMS\_NBR_j \;+\; \delta_5 \, DDAMS\_NBR_j \\ &+\; \gamma \, X_{ij} \;+\; \theta_j \;+ t_i \;+\; \epsilon_{ij} \end{aligned} \tag{3}$$

so that the specification now includes the total number of dams *ever built* in basin j, in all the upstream and downstream basins along the river from basin j, and also separately the total dams ever built in the neighbouring upstream and neighbouring downstream basins from basin j. We represent them the same way as we do the number of dams in built in these basins before the child's birth year t_i, but we remove the superscript 'B' and subscript 'i' to indicate that they are the total counts of dams ever built in these basins.[4] These dam counts capture the effects of the various influences behind dam construction in the basins where they are built, therefore conditioning on the time-invariant factors behind "selection" into the different kinds of dam exposure all children born in basin j are subject to. The actual intensity of exposure for each child in the first 12 months of life however, is determined by the number of dams in each category of basin already operating at the time of the child's birth. These dam counts are the ones we began with in (1) and (2), but in (3) these regressors will identify their differential impact from total dams ever built on mortality probability for child i. The specification in (3) is therefore our baseline specification, and the beta coefficients on the superscripted dam-count variables are our treatment effects of interest. To link these coefficients to the previous discussion on Figure 1b, we show in Table

[4]Explicitly $UDAMS_j$, $WDAMS_j$, and $DDAMS_j$ respectively denote the total number of upstream, within-basin, and downstream dams from basin j that have been constructed. $UDAMS\_NBR_j$ and $DDAMS\_NBR_j$ separately represent the current total number of dams in neighbouring upstream and downstream basins respectively.

2 each dam count from the specification paired with its corresponding null hypothesis from Table 1. The basin linkages by river flow and the resulting dam counts are calculated at the level of the level 6 drainage basin, the smallest level of regional basin disaggregation.

We also include several other independent variables in the vector X_{ij} that influence infant survival probability, such as mother's education and age, birth order, the number of previously born living children and living sons in the household, the number of previously born children who have died, a child gender indicator, dummy variables indicating a child of a multiple birth, and several household wealth indicator variables such as the kind of toilet in the house, and whether the household owns durable assets such as a television, car, refrigerator, or motorcycle.[5]

We do not control for region-specific time trends in our specification, and it is possible that some of these determine both dam counts and infant survival probabilities. There are also still concerns arising from the fact that the error term contains unobservables that determine the household's decision to migrate, and are also potentially correlated with dam counts and infant mortality risk. There are also child-specific heterogenous unobserved factors that are part of the error term to consider. We check carefully for any signs of omitted variable bias in our robustness checks, and accordingly re-examine what our results reveal in the context of any such signs.

We also attempt to find out whether there are differential effects on infant mortality in regions where floodplain ecology is most prevalent compared to other forms of freshwater ecology. This is because dams may have magnified impacts on floodplain recession agriculture and fisheries reliant on annual inundation. To do this we interact the treatment dam counts of interest with a dummy variable D_i^F that takes the value one if the child under consideration was born in a majority floodplain region, and zero otherwise.[6] In all our specifications we include country fixed effects as well as river basin fixed effects. We also carry out estimations with heteroscedasticity-robust errors, which we cluster according to the size of the river basin fixed effects.

[5]Each mother in our sample is treated as a single household.

[6]Regions of majority floodplain ecology are identified based on the freshwater ecoregions of Africa as defined by the World Wildlife Fund and The Nature Conservancy (FEOW, 2008).

4 Results

In this section we present the results from our estimations. The baseline results from estimating (3) on children of non-migrants are reported in Table 7. Column (1) shows the coefficient estimates for the treatment dam counts from the specification with level 5 basin fixed effects. The estimates indicate that each neighbouring upstream dam at the time of a child's birth increases the child's probability of survival past age 12 months by 3.95%, which is significant at the 5% level. On the other hand, each upstream dam operating in a basin farther upstream increases the probability of the child dying by age 12 months by 2.24%. This coefficient estimate is significant at the 1% level. Column (2) report coefficients from the specification with level 6 basin fixed effects. Inserting fixed effects at this regional level absorbs the impact of the total dams ever built in upstream and downstream level 6 basins, and in the same level 6 basin. However these fixed effects control more locally for regional time invariant factors that might influence dam coverage as well infant mortality. The estimates from column (2) show increased magnitude of impacts compared to column (1), with neighbouring upstream dams reducing infant mortality probability by 4.6% and upstream dams farther away increasing infant mortality probability by 2.36% on average. There are no significant effects of downstream dams, neighbouring or farther away, in these estimates either. The results from the same specifications with the propensity score for having a within-basin dam included are presented in columns (5) and (6). For children of non-migrant mothers the results are close to identical to those in the previous columns with little change.

The lack of significant results for within-basin dams could be due to command area benefits within each basin being counteracted by the detriments of dam catchment areas. It is also possible that households simply live beyond the reach of harmful catchment area effects, and therefore also end up not receiving any command area services. It appears that neighbouring upstream dams provide significant command area benefits that outweigh the negative effect of reduced water levels due to these dams' presence, and therefore significantly reduce infant mortality. The large exacerbating impact of dams farther upstream on infant mortality is in line with our exante hypothesis, as the river flow downstream is restricted without any compensating command area benefits. The lack of any impact of downstream dams is also consistent with the dam engineering literature.

We now turn to the results from estimating (3) with floodplain interaction terms for children of non-migrants. These are presented in Table 8. Within-basin dams appear to increase infant mortality by 0.76% on average for children born in majority floodplain regions. This marginal effect specific to floodplain areas is possibly due to the lack of annual river inundation in the basin once the catchment area is created. It could also be due to increased incidence of malaria and other waterborne diseases near the dam reservoir. There are no differential effects of neighbouring upstream dams or upstream dams farther away in majority floodplain regions, indicating that the impacts we find in Table 7 are equally spread between these areas and areas where other forms of freshwater ecology are more prevalent. This is probably due to the fact that we do not identify exactly the extent of the floodplains in Africa, and rely on more broadly classified ecoregions that do not reveal the geographic extent of ecology types that are not the most prevalent. There seems to be a harmful effect of distant downstream dams in majority floodplain areas, which is contrary to what we would expect given that they have no impact in theory. However this effect disappears when we condition on basin geography explicitly in our robustness checks, which we show in the next section.

4.1 Robustness Checks

The results we have shown thus far are large, and at face value they point to the importance of dams in determining child welfare levels. However we still cannot be sure that our results are actually reflecting the effects of dam operations, and not any other household-level omitted variables that determine migration status as well as infant mortality rates. To verify whether there is such bias in our results, we implement additional econometric procedures on both our estimation samples.

Our first robustness check is to estimate whether there any impacts on infant mortality risk of dams built in each category of exposure when the child is aged 10 years or older. There should be no significant effects of such dams as they are built well past the child's first year of life. We insert these dam counts into specification (3), and report their estimated coefficients in Table 9. The notation for the dam counts is the same as for those representing dam counts at birth, except we change the superscript from B to A to indicate that these counts are for dams built after the child is born. In both columns (1) and (2) of Table 9, the coefficients on neighbouring upstream dams and upstream dams farther away are insignificant. This is encouraging for the validity of the impacts of these dams we found previously. There is a small increasing effect of 0.47% of within-basins dams built when the child is aged ten or older, which is significant but small enough to be negligible considering we find no impacts of within-basin dams at birth.

The second robustness check we carry out is to redefine the dam counts at the level of the level 4 river drainage basin. By changing the unit of land area in our analysis from the level 6 to the level 4 basin, we effectively ignore the river network linkages between the smaller, more closely connected areas and focus instead on linkages between much larger areas. It is equivalent, for example, to defining a child in country A as downstream from a dam if the dam is in country B which lies upstream, and ignoring all the dams that are actually in the city upstream from the child's own city. We therefore effectively create "pseudo-treatment" dam counts, as by greatly expanding the area of the basin that defines river linkages we ignore much stronger local linkages and markedly weaken any possible dam impacts from one basin to another. We should therefore find either much smaller effects or zero effects of any dam counts by level 4 basin. Finding reduced impacts would indicate that we are capturing dam effects rather than bias from unobservables correlated with our dam counts, as we use the same regional fixed effects and the potential contaminating unobservable factors remain the same. We re-estimate specification (3) using the new dam counts and report the results in Tables 10. The results show statistically significant impacts of upstream dams farther away and neighbouring upstream dams, but the effects are ten to twenty times smaller that those of the corresponding level 6 dam counts in Table 7. When we additionally disaggregate the effects of level 4 basin dam counts by whether children are born in floodplain regions, we find no effects of any of the dam count interactions with the floodplain indicator. This additional evidence in favour of our results.

While river basin fixed effects control for time invariant basin features, there is still much geographical variation within each basin that determines both dam placement and also potentially infant mortality. To reduce the possibility of bias from omitted geographic features within each basin that are correlated with dam placement and infant mortality, we attempt to control explicitly for such features in a final robustness check. We use the geographical features in each level 6 drainage basin to generate a propensity score for the probability of the basin containing a dam. As discussed earlier, irrigation dams rely on gravity from moderate river gradients to disperse water to the command area, whereas hydroelectric dams need steep river gradients to power electricity generation. We should then expect more dams in areas with steeper river gradients, and much fewer dams in areas with flat river gradients. To exploit this empirically we use the GTOP030 dataset on global elevations combined with the FAO geographic dataset on African rivers to calculate river lengths in each level 6 river basin within four gradient categories, which are low slope (0-1.5%), medium slope (1.5-3%), steep slope (3-6%), and very steep slope (6% or more). We then estimate a Poisson regression with the number of dams in each level 6 basin as the outcome variable, and these geographical variables as regressors.[7] We include river lengths and areas in the first three slope categories explicitly, and then the river length and area totals within the basin to capture the effects of the omitted category of very steep gradient. The results are reported in Table 11. The coefficients show that river lengths of low gradient have a strong negative impact on the number of dams in the basin as expected, and river lengths with very steep gradient have a positive impact.[8]

We use the coefficients from Table 11 to predict the number of dams in each basin, which creates a geographic index of suitability for dam construction within the basin. The index values are shown in Figure 6. We generate a propensity score for the presence of a dam in each basin using one-to-one matching methods and including linear and higher order terms of the geographic index, river lengths, and also country fixed effects as predictors.[9] The propensity scores are shown in Figure 7. Given that Africa is considered under-dammed and there are various factors besides geography that determine dam placement, Figure 7 shows that our procedure performs quite well in predicting where dams are located. We include this propensity score for each basin as a regressor in our specification to condition on geography directly related to dam placement and potential impacts within each basin. We show the results from estimating (3) with the propensity score included in column (3) of Table 12, where columns (1) and (2) show the original results from Table 7. The estimates show that the coefficients barely change across the columns after including the propensity score. The results for the specification with both floodplain interactions and propensity score are shown in column (2) of Table 13, where column (1) shows the original results from Table 8. The increasing effect of within-basin dams remains the same after including the propensity score, but the effect of downstream dams farther away disappears. This is reassuring as downstream dams farther away should not have any impact in theory. It also shows that the

[7]We use a procedure that corrects for potential over-dispersion and relies only on the conditional mean assumption. We also run the regression only in basins where rivers are present so as to not skew the results.

[8]steeper gradients most likely produce a positive impact on dams due to the high number of multi-purpose dams in the continent that also generate hydroelectricity.

[9]We control for every country that has overlapping areas with the level 6 river drainage basins.

differential effect of within-basin dams in majority floodplain areas is most likely unbiased by omitted variables.

5 Discussion

Our results show significant dam impacts on infant mortality among both samples of children. For children born to non-migrants we find that neighbouring upstream dams reduce infant mortality by 3.84-4.60%. Upstream dams further upriver on the other hand increase infant mortality by 2.18-2.36% among these children. This is because households are able to benefit from the irrigation services in the command areas of neighbouring upstream dams, but downriver beyond the command areas households suffer due to declining water levels that harm floodplain recession agriculture. Within-basin dams appear to increase infant mortality by 0.74-0.79% among children born in majority floodplain areas, probably because the river inundation cycle is disrupted and waterborne disease incidence increase in basins where dams are built.

The infant mortality rate in our pooled sample for birth cohorts born 1960 or later is 10.36% among children of non-migrants and 9.76% among children of migrants. In the context of these mortality rates, our estimated dam impacts are large. For instance neighbouring upstream dams reduce this incidence rate of infant mortality among children of non-migrants by more than a third. The implications of dam construction for child survival are therefore very important, and should be taken into consideration given the surge in dam building taking place across Africa. While we cannot be certain of the benefits the new large dams being planned will bring, their impacts on river flow and agricultural productivity have been documented previously. These impacts are ultimately absorbed by entire communities whose livelihoods are altered as a result, either for the better or for the worse. Infant mortality is a new dimension of welfare within which to measure dam impacts, and we feel our results reflect the importance of considering this dimension as part of the dam building process.

Still to come:

- Extrapolation of results to other parts of Africa.
- Estimating impacts on infant mortality of proposed dams.

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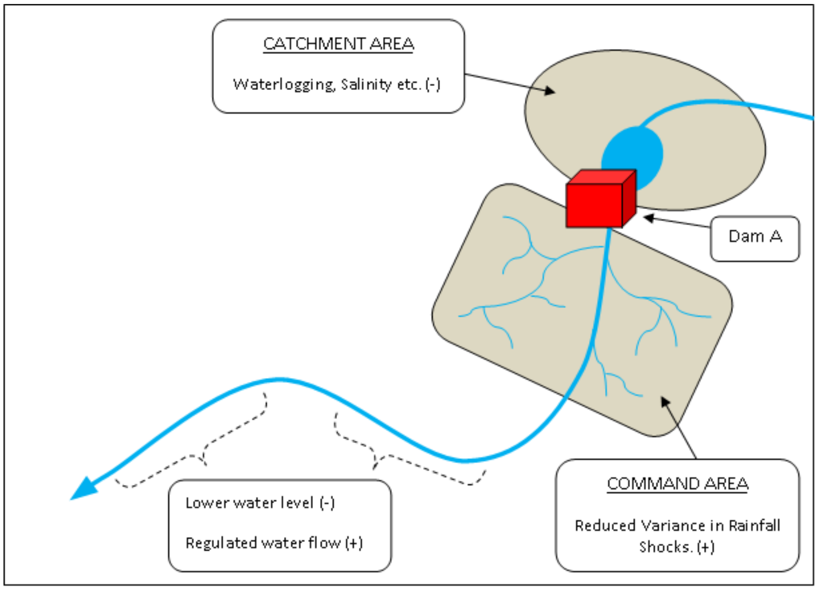
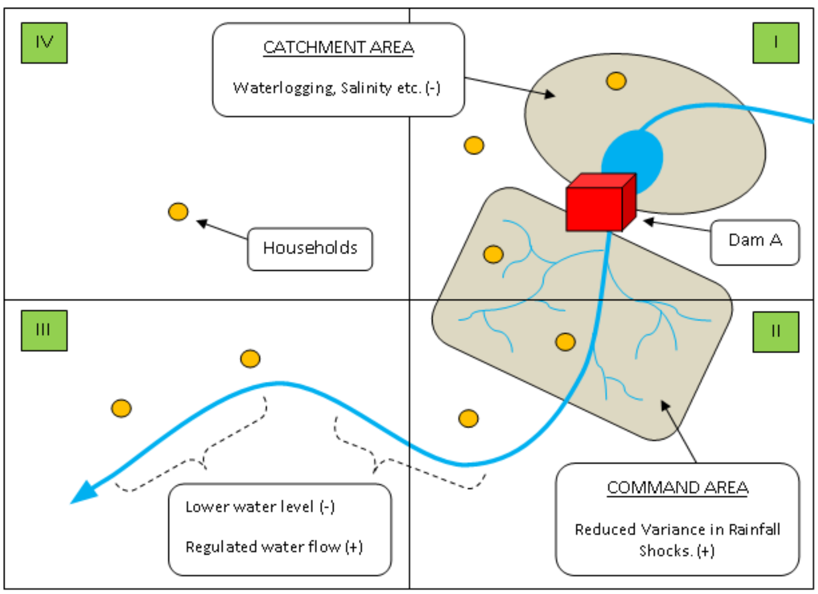
Figure 1: Dams Impacts by Region



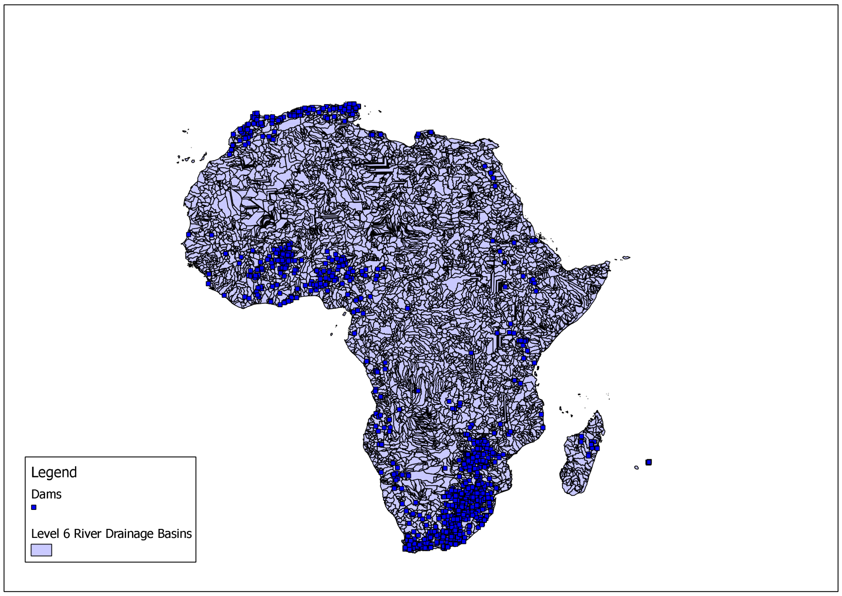
(a) Dam Catchment and Command Areas



(b) Households and Quadrants

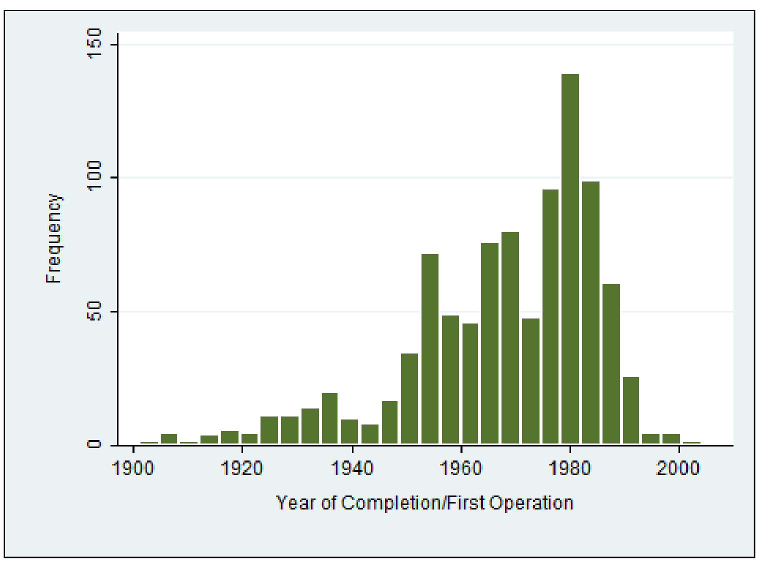
Notes: The figure is based on a diagram in Strobl and Strobl (2009). Plus signs indicate benefits from dams, and negative signs indicate detriments. Quadrants are theoretical representations of river basins, which are our geographical unit of analysis.

Figure 2: Dams and River Drainage Basins in Africa



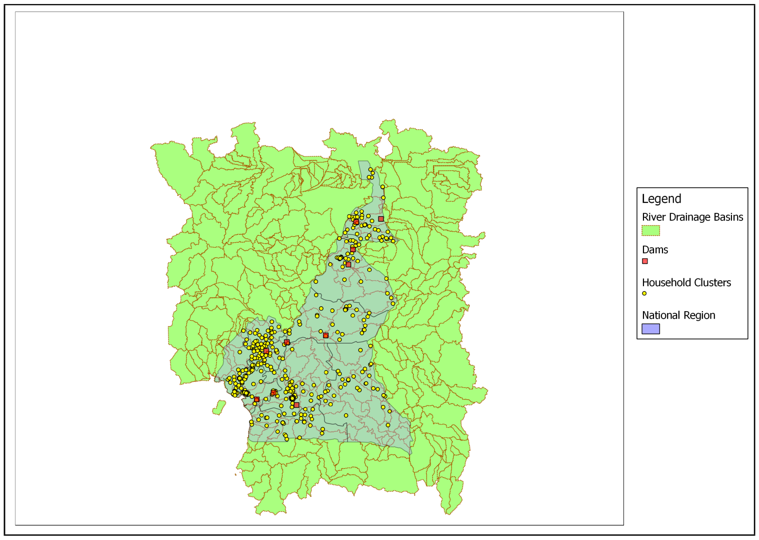
Notes: The river drainage basins depicted are from the HYDRO1K dataset provided by the US Geological Survey. The locations of the dams are taken from the geo-referenced database on African dams created by the Aquastat programme at the FAO.

Figure 3: Dams Completed Annually in Africa (1900-2008)



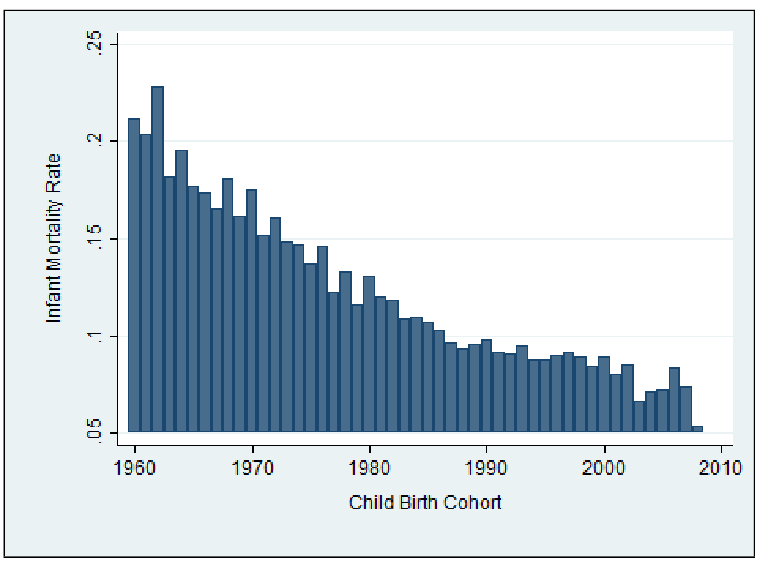
Notes: The year of completion/start of operation for each dam is taken from the FAO geo-referenced database on African dams, ICOLD data, or our own internet research.

Figure 4: Cameroon DHS 2004 - Households, Dams, and River Basins



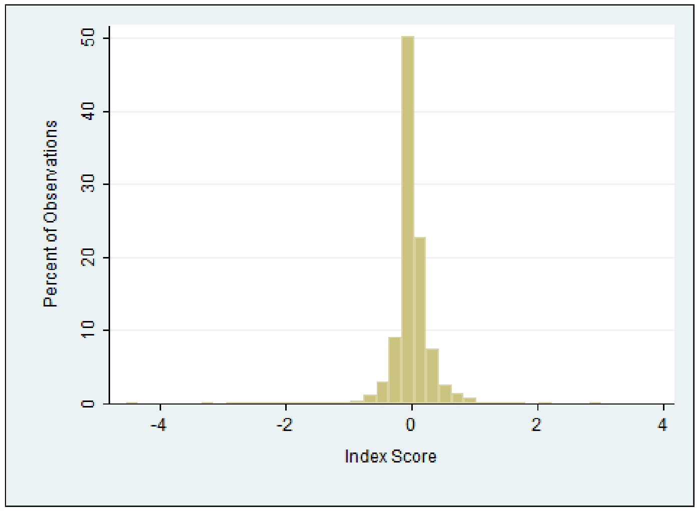
Notes: The household clusters are sampled for the Measure DHS Survey in Cameroon in 2004. The cluster locations are accurate within a ten kilometre radius.

Figure 5: Annual Infant Mortality Rate



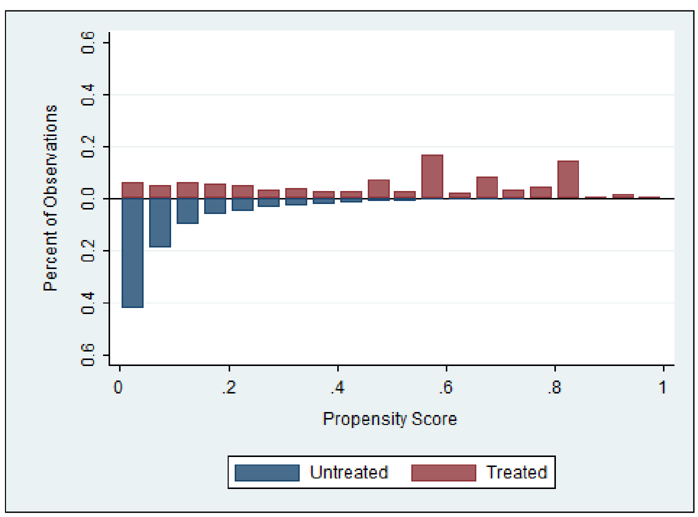
Notes: Infant mortality rates are calculated from the pooled final dataset used in our estimations, using several DHS survey waves from 17 countries in Africa as reported in Table 3.

Figure 6: Geographic Index of Suitability for Dams



Notes: The river drainage basins used as observations are from the HYDRO1K dataset provided by the US Geological Survey. The elevations used to calculate land and river gradients are from the GTO030 global elevations dataset. The river lengths in each basin are calculated using the FAO shapefile of African rivers.

Figure 7: Propensity Score - Dam in Level-6 Basin



Notes: The propensity scores are calculated based on the geographic index of dam suitability, river lengths in drainage basins, and basin areas within each African country. The river drainage basins used as observations are from the HYDRO1K dataset provided by the US Geological Survey.

Table 1: Dam Impacts by Relative Location to Household

Dam Location	Quadrant	Benefits	Detriments	Net Effect
Within Same Basin	Q1	Command area irrigation.	Salinisation; Waterlogging; Waterborne disease; Disruption of inundation cycle.	Ambiguous
Neighbouring Upstream Basin	Q2	Command area irrigation	Declining water flow from upriver.	Ambiguous
Farther Upstream Basin	Q3	Regulated water flow.	Declining water flow from upriver.	Harmful
Neighbouring Downstream Basin	-	None in theory.	None in theory.	None
Farther Downstream Basin	-	None in theory.	None in theory.	None

Notes: The dam impacts discussed are not exhaustive. They include those that are relevant for agricultural productivity via changes to the river flow cycle, and the impact of dam command area services and catchment areas. The position of the river basin where the dam is located is defined in the first column relative to the river basin where the household in question resides. The second column shows the quadrant of household residence in Figure 1b the null hypothesis refers to, assuming Dam A is the treatment dam in the exposure category being considered.

Table 2: Dam Impacts by Regressor

Dam Location	Quadrant	Regressor	Net Effect
Within Same Basin	Q1	$WDAMS^B$	Ambiguous
Neighbouring Upstream Basin	Q2	$UDAMS\_NBR^B$	Ambiguous
Farther Upstream Basin	Q3	$UDAMS^B$	Harmful
Neighbouring Downstream Basin	-	$DDAMS^B$	None
Farther Downstream Basin	-	$DDAMS\_NBR^B$	None

Notes: position of the river basin where the dam is located is defined in the first column relative to the river basin where the household in question resides. The second column shows the quadrant of household residence in Figure 1b the null hypothesis refers to, assuming Dam A is the treatment dam in the exposure category being considered. The third column shows the corresponding regressor from specification (3)

Table 3: DHS Survey Years and Frequency by Country

		Mothers		Children	
Country	DHS Year	Migrant	Non-Migrant	Migrant	Non-Migrant
Burkina Faso	1993, 1998-99, 2003	11,524	7,245	50,761	32,164
D.R. Congo	2007	2,871	3,983	12,435	15,902
Cote d'Ivoire	1994, 1998-99	4,076	1,652	16,821	6,754
Cameroon	1991, 2004	7,003	2,947	28,391	11,418
Egypt	1995, 2000, 2003, 2005	16,411	33,470	60,563	131,361
Ethiopia	1992, 1997	8,471	10,678	35,338	47,470
Ghana	1993, 1998, 2003	7,387	3,486	28,402	12,783
Kenya	1998, 2003	6,262	2,285	24,018	9,468
Morroco	2003-04	5,333	3,201	20,123	12,049
Madagascar	1997	2,567	2,574	11,006	10,363
Malawi	2000, 2004	10,598	8,665	39,148	36,012
Nigeria	2003, 2008	18,252	10,166	78,755	47,518
Namibia	2000, 2006-07	5,599	5,239	17,237	15,684
Swaziland	2006-07	2,505	804	8,857	2,067
Tanzania	1999	1,528	1,237	6,359	4,984
Zambia	2007	3,661	1,565	14,265	6,509
Zimbabwe	1999, 2005-06	6,289	4,014	20,105	13,042
Total		120,337	103,211	472,584	415,548

Notes: All frequencies are reported from the DHS surveys where number of years in current residence was available.

Table 4: Dam Coverage by Time Period of Birth

	1960-69	1970-79	1980-89	1990-99	2000-08	Total
Children Born in Period	8,015	54,250	143,193	166,855	67,076	439,389
Infant Deaths in Period	1,484	7,994	15,986	15,095	4,999	45,558
One Within-Basin Dam	909	8,651	27,785	31,856	10,740	79,942
One Neighbouring Upstream Dam	16	483	1,734	2,306	792	5,331
One Farther Upstream Dam	13	163	737	975	411	2,299
One Farther Downstream Dam	349	2,712	7,260	8,653	2,542	21,516
One Neighbouring Downstream Dam	40	402	1,212	2,110	686	4,450

Notes: Figures are for children born to non-migrant mothers. The sample of children is from 32 waves of DHS surveys across 17 African countries. Data on dams is from the geo-referenced database on African dams. The total refers to the number of children with at least one dam in the corresponding category of dam exposure at the time of their birth.

Table 5: Dam Counts By Exposure Category

	Dams Present at Birth		
	Mean	Min	Max
Within-Basin	1.06	0	67
Neighbouring Upstream	0.02	0	4
Farther Upstream	0.02	0	6
Neighbouring Downstream	0.04	0	69
Farther Downstream	0.18	0	11

Notes: Figures are for children born to non-migrant mothers. Data on dams is from the geo-referenced database on African dams.

Table 6: Non-Migrant Mother Characteristics by Dam Coverage

	No Dam Upstream		One Dam Upstream			
	(1)	(2)	(3)	(4)	(5)	(6)
	Mean	S.D.	Mean	S.D	Diff.	Stan. Diff.
Completed Primary School	0.332	-	0.327	-	0.005	0.014
Sand or Earth Floor	0.443	-	0.253	-	0.190**	0.429
Poorest Two Quintiles	0.459	-	0.424	-	0.035**	0.076
Height (cm)	158.15	6.34	158.42	6.46	-0.27	-0.042
Weight (kg)	60.98	14.91	62.77	13.51	-1.78**	-0.120
Number of Births	4.03	2.64	3.61	2.45	0.43**	0.162
	No Dam in Basin		One Dam in Basin			
	Mean	S.D.	Mean	S.D	Diff.	Stan. Diff.
Completed Primary School	0.333	-	0.327	-	0.006	0.020
Sand or Earth Floor	0.466	-	0.333	-	0.133**	0.286
Poorest Two Quintiles	0.466	-	0.428	-	0.038**	0.082
Height (cm)	157.86	6.31	159.28	6.34	-1.42**	-0.223
Weight (kg)	61.24	15.31	60.16	13.06	1.09**	0.073
Number of Births	4.04	2.64	3.95	2.64	0.09**	0.035
	No Dam Downstream		One Dam Downstream			
	Mean	S.D.	Mean	S.D	Diff.	Stan. Diff.
Completed Primary School	0.329	-	0.378	-	-0.049**	-0.149
Sand or Earth Floor	0.450	-	0.266	-	0.184**	0.409
Poorest Two Quintiles	0.458	-	0.471	-	-0.013	-0.028
Height (cm)	158.12	6.34	158.61	6.38	-0.48**	-0.076
Weight (kg)	60.65	14.67	67.39	16.97	-6.73**	-0.452
Number of Births	4.04	2.65	3.80	2.45	0.23**	0.089

Notes: Observations are from the combined DHS datasets used in the estimations. For indicator variables, the standardised difference in column (10) is the difference in column (9) divided by the mean in the control group in column (3). For continuous variables it is the difference in column (9) divided by the standard deviation in the control group in column (4). ** Significant at 1% ; * Significant at 5%

Table 7: Infant Mortality and Level-6 Dams

	Child Died Aged 0-12 Months	
	Level-5 FE	Level-6 FE
	(1)	(2)
$WDAMS^B$	0.0006	0.0007
	(0.0006)	(0.0008)
$UDAMS\_NBR^B$	-0.0395*	-0.0460*
	(0.0174)	(0.0222)
$UDAMS^B$	0.0224**	0.0236**
	(0.0069)	(0.0074)
$DDAMS^B$	-0.0016	-0.0001
	(0.0048)	(0.0045)
$DDAMS\_NBR^B$	0.0035	0.0015
	(0.0062)	(0.0055)
Observations	263,918	263,918
Level-5 Fixed Effects	Yes	No
Level-6 Fixed Effects	No	Yes
Basins	1,060	1,151

Notes: Robust clustered standard errors are reported in parentheses. Additional regressors include mother's educational attainment, mother's current age, mother's height, a child gender indicator, child of multiple birth indicators, birth order and sibling composition variables, birth year fixed effects, and wealth indicator variables. ** Significant at 1% ; * Significant at 5%

Table 8: Infant Mortality, Level-6 Dams, and Floodplains

	Child Died Aged 0-12 Months
	(1)
$WDAMS^{B*}D_i^F$	0.0076*
	(0.0031)
$UDAMS^{B*}D_i^F$	0.0059
	(0.0096)
$DDAMS^{B*}D_i^F$	0.0089*
	(0.0042)
$UDAMS\_NBR^{B*}D_i^F$	0.0223
	(0.0194)
$DDAMS\_NBR^{B*}D_i^F$	-0.0182
	(0.0177)
Observations	263,918
Level-6 Fixed Effects	Yes
Basins	1,151

Notes: Robust clustered standard errors are reported in parentheses. Additional regressors include mother's educational attainment, mother's current age, mother's height, a child gender indicator, child of multiple birth indicators, birth order and sibling composition variables, birth year fixed effects, and wealth indicator variables. ** Significant at 1% ; * Significant at 5%

Table 9: Infant Mortality and Level-6 Dams After Birth

	Child Died Aged 0-12 Months	
	Level-5 FE	Level-6 FE
	(1)	(2)
$WDAMS^A$	0.0047**	0.0047**
	(0.0009)	(0.0009)
$UDAMS\_NBR^A$	-0.0056	-0.0508
	(0.0318)	(0.0398)
$UDAMS^A$	-0.0111	-0.0139
	(0.0150)	(0.0177)
$DDAMS^A$	0.0005	-0.0058
	(0.0080)	(0.0054)
$DDAMS\_NBR^A$	-0.0044	-0.0022
	(0.0058)	(0.0256)
Observations	263,918	263,918
Level-5 Fixed Effects	Yes	No
Level-6 Fixed Effects	No	Yes
Basins	1,060	1,151

Notes: Robust clustered standard errors are reported in parentheses. Dam counts are numbers of dams built in each category ten years or more after the child is born. Additional regressors include mother's educational attainment, mother's current age, mother's height, a child gender indicator, child of multiple birth indicators, birth order and sibling composition variables, birth year fixed effects, and wealth indicator variables. ** Significant at 1% ; * Significant at 5%

Table 10: Infant Mortality and Level-4 Dams

	Child Died Aged 0-12 Months
	(1)
$WDAMS^B$	0.0004
	(0.0006)
$UDAMS\_NBR^B$	-0.0025*
	(0.0011)
$UDAMS^B$	0.0023*
	(0.0009)
$DDAMS^B$	-0.0003
	(0.0026)
$DDAMS\_NBR^B$	0.0021
	(0.0033)
Observations	263,918
Level-6 Fixed Effects	Yes
Level-6 Basins	1,151

Notes: Robust clustered standard errors are reported in parentheses. Additional regressors include mother's educational attainment, mother's current age, mother's height, child of multiple birth indicators, birth order and sibling composition variables, birth year fixed effects, and wealth indicator variables. ** Significant at 1% ; * Significant at 5%.

Table 11: Dams and River Gradients in Level-6 Basin

	Number of Dams in Basin
River Length – Low Slope	-1.879*
	(0.851)
River Length – Medium Slope	-0.518
	(1.846)
River Length – Steep Slope	1.837
	(1.573)
Total River Length	0.963*
	(0.385)
Area in Basin – Low Slope	-87.026**
	(20.291)
Area in Basin – Medium Slope	-97.582*
	(38.751)
Area in Basin – Steep Slope	-140.054
	(95.756)
Total Area in Basin	89.772**
	(18.954)
Observations	5,746
Level-1 Fixed Effects	Yes
Level-1 Basins	10

Notes: Robust standard errors are reported in parentheses. River lengths are in thousands of kilometres, and areas are in thousand kilometres square. ** Significant at 1% ; * Significant at 5%.

Table 12: Infant Mortality, Level-6 Dams, and P-Score

	Child Died Aged 0-12 Months		
	Level-5 FE	Level-6 FE	P-Score
	(1)	(2)	(3)
$WDAMS^B$	0.0006	0.0007	0.0005
	(0.0006)	(0.0008)	(0.0006)
$UDAMS\_NBR^B$	-0.0395*	-0.0460*	-0.0384*
	(0.0174)	(0.0222)	(0.0169)
$UDAMS^B$	0.0224**	0.0236**	0.0218**
	(0.0069)	(0.0074)	(0.0072)
$DDAMS^B$	-0.0016	-0.0001	0.0036
	(0.0048)	(0.0045)	(0.0063)
$DDAMS\_NBR^B$	0.0035	0.0015	-0.0016
	(0.0062)	(0.0055)	(0.0048)
Observations	263,918	263,918	258,223
Level-5 Fixed Effects	Yes	No	Yes
Level-6 Fixed Effects	No	Yes	No
Basins	1,060	1,151	1,025

Notes: Robust clustered standard errors are reported in parentheses. Additional regressors include mother's educational attainment, mother's current age, mother's height, a child gender indicator, child of multiple birth indicators, birth order and sibling composition variables, birth year fixed effects, and wealth indicator variables. ** Significant at 1% ; * Significant at 5%

Table 13: Infant Mortality, Floodplains, and P-Score

	Child Died Aged 0-12 Months	
	(1)	(2)
$WDAMS^{B*}D_i^F$	0.0076*	0.0075*
	(0.0031)	(0.0031)
$UDAMS^{B*}D_i^F$	0.0059	0.0254
	(0.0096)	(0.0170)
$DDAMS^{B*}D_i^F$	0.0089*	-0.0121
	(0.0042)	(0.0079)
$UDAMS\_NBR^{B*}D_i^F$	0.0223	-0.0068
	(0.0194)	(0.0061)
$DDAMS\_NBR^{B*}D_i^F$	-0.0182	0.0052
	(0.0177)	(0.0043)
Observations	263,918	258,223
Level-6 Fixed Effects	Yes	No
Level-5 Fixed Effects	No	Yes
P-Score	No	Yes
Basins	1,151	1,025

Notes: Robust clustered standard errors are reported in parentheses. Additional regressors include mother's educational attainment, mother's current age, mother's height, a child gender indicator, child of multiple birth indicators, birth order and sibling composition variables, birth year fixed effects, and wealth indicator variables. ** Significant at 1% ; * Significant at 5%