Paving the Way for Livestock Development: Rural Road Access and Agricultural Production in Ethiopia

Musa Hasen Ahmed[a*], Molly J. Doruska [b]

[a] *World Bank Group, Ethiopia*

[b] *Charles H. Dyson School of Applied Economics and Management, Cornell University*

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Abstract

Livestock is a cornerstone of rural livelihoods in Sub-Saharan Africa, yet productivity remains persistently low due to suboptimal management practices, low-yield breeds, and recurrent disease outbreaks. This paper investigates whether improved rural connectivity can enhance livestock production, using the large-scale rollout of Ethiopia's Universal Rural Roads Access Program as a quasi-experimental setting. We merge road network data with multiple rounds of nationally representative household surveys collected during the expansion period. To address endogeneity in road placement, we implement an instrumental variables strategy that exploits variation in topography and pre-existing administrative budget allocations. We find that improved road access leads to significant gains in livestock production, including greater adoption of improved cattle breeds, increased use of veterinary services and purchased feed, and reduced reliance on open grazing. Most notably, road access lowers the likelihood of cattle mortality by 5.3 percentage point.

Keywords: Rural roads, livestock production, instrumental variables, Ethiopia

JEL Classification: R42, Q12, O18

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1. Introduction

Livestock plays a vital role in rural communities, contributing to food security, household income, and supporting crop production through manure, draft power, and income for agricultural inputs (Rosegrant et al., 2009; Grace et al., 2008). However, the livestock sub-sector in Sub-Saharan Africa (SSA) faces significant challenges, including poor animal husbandry practices, reliance on low-yield breeds, and frequent disease outbreaks (Ahmed et al., 2018, 2022; Rufael et al., 2008; Tschopp et al., 2022). Climate change exacerbates these problems by reducing water availability, increasing disease risks, and limiting access to adequate feed (Rojas-Downing et al., 2017; Feng et al., 2021; Emediegwu and Ubabukoh, 2023).

Access to roads has the potential to alleviate key constraints in the livestock sector by improving connectivity between producers, markets, and service providers. Better infrastructure can reduce information frictions, enabling farmers to access input and output markets more efficiently (Mu and Van de Walle, 2011; Kebede, 2022). Given the perishable nature of many livestock products, such as dairy, reliable transport allows for more regular market participation and reduced spoilage, which may in turn encourage investment in high-yielding breeds and complementary technologies. Supporting this view, Abay and Jensen (2020) finds that proximity to markets is positively associated with the adoption of market-oriented livestock practices and modern inputs. Improved road access may also enhance animal health and productivity by expanding access to veterinary services and promoting the adoption of better management practices (Ochieng and Hobbs, 2016). On the other hand, increased connectivity may open up more attractive non-agricultural employment opportunities, drawing labor away from farming activities (Asher and Novosad, 2020). As a result, the net impact of rural roads on livestock production is theoretically ambiguous and remains an empirical question.

This paper examines the impact of rural road expansion on livestock production, using Ethiopia's Universal Rural Roads Access Program (URRAP) as a case study. Launched in 2011, URRAP aimed to connect all villages to the national road network by constructing 71,523 kilometers of all-weather roads. By the end of its first phase, more than 62,000 kilometers had been completed, increasing the share of villages with road access from 42 percent to over 76 percent (Gebresilasse, 2023; Kebede, 2022). We leverage this large-scale expansion in rural connectivity to examine its effects on smallholder livestock production, with a particular focus on cattle-keeping communities, a dimension that has received limited attention in the existing literature.

Validating the impact of road infrastructure poses substantial empirical challenges, particularly due to endogeneity and data limitations. Road construction requires considerable financial and logistical resources, making random placement infeasible. In practice, policymakers allocate roads strategically, often targeting areas expected to yield high socio-economic returns or political advantages (Perra, 2022; Coşar and Demir, 2016; Burgess et al., 2015; Asher and Novosad, 2020; Jedwab and Moradi, 2016). This targeted placement introduces selection bias and complicates efforts to identify the causal effects of road access. To address this, we employ an instrumental variables approach that exploits exogenous variation in natural factors such as terrain slope and land use, as well as baseline proximity to roads and regional budget allocation decisions made prior to the implementation of the expansion program. The instrument is determined by geographic features or higher-level administrative decisions and is plausibly unrelated to unobserved household-level determinants of livestock outcomes.

For the analysis, we combine a novel geospatial dataset on road infrastructure with a nationally representative household survey collected annually from 2010 to 2016, corresponding to the road expansion period. Our results show that road access leads to substantial improvements in livestock management. Specifically, better connectivity increases the adoption of exotic or hybrid cattle breeds, raises vaccination rates, and promotes the use of improved feeding practices. Most notably, road access reduces livestock mortality. We find that the presence of a road in the village is associated with a 5.3 percentage point reduction in the probability of cattle deaths, likely due to improved access to veterinary services and more consistent feeding. In addition, road access is associated with a 5.7 percentage point reduction in the use of grazing and a 4.7 percentage point increase in the likelihood of feed purchase. Vaccination rates also rise by 8.4 percentage points in connected areas.

Although a growing literature explores the economic effects of infrastructure, most studies focus on large-scale investments such as highways and railways, with comparatively little attention given to rural roads.[1] While these studies offer valuable insights, they often overlook the context of low-income, agriculturally dependent regions, where rural connectivity remains a primary development constraint. In many such settings, large segments of the population live in remote areas where agriculture is central to income, food security, and overall welfare (Kebede, 2024; Acosta

[1]For example, studies such as Allen and Arkolakis (2022) in the United States, Coşar and Demir (2016) in Turkey, Heblich et al. (2020) in the United Kingdom, and Ghani et al. (2016) and Donaldson (2018) in India, as well as Faber (2014), Baum-Snow et al. (2017), Li et al. (2019), and Banerjee et al. (2020) in China, primarily examine the effects of highways and railways on outcomes such as trade, manufacturing, urbanization, and knowledge diffusion.

et al., 2021; Shamdasani, 2021; Asher and Novosad, 2020; Jones and Salazar, 2021).

Existing studies that do examine rural roads primarily emphasize effects on household welfare (Dercon et al., 2009; Asher and Novosad, 2020), crop production (Aggarwal, 2018; Gebresilasse, 2023; Shamdasani, 2021; Damania et al., 2017), market integration (Shively and Thapa, 2017; Kebede, 2024; Jones and Salazar, 2021), education (Adukia et al., 2020), health (Aggarwal, 2021), and labor mobility (Asher and Novosad, 2020; Dappe and Lebrand, 2024), with relatively little attention to livestock production.[2] Our study extends this literature by analyzing rural road investments in a low-income setting and focusing specifically on the livestock sector, which remains a critical yet understudied component of rural economies. More precisely, we contribute to the literature by examining how improved road infrastructure affects livestock management practices, including the adoption of improved breeds, use of veterinary services, and feeding strategies, with a focus on cattle-keeping households. We further assess whether road access reduces livestock mortality.[3] By doing so, our analysis sheds light on how rural infrastructure can support agricultural transformation and enhance household resilience in low-income settings.

The remainder of this paper is organized as follows: Section 2 discusses the livestock production profile in Ethiopia and the road expansion program. Section 3 describes the data sources and variable definitions. Section 4 outlines our methodology, including the IV regression approach and the construction of instrumental variables. Section 5 presents the results, discusses their implications, and includes robustness checks. Section 6 concludes with final remarks.

2. The Context

Ethiopia has one of the largest cattle populations in Africa, with over 66 million heads (Ethiopian Statistics Service, 2023). Cattle play a central role in rural livelihoods, providing draft power, manure, fuel, and serving as symbols of wealth and social status (Ahmed and Tesfaye, 2024). Despite their importance, livestock productivity in Ethiopia remains low due to persistent challenges such as inadequate feed, widespread disease, the low genetic potential of indigenous breeds, and

[2]Several of these studies explore complementarities between roads and other interventions. For instance, Dappe and Lebrand (2024) examines the joint effects of roads and electricity on structural transformation, while Gebresilasse (2023) and Dercon et al. (2009) study the interaction of roads with agricultural extension services in Ethiopia.

[3]Previous research emphasizes the role of disease and poor production systems in constraining livestock productivity (Ahmed et al., 2022; Marsh et al., 2016; Ahmed and Tesfaye, 2024), as well as the broader welfare benefits of livestock ownership through food provision (Hirvonen and Hoddinott, 2017; Fadare et al., 2024) and consumption smoothing (Acosta et al., 2021; Kazianga and Udry, 2006). Other work investigates the adoption and impact of livestock insurance (Takahashi et al., 2020; Jensen et al., 2016, 2018).

limited access to markets (Livestock Systems Innovation Lab, 2021). Indigenous breeds, which constitute the majority of Ethiopia's cattle population, yield substantially less milk and meat than exotic breeds. For example, the average beef yield of local breeds is approximately 110 kilograms per head, compared to a global average of 212 kilograms (Abebe et al., 2022).

Feed scarcity is a major constraint, exacerbated by population pressure and climate change (Daba and Mammo, 2024). The primary sources of cattle feed include green fodder, crop residues, and hay (Ethiopian Statistics Service, 2023). Animal health also poses a serious challenge, with diseases such as foot-and-mouth disease, lumpy skin disease, and brucellosis contributing to high mortality and reduced productivity (Tschopp et al., 2009; Kaba, 2022; Rasmussen et al., 2024). Calf mortality, in particular, remains high due to malnutrition, limited access to veterinary care, and exposure to infectious diseases (Fentie et al., 2020; Wong et al., 2022). Furthermore, fewer than one percent of Ethiopian farmers report access to livestock-related extension services (Ethiopian Statistics Service, 2023).

This study examines the impact of rural road infrastructure on livestock production, focusing on the implementation of the Universal Rural Roads Access Program (URRAP) between 2011 and 2016.[4] URRAP prioritized the construction of unpaved gravel roads with drainage systems, designed to handle daily traffic of 25 to 75 vehicles (Gebresilasse, 2023). By the end of its first phase, over 62,000 kilometers of roads had been completed, raising road density from 44.4 to 100.4 kilometers per 1,000 square kilometers (Kebede, 2022). Leveraging spatial and temporal variation in road access during this period, the study investigates how rural connectivity affects livestock productivity and management practices among cattle-keeping communities in Ethiopia.

3. Data Sources and Types

This study combines livestock data from the Central Statistics Service of Ethiopia, road data from the Ethiopian Road Authority, and weather and Environmental data from various sources.

3.1. Annual Livestock Sample Survey

The Central Statistical Service (CSS) of Ethiopia conducts an annual national Livestock Sample Survey. The survey primarily focuses on livestock production and is one of the largest of its kind. This survey provides detailed information on livestock holdings, including livestock numbers,

[4] URRAP initially aimed to cover all regions but excluded the Afar and Somali regions (Kebede, 2024).

species, and key health indicators such as cattle mortality, vaccination rates, and feeding practices. We use repeated cross-sectional data collected between 2011 and 2016. The survey targets rural agricultural households across all regions, excluding those with non-sedentary lifestyles. It follows a two-stage stratified cluster sampling design. In the first stage, Enumeration Areas (EAs) are selected from the Population and Housing Census cartographic frame using probability proportional to size, yielding a sample of approximately 2,273 EAs. In the second stage, 30 agricultural households are systematically selected from each EA using an updated household list available at the time of the survey. To assess consistency across survey rounds, we examine whether key household characteristics such as age, sex, education of the household head, family size, and production orientation remain stable over time. As shown in Table A2, these variables display no significant changes, suggesting that the sampled population remains broadly comparable across waves.

Our study focuses on cattle-keeping households, as cattle are the most common livestock species in Ethiopia (Ethiopian Statistics Service, 2023).[5] By focusing on cattle, we avoid aggregation issues that arise from including multiple livestock species with distinct production characteristics and responses to external factors. Additionally, improved production systems are predominantly concentrated within the cattle sector, making it the most relevant for examining the impact of infrastructure on livestock productivity and management. The annual Livestock Sample Survey is used to construct our outcome and control variables.

The first outcome involves household cattle ownership and breed composition. We use two variables: the total number of cattle, which measures herd size, and the proportion of hybrid or exotic breeds, calculated as the fraction of hybrid/exotic cattle relative to the total herd. We also use two variables for cattle health as well. The first is a binary indicator for whether a household has experienced at least one cattle death (1 for reported deaths, 0 otherwise). The second is the proportion of vaccinated cattle, calculated as the fraction of vaccinated cattle relative to the total herd. We also examine livestock feeding practices with two variables. The first is a binary indicator for whether the household purchases feed (1 for purchase, 0 otherwise). The second variable reflects the share of grazing in total feed, expressed as a fraction. In the survey, farmers specify the share of different feed sources, which allows us to calculate the proportion of livestock feed derived from grazing compared to purchased or stored feed.

Descriptive statistics in Table A1 summarize key variables from 128,497 cattle-keeping households between 2011 and 2016, focusing on kebeles that received new roads or remained untreated.

[5]Ethiopia ranks first in Africa and fourth globally in cattle population. See World Population Review.

The average household head is 42.71 years old, with a household size of 5.24 members. 81% of household heads are male. Households own an average of 2.90 cattle, with minimal non-local breeds (0.02 per household). 12% of households reported at least one cattle death, and 62% of cattle are vaccinated. Grazing accounts for 59% of feed, while 10% of households purchase additional feed.

3.2. Road Network

We use a road network shapefile accessed from the Ethiopian Roads Authority to construct our treatment variable. The shapefile provides a detailed map of all roads in Ethiopia, along with geographic data for spatial analysis. It also includes metadata on the construction history of each road segment, such as start and completion dates, allowing us to distinguish between villages that gained road access from 2011 to 2016 and those that did not. Figure 1 shows the expansion of Ethiopia's rural road network under URRAP. As shown in the figure, road connectivity improved significantly over the study period, with the share of villages connected by roads increasing from 42 percent to 76 percent. By exploiting these spatial and temporal variations in road access, this study estimates the impact of improved rural infrastructure on rural livelihoods, focusing on cattle production outcomes.

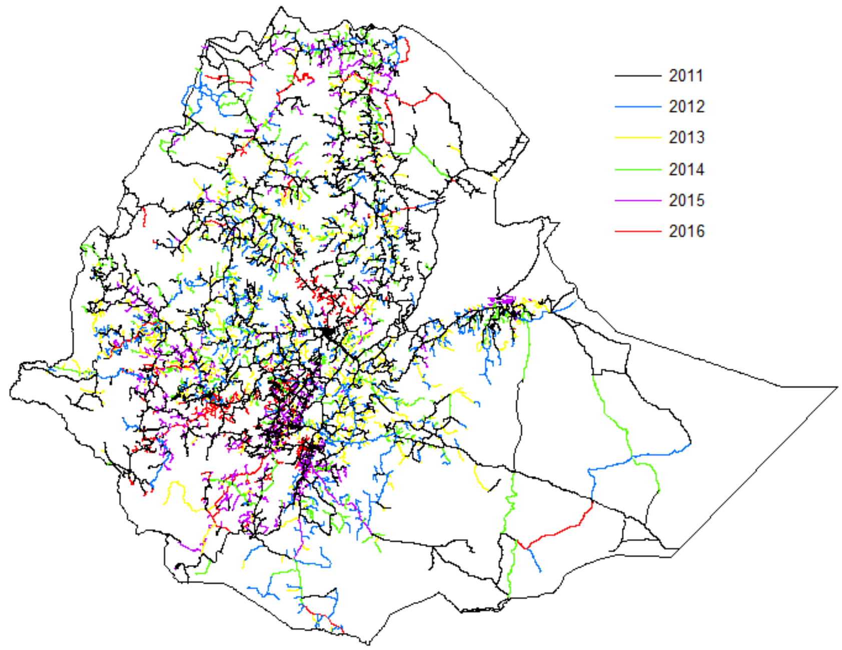

Figure 1: Annual road network development during the study period.

Note: The figure shows the road segments constructed each year during the study period, with colors corresponding to each year as indicated in the legend. Source: Authors' illustration using the shapefile from the Ethiopian Roads Authority.

3.3. Additional Data Sources

In addition to the livestock survey and road network shapefiles, we include several datasets to control for environmental and agricultural factors that influence road placement and livestock production outcomes. We use the Standardized Precipitation-Evapotranspiration Index (SPEI) to account for fluctuations in water availability.[6] The SPEI controls for local water availability, a critical factor affecting livestock health, feed resources, and productivity. We employ a high-resolution SPEI dataset (0.05 x 0.05 degrees), developed by Peng et al. (2020), using precipitation data from CHIRPS and evapotranspiration data from the Global Land Evaporation Amsterdam Model. The index is standardized to have a mean of zero. Values around zero indicate a normal water balance, positive values reflect above-average water availability and negative values signify drought conditions. As shown in the Table A1, the lagged SPEI value of 0.12 indicates a relatively

[6] Unlike the Standardized Precipitation Index (SPI), which measures only precipitation, the SPEI incorporates both precipitation and potential evapotranspiration, offering a more comprehensive view of water balance.

balanced water balance.

Additionally, we use the Global Agro-Ecological Zones (GAEZ v4) dataset to control for agro-climatic conditions and land productivity (FAO and IIASA, 2021). This dataset provides suitability indices for various crops based on factors such as topography, soil characteristics, and input assumptions such as irrigation and mechanization. It helps account for variations in productivity potential that could influence road infrastructure development and livestock production. The GAEZ dataset has a 30 arc-second (approximately 0.9 x 0.9 km) resolution. We use the baseline data from 1961 to 2010 to mitigate endogeneity issues related to agricultural potential and road access.[7]

4. Estimation Strategy

Estimating the impact of rural road infrastructure on livestock production requires a robust empirical strategy due to the non-random nature of road placement. Ideally, if road placement were random, we could use a straightforward regression model:

$$Y_{ivt} = \beta_0 + \beta_1 \text{Road}_{vt} + \beta_2 X_{ivt} + \epsilon_{it} \tag{1}$$

where Y_{ivt} represents livestock production outcomes for farmer i in village v at time t, $Road_{vt}$ is a binary indicator of road presence, X_{ivt} is a vector of control variables, and ϵ_{ivt} is the error term. Under random placement, β_1 would provide an unbiased estimate of the impact of roads on livestock production. However, random road placement is unlikely due to the significant construction and maintenance costs. Policymakers typically allocate road investments strategically, targeting locations where roads are expected to have the greatest economic impact, such as facilitating trade, improving market access, and promoting regional development (Coşar and Demir, 2016; Burgess et al., 2015; Asher and Novosad, 2020; Jedwab and Moradi, 2016). Political incentives also play a role in road placement decisions. One mitigating factor in the Ethiopian context, as argued by Shiferaw et al. (2015), Perra et al. (2024), and Fiorini et al. (2021), is that road improvement plans were devised as part of a five-year strategic planning process under the national development program. This long-term planning mechanism reduces the likelihood of short-term political opportunism affecting road placement, as decisions were based on predefined plans and broader national development goals. Specific to the URRAP, the level of such bias is minimal, as its primary objec-

[7] For more information on the GAEZ methodology, visit http://www.fao.org/nr/gaez/en/.

tive was to connect all villages to baseline roads.[8] However, even within this framework, economic potential, along with geographic, and budgetary constraints likely influenced the sequencing of road construction. Addressing these estimation challenges is crucial for obtaining unbiased estimates of the impacts of road investments.

Conducting a randomized controlled trial (RCT) for road placement is generally impractical due to the financial resources and coordination required. An alternative approach is to exploit policy-induced cut-off points, which provide a natural experiment for impact evaluation. If road construction funding is allocated based on eligibility criteria, such as population thresholds, these cut-offs can help estimate causal effects. However, the Ethiopian Road Authority does not publicly provide clear cut-off points, making this method difficult to implement.

In the absence of policy-induced cut-offs, our empirical strategy employs instrumental variables (IV) derived from exogenous factors that influence road placement decisions. More precisely, we construct an IV by calculating the least-cost path from each village centroid to the baseline road network using algorithms from civil engineering and network theory, following related works of Wu et al. (2023), Kebede (2022), and Gebresilasse (2023). The instrument is based on the idea that road allocation decisions are influenced by two factors: (1) construction costs, which are shaped by geographic features, and (2) the sequence of construction, which is driven by annual budget constraints. Geographic features such as elevation, terrain slope, and natural obstacles like river crossings significantly affect road construction costs. Shorter, flatter roads are typically less costly, while roads crossing mountains, wetlands, rivers, or densely populated areas incur higher costs (Wu et al., 2023). Proximity to pre-existing roads also affects the likelihood of a village receiving road infrastructure by influencing the transport of construction materials (Gebresilasse, 2023). An engineer adopting a cost-minimization approach would prioritize constructing less expensive roads first under a fixed budget. These factors are likely exogenous to livestock production but influence the probability of receiving road infrastructure, making them suitable instruments for our analysis.

To construct our IV, we first develop a cost raster using publicly available Digital Elevation Model (DEM) and land use data. The DEM is used to estimate terrain slope, while different land use types—such as rivers, lakes, forests, or urban areas—are assigned weights based on their construction difficulty. For example, water bodies require bridges, increasing costs. After generating the slope raster and assigning weights to land use types, we use a cost-distance analysis tool of

[8] The Ethiopian Road Authority states URRAP's mission as: "To connect all kebeles by all-weather road and provide year-round access, ensuring that all road infrastructure meets the needs of rural communities and remains affordable to build and maintain" (Ethiopian Roads Authority, 2012).

ArcGIS to calculate the least-cost paths from each village centroid to the nearest point on the baseline road network. Following this, we apply a cost-minimization strategy that aligns with regional budget constraints set by national road authorities prior to the start of URRAP, following Kebede (2022) and Gebresilasse (2023). Roads are sequentially allocated from nearest to farthest until the cumulative length reaches the annual budget limit for each region. Details on these budgets are provided in Table A3.

Once the IV is constructed, we apply a two-stage instrumental variable approach. In the first stage, we regress the endogenous variable, road placement, on the IV and other controls to obtain predicted values for road placement as shown in equation 2:

$$Road_{vt} = \pi_0 + \pi_1 IV_{it} + \pi_2 X_{ivt} + \mu_i + \epsilon_{it} \tag{2}$$

Here, $Road_{vt}$ is a binary indicator denoting the presence of a road in village v at time t; IV_{it} represents the predicted road placement decision (1 if the village is identified to receive a road, 0 otherwise); μ_i accounts for district fixed effects, and ϵ_{it} is the error term. X_{ivt} includes control variables that capture factors potentially confounding the relationship between road infrastructure and livestock production. We control for demographic, socioeconomic, geographic, and environmental variables, including household characteristics such as the gender, age, and size of the household head. To address the effects of remoteness, we incorporate interactions between the distance to baseline roads and survey year dummies. Agricultural suitability, which may simultaneously influence road placement and livestock production due to high crop production potential, is also accounted for. Climate variability is controlled using the one year lag SPEI, while kebele-level population data from the 2007 Ethiopian census accounts for population size. Population density is relevant, as densely populated areas are more likely to receive roads due to higher demand and political considerations. Larger populations may also drive increased demand for livestock products or provide additional labor. By using pre-expansion census data, we mitigate concerns about population shifts caused by improved road access. District fixed effects (μ_i) are also included to address unobserved heterogeneity across regions, such as differences in governance, agroecological conditions, and cultural practices, which could influence both road placement and livestock outcomes.

The predicted values of road placement, $\hat{Road}_{it}$, are derived from the first-stage regression, with results detailed in Table A4. These predicted values are then used to estimate the impact of road infrastructure on livestock production outcomes, Y_{it}, in the second stage:

$$Y_{it} = \alpha + \beta \hat{Road}_{it} + \gamma X_{it} + \mu_i + \epsilon_{it} \tag{3}$$

Here, the coefficient β captures the effect of road infrastructure on livestock production.

To ensure a clearer evaluation of the causal impact of road investments, we excluded kebeles with pre-existing road infrastructure prior to the program. Hence, the analysis focuses solely on kebeles that either received new road infrastructure or remained untreated. Among the 2,085 kebeles surveyed, 371 never received a road, 872 received new road infrastructure during the study period, and 842 had pre-existing roads at baseline.

5. Results and Discussions

Before presenting the main results, we assess the validity of the instrumental variable used to identify the causal impact of road access on livestock outcomes. Our instrument is constructed from three components: proximity to the baseline road network, geographic features such as slope and land use, and the official road construction plan formulated before the URRAP program began. Following Kebede (2022, 2024); Gebresilasse (2023), we simulate road allocation to villages based on these factors, constrained by annual regional budget limits. Roads are assigned until the budget for each region is fully used each year. We test instrument relevance with a first-stage regression. The instrument is strongly correlated with road access, shown by a first-stage F-statistic of 4887.02 and P-value of 0.000 as shown in Table A4.

We also conducted an additional analysis to assess whether baseline livestock production influenced kebele selection for road expansion. This tested the correlation between the year a kebele received a road and its baseline livestock production. If road placement was influenced by livestock potential, kebeles with higher baseline production would have received roads earlier. Results in Tables A5 and A6 show no significant relationship between baseline livestock production and road timing. Together, these tests support the validity of our instrument and allow credible estimation of rural road access effects on livestock outcomes.

5.1. Main Results

In this section, we present the findings of our econometric models. Our analysis reveals that rural roads significantly influence the livestock production system. As shown in Table 1, road access is associated with a decrease of 0.7 in the total number of cattle owned, alongside a 1.8 percentage points increase in the proportion of exotic and hybrid cattle. This shift suggests that improved road access encourages farmers to prioritize high-value breeds over larger herd sizes, focusing on quality and economic efficiency. Several factors linked to improved road infrastructure can explain the increased share of exotic and hybrid cattle. Enhanced roads provide farmers with access to high-quality cattle breeds, which are more productive in terms of milk and meat output. In remote areas, such breeds are less accessible due to high transportation costs and logistical challenges. Furthermore, exotic and hybrid breeds cater to the demands of higher-value urban and regional markets, especially for perishable products like milk, which require efficient transportation to market. Our findings complement and extend those of Stifel et al. (2016), who study the broader effects of rural feeder roads in Ethiopia. Unlike their work, we focus specifically on livestock outcomes and employ a novel simulated IV approach based on planned road placement under URRAP, offering sharper causal identification and deeper insight into mechanisms.

Table 1: Impact of Road on Livestock Size and Types

VARIABLES	**Cattle Owned**	**Share of Exotic and Hybrid Cattle**
Road	-0.704***	0.018***
	(0.196)	(0.003)
Controls	Yes	Yes
Observations	128,497	128,497

Note: The table presents results examining the impact of road exposure on livestock production, utilizing proxies for herd type and size. The impacts are estimated using a two-stage instrumental variable regression model. Controls include household characteristics (age and gender of the household head, family size), village-level characteristics (crop suitability for various cash and food crops, and the SPEI). The model also includes three fixed effects: time, district, and remoteness (the interaction between baseline distance and survey year). Robust standard errors are in parentheses. Significance levels *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.

Additionally, our findings suggest that the improved road network facilitates better access to veterinary care and improved feeding practices. Table 2 underscores the crucial role of road infrastructure in shaping cattle feeding practices. Our analysis reveals that the presence of roads is associated with a significant shift away from traditional grazing-based feeding methods. Specifically, we find that the presence of road is found to be correlated with a 5.7 percentage point reduction in the share of grazing in total feed. Concurrently, road access increases the likelihood of farmers purchasing feed by 4.7 percentage point.

Table 2: Influence of Road Access on Feeding Practices

VARIABLES	Share of Grazing in Total Feed	Feed Purchase (1 = Yes)
Road	-0.057***	0.047***
	(0.008)	(0.011)
Controls	Yes	Yes
Observations	128,497	128,497

Note: The table presents results examining the impact of road exposure on livestock feeding practices, utilizing proxies such as the share of grazing in total feed and feed purchase. The impacts are estimated using a two-stage instrumental variable regression model. Controls include household characteristics (age and gender of the household head, family size), village-level characteristics (crop suitability for various cash and food crops, and the SPEI). The model also includes three fixed effects: time, district, and remoteness (the interaction between baseline distance and survey year). Robust standard errors are in parentheses. The significance levels *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.

The decline in reliance on grazing stems from multiple interconnected factors. Roads reduce the opportunity costs of market travel and transport, making the purchased feed more accessible and convenient. Paradoxically, road access may also increase the opportunity cost of grazing itself, as time spent in grazing could instead be dedicated to other income-generating activities enabled by enhanced market access and infrastructure.

This shift from grazing to purchased feed has significant implications for rural livelihoods and agricultural sustainability. On one hand, it signals a trend toward greater commercialization in livestock farming. On the other, it can alleviate local ecosystem pressures by reducing overgrazing. Furthermore, grazing as a primary feeding method has been associated with increased disease transmission due to direct and indirect inter-herd contact (Boehm et al., 2009; Keyyu et al., 2006). Therefore, the reduction in grazing practices may also positively impact livestock health by lowering disease exposure.

Table 3 highlights the association between road access and cattle health. Our findings indicate that access to roads is associated with an 8.4 percentage point rise in vaccination rates. Vaccination is a crucial component of livestock health management, particularly in rural areas where cattle face greater risks from poor sanitation, uncontrolled grazing, and exposure to wildlife. Improved road access enables veterinary workers to reach remote areas more consistently, making vaccination campaigns more accessible and effective. Vaccinated cattle are less likely to become infected, thereby reducing the risk of transmission to other animals.

Additionally, our analysis reveals that road access is associated with a statistically significant

Table 3: Effect of Road on Cattle Mortality and Veterinary Utilization

VARIABLES	Cattle Death	Share of Cattle Vaccinated
Road	-0.058***	0.084***
	(0.011)	(0.014)
Controls	Yes	Yes
Observations	128,497	128,497

Note: The table presents results examining the impact of road exposure on livestock welfare, utilizing proxies such as mortality and vaccination rates. The impacts are estimated using a two-stage instrumental variable regression model. Controls include household characteristics (age and gender of the household head, family size), village-level characteristics (crop suitability for various cash and food crops, and the SPEI). The model also includes three fixed effects: time, district, and remoteness (the interaction between baseline distance and survey year). Robust standard errors are in parentheses. The significance levels *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.

reduction in cattle mortality. The probability of experiencing at least one cattle death decreases by 5.3 percentage points, likely due to improved access to veterinary services, better feeding practices, and enhanced market access. These improved health outcomes have profound implications for rural communities, where livestock, particularly cattle, are vital for income, food security, and social status.

5.2. Robustness tests

In our main analysis, we included both to-be-treated households and those that were never treated as part of the control group. To enhance the robustness of our results, we conducted a reanalysis that focused solely on households from kebeles that received road infrastructure during the study period, excluding those that never benefited from such developments. Given that treated and untreated areas can differ significantly in unobserved characteristics, excluding untreated areas helps mitigate endogeneity issues that could arise from comparing two distinct populations. Additionally, since treated units share latent similarities based on unobserved factors, this approach allows for more accurate modeling of the data generation process concerning pre-intervention outcomes. The results are presented in Tables A7-A9. As shown in the tables, the results remain qualitatively consistent, except in the case of feeding practices.

To further evaluate the robustness of our IV, we reconstructed it in multiple ways. First, we used the least-cost path from the baseline road to each kebele centroid as an IV, disregarding budget constraints and acknowledging that actual government road expenditures may not strictly follow planned budgets. Second, after constructing the least-cost path for each kebele centroid to the baseline road, we calculated road access to villages based on distance per person along this path. This measure utilized population data from the 2007 census, allowing us to create a per-capita road accessibility variable, which we then used as an IV. Third, we hypothesized that kebeles near those directly intersected by the baseline road network may have a higher probability of gaining road access due to their proximity. Hence, we grouped kebeles by proximity: the first group included kebeles directly intersected by the baseline road; the second group included kebeles adjacent to the first group; the third group included those adjacent to the second, and so forth. Kebeles were then connected to either the baseline road or new roads, depending on which connection was more cost-effective. This iterative method was repeated for each successive group. The results remain consistent, and are presented in Tables A10 and A18.

We conducted an additional analysis using kebeles as the unit of observation. For this, we aggregated observations at the kebele level and applied a fixed-effect IV model. Since the CSS used the same Enumeration Areas (EAs) while resampling households across survey waves, this aggregation was feasible. The results of this kebele-level analysis were consistent with our main findings and are presented in Tables A19 and A21.

6. Conclusion

While existing literature extensively examines the effects of road expansion on crop production and market access, the livestock sector, particularly in Sub-Saharan Africa, has received comparatively little attention despite its critical importance to rural economies. This research addresses that gap by investigating the impact of rural road infrastructure on livestock production in Ethiopia, focusing on the URRAP implemented from 2011 to 2016.

The analysis reveals significant effects of rural road expansion on cattle farming. Households with improved road access are more likely to adopt modern livestock management practices, including the use of superior breeds, improved feeding techniques, and better veterinary care. These findings support the idea that improved roads reduce transaction costs and enhance access to essential inputs and technologies. This shift facilitates a move from traditional to more efficient production systems. In addition, road infrastructure improves access to veterinary services. Households in better-connected areas report higher vaccination rates, consistent with existing literature that highlights how infrastructure expands access to services such as healthcare and agricultural extension. In livestock farming, better access to veterinary care reduces mortality and improves herd health. These outcomes are crucial for increasing productivity and building resilience against disease outbreaks. However, several limitations should be considered when interpreting the findings.

Although tests show no significant differences in household characteristics across survey waves, the use of repeated cross-sectional data limits the ability to observe household-level changes over time. Data constraints also limit the assessment of broader welfare outcomes such as income growth or improvements in overall household well-being. The analysis primarily focuses on cattle management due to both data limitations and the nature of livestock practices in Ethiopia, where animals such as equines typically receive minimal care.

The URRAP road expansion program was implemented in phases, but construction activity was uneven across years. During the first one to two years, efforts focused on planning, surveying, and securing materials rather than construction (Kebede, 2024). Road construction accelerated in the middle years, with most roads completed toward the program's end. This uneven rollout limits the use of a staggered difference-in-differences design, as too few kebeles received roads early enough to allow for reliable comparisons between early and late treatment groups.

Despite these limitations, the study provides valuable evidence to the literature on infrastructure development, rural economics, and livestock management. It complements previous research on road connectivity and crop production and extends those insights to the livestock sector. The findings show how rural road infrastructure can support improvements in livestock practices and access to essential services. These results strengthen the case for continued investment in rural infrastructure to promote broader agricultural development.

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A. Tables

Table A1: Descriptive Statistics of Variables

Variable	**Mean**	**Std. Dev.**
Cattle size (number of cattle)	2.90	5.78
Non-local breed (number)	0.02	0.99
Share of grazing in feeding	0.59	0.32
Feed purchased (1 = Yes)	0.10	0.30
Cattle Death (1 = If at least one cattle death)	0.12	0.33
Share of Cattle Vaccinated	0.62	0.47
Male household head (1 = Yes)	0.81	0.39
Age of the household head (years)	42.71	16.13
SPEI	0.12	1.02
Family size (number)	5.24	2.47

Note: This dataset provides descriptive statistics for the main working variables. The annual livestock survey from 2011 to 2016 is the source of livestock and household-related variables.

Table A2: Household Characteristics Across Survey Years

Year	**Female (Head)**	**Age (Head)**	**Education (Years)**	**HH Size**	**Livestock-Oriented**
2010	0.18	42.43	2.89	5.38	0.84
	(0.11)	(4.81)	(1.43)	(0.85)	(0.17)
2011	0.18	42.43	2.89	5.38	0.84
	(0.11)	(4.81)	(1.43)	(0.85)	(0.17)
2012	0.20	43.53	3.06	5.31	0.83
	(0.11)	(6.95)	(1.46)	(0.86)	(0.18)
2013	0.20	42.74	3.17	5.24	0.84
	(0.11)	(4.92)	(1.65)	(0.83)	(0.18)
2014	0.20	43.07	3.64	5.18	0.84
	(0.11)	(4.86)	(4.52)	(0.83)	(0.17)
2015	0.20	42.94	3.44	5.18	0.83
	(0.11)	(4.99)	(1.63)	(0.83)	(0.17)
2016	0.19	43.60	3.66	5.15	0.82
	(0.11)	(4.96)	(1.71)	(0.87)	(0.20)
Total	0.19	42.96	3.25	5.26	0.84
	(0.11)	(5.26)	(2.26)	(0.85)	(0.18)

Notes: This table reports mean household characteristics by survey year. Standard deviations are shown in parentheses beneath the means. “Female (Head)” equals 1 if the household head is female. “Age (Head)” and “Education” refer to the age and years of formal schooling of the household head. “Livestock-Oriented” equals 1 if the household engaged in the production of both crop and livestock production.

Table A3: Annual Road Construction Plan

Region	**2011**	**2012**	**2013**	**2014**	**2015**	**Total**
Tigray	335	515	550	550	550	2,500
Afar	241	371	396	396	396	1,800
Amhara	2,408	3,708	3,963	3,964	3,960	18,003
Oromiya	4,014	6,180	6,606	6,607	6,600	30,007
SNNP	1,873	2,884	3,083	3,083	3,080	14,003
Gambella	27	41	44	44	44	200
Benshangul-Gumuz	241	371	396	396	396	1,800
Somali	401	618	661	661	660	3,001
Dire Dawa	21	33	35	35	35	159
Harar	7	10	11	11	11	50
Annual Total	9,568	14,731	15,745	15,747	15,732	71,523

Note: The table shows the plan set by the Ethiopian Road Authority to be contracted each year, measured in kilometers..

Table A4: First-Stage Regression Results and Model Statistics

Variable	**Adjusted R-sq.**	**Robust F(1,127974)**	**Prob > F**
Road (1=yes)	0.486	4887.02	0.000
Controls	Yes		
Observations	128,497		

Notes: This table summarizes key model statistics from the first-stage regression used to assess instrument relevance. The F-statistic for the excluded instrument is reported along with its p-value. A strong F-statistic (above the conventional threshold) indicates that the instrument is strongly correlated with the endogenous treatment variable (road access), supporting the validity of the instrument.

Table A5: Impact of Road Construction Timing on Baseline Livestock Outcomes (Part 1)

Year of Construction	Total Cattle	Share of Exotic/Hybrid	Cattle Mortality
2012	-0.051	-0.192	2.357
	(0.469)	(0.246)	(1.606)
2013	-0.193	0.375	0.896
	(0.474)	(0.758)	(1.873)
2014	-0.158	0.223	2.334
	(0.609)	(0.373)	(2.512)
2015	-0.267	0.344	1.776
	(0.555)	(0.638)	(1.901)
2016	-0.018	-0.509	0.103
	(0.507)	(0.333)	(2.545)
Observations	866	860	866

Note: The table presents regression results examining the relationship between baseline village-level livestock outcomes and the timing of road construction. The analysis aims to determine whether road placement decisions were influenced by the village's production potential. Livestock outcomes are measured during the baseline period, with the year 2011 serving as the reference category for road construction timing. Variable definitions are consistent with previous tables. Standard errors are shown in parentheses. Statistical significance levels are denoted as: * p<0.10, ** p<0.05, *** p<0.01.

Table A6: Impact of Road Construction Timing on Baseline Livestock Outcomes (Part 2)

Year of Construction	Share of Grazing	Feed Purchase	Share Vaccinated
2012	-0.821	-0.386	-1.703
	(2.873)	(2.108)	(4.404)
2013	-3.959	-1.195	1.280
	(3.398)	(2.553)	(4.714)
2014	-7.527*	2.481	-0.721
	(4.167)	(3.620)	(7.318)
2015	-2.580	-2.184	-6.323
	(3.513)	(2.917)	(5.501)
2016	0.725	-2.306	0.810
	(3.593)	(2.381)	(4.546)
Observations	865	866	866

Note: The table presents regression results examining the relationship between baseline village-level livestock outcomes and the timing of road construction. The analysis aims to determine whether road placement decisions were influenced by the village's production potential. Livestock outcomes are measured during the baseline period, with the year 2011 serving as the reference category for road construction timing. Variable definitions are consistent with previous tables. Standard errors are shown in parentheses. Statistical significance levels are denoted as: * p<0.10, ** p<0.05, *** p<0.01.

Table A7: Effect of Road Access on Livestock Production (Excluding Never Treated Group)

VARIABLES	**Total Cattle**	**Share of Exotic or Hybrids Cattle**
Treatment	-0.863**	0.039***
	(0.398)	(0.008)
Observations	87,864	87,864

Note: The table presents results examining the impact of road exposure on livestock production, utilizing proxies such as total cattle and the share of exotic or hybrid breeds. The impacts are estimated using a two-stage instrumental variable regression model. Villages that never received roads during the study period are excluded.Controls include household characteristics (age and gender of the household head, family size), village-level characteristics (crop suitability for various cash and food crops, and the SPEI). The model also includes three fixed effects: time, district, and remoteness (the interaction between baseline distance and survey year). Robust standard errors are in parentheses. The significance levels *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.

Table A8: Effect of Road Access on Livestock Feeding Practice (Excluding Never Treated Group)

VARIABLES	**Grazing Share**	**Feed purchased (1 = Yes)**
Treatment	-0.095***	0.000
	(0.016)	(0.016)
Observations	87,864	87,864

Note: The table presents results examining the impact of road exposure on feeding practice. The impacts are estimated using a two-stage instrumental variable regression model. Villages that never received roads during the study period are excluded. Controls include household characteristics (age and gender of the household head, family size), village-level characteristics (crop suitability for various cash and food crops, and the SPEI). The model also includes three fixed effects: time, district, and remoteness (the interaction between baseline distance and survey year). Robust standard errors are in parentheses. The significance levels *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.

Table A9: Effect of Road Access on Livestock Welfare (Excluding Never Treated Group)

VARIABLES	Cattle Death (1 =Yes)	Share of Vaccinated Cattle
Treatment	-0.102***	0.251***
	(0.037)	(0.041)
Observations	87,864	87,864

Note: The table presents results examining the impact of road exposure on cattle mortality and vaccination rates. The impacts are estimated using a two-stage instrumental variable regression model. Villages that never received roads during the study period are excluded. Controls include household characteristics (age and gender of the household head, family size), village-level characteristics (crop suitability for various cash and food crops, and the SPEI). The model also includes three fixed effects: time, district, and remoteness (the interaction between baseline distance and survey year). Robust standard errors are in parentheses. The significance levels *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.

Table A10: Impact of Rural Roads on Cattle Size and Type Using Least Cost Path Length Per Person to Allocate Road Access

VARIABLES	Total Cattle	Share of Exotic or Hybrids Cattle
Road	-0.704***	0.018***
	(0.196)	(0.003)
Controls	Yes	Yes
Observations	128,497	128,497

Note: This table presents the effects of rural road access on total cattle size and type, using an alternative instrumental variable (IV). The IV is constructed using the least cost path length per person in the kebele during 2007 to determine the sequence of road allocation to each kebele. The impacts are estimated using a two-stage instrumental variable regression model. Controls include household characteristics (age and gender of the household head, family size), village-level characteristics (crop suitability for various cash and food crops, and the SPEI). The model also includes three fixed effects: time, district, and remoteness (the interaction between baseline distance and survey year). Robust standard errors are reported in parentheses. Significance levels *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.

Table A11: Impact of Road on Grazing Share and Feed Purchase using Least Cost Path Length Per Person to Allocate Road Access

VARIABLES	**Grazing Share**	**Feed purchased (1 = Yes)**
Road	-0.057***	0.047***
	(0.006)	(0.016)
Controls	Yes	Yes
Observations	128,439	128,497

Note: This table presents results examining the impact of road exposure on livestock feeding practices using an alternative instrumental variable (IV). The IV is constructed using the least cost path length per person in the kebele during 2007 to determine the sequence of road allocation to each kebele. The impacts are estimated using a two-stage instrumental variable regression model. Controls include household characteristics (age and gender of the household head, family size), village-level characteristics (crop suitability for various cash and food crops, and the SPEI). The model also includes three fixed effects: time, district, and remoteness (the interaction between baseline distance and survey year). Robust standard errors are reported in parentheses. Significance levels *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.

Table A12: Impact of Road Access on Cattle Death and Share Vaccinated Using Least Cost Path Length Per Person to Allocate Road Access

VARIABLES	**Cattle Death (1 =Yes)**	**Share of Vaccinated Cattle**
Road	-0.058***	0.084***
	(0.015)	(0.016)
Controls	Yes	Yes
Observations	128,497	128,497

Note: This table presents the effects of road access on cattle death and the share of vaccinated cattle, using an alternative instrumental variable (IV). The IV is constructed using the least cost path length per person in the kebele during 2007 to determine the sequence of road allocation to each kebele. The impacts are estimated using a two-stage instrumental variable regression model. Controls include household characteristics (age and gender of the household head, family size), village-level characteristics (crop suitability for various cash and food crops, and the SPEI). The model also incorporates three fixed effects: time, district, and remoteness (the interaction between baseline distance and survey year). Robust standard errors are reported in parentheses. Significance levels *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

Table A13: Impact of Road on Cattle Size and Type using the Length of Least Cost Path as an IV

VARIABLES	**Total Cattle**	**Share of Exotic or Hybrids Cattle**
Road	-0.760*	0.010***
	(0.418)	(0.003)
Controls	Yes	Yes
Observations	128,497	128,497
R-squared	0.251	0.157

Note: This table presents the effects of road access on the total cattle count and the share of exotic or hybrid cattle breeds, using the length of the least cost path from the baseline road to kebele centroid as an alternative instrumental variable (IV). The impacts are estimated using a two-stage instrumental variable regression model. Controls include household characteristics (age and gender of the household head, family size), village-level characteristics (crop suitability for various cash and food crops, and the SPEI). The model also includes three fixed effects: time, district, and remoteness (the interaction between baseline distance and survey year). Robust standard errors are in parentheses. The significance levels *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.

Table A14: Impact of Road on Grazing Share and Feed Purchase using the Length of Least Cost Path as an IV

VARIABLES	**Grazing Share**	**Feed purchased (1 = Yes)**
Road	-0.026**	0.069***
	(0.012)	(0.025)
Controls	Yes	Yes
Observations	128,439	128,497
R-squared	0.210	0.065

Note: This table presents the effects of road access on grazing share and feed purchase, using the length of the least cost path from the baseline road to the kebele centroid as an alternative instrumental variable (IV). The impacts are estimated using a two-stage instrumental variable regression model. Controls include household characteristics (age and gender of the household head, family size), village-level characteristics (crop suitability for various cash and food crops, and the SPEI). The model also includes three fixed effects: time, district, and remoteness (the interaction between baseline distance and survey year). Robust standard errors are in parentheses. The significance levels *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.

Table A15: Impact of Road on Cattle Death and Vaccinated Cattle using the Length of Least Cost Path as an IV

VARIABLES	Cattle Death (1 =Yes)	Share of Vaccinated Cattle
Road	-0.068***	0.074***
	(0.026)	(0.026)
Controls	Yes	Yes
Observations	128,497	128,497
R-squared	0.195	0.195

Note: This table presents the effects of road access on cattle death and the share of vaccinated cattle, using the length of the least cost path from the baseline road to the kebele centroid as an alternative instrumental variable (IV). The impacts are estimated using a two-stage instrumental variable regression model. Controls include household characteristics (age and gender of the household head, family size), village-level characteristics (crop suitability for various cash and food crops, and the SPEI). The model also includes three fixed effects: time, district, and remoteness (the interaction between baseline distance and survey year). Robust standard errors are in parentheses. The significance levels *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.

Table A16: Impact of Road on Cattle Size and Type using Alternative IV construction method

VARIABLES	Total Cattle	Share of Exotic or Hybrids Cattle
Road	-1.296***	0.023***
	(0.228)	(0.004)
Controls	Yes	Yes
Observations	128,378	128,378

Note: This table presents the effects of road access on cattle size and type, using an alternative instrumental variable (IV). The IV categorizes kebeles into four groups based on proximity to the baseline road network: the first group includes villages on the baseline network, the second includes those adjacent to the first, and so on. For each group, least-cost paths from village centers to the nearest baseline road are computed, connecting neighboring villages to the nearest baseline or newly constructed road. This process repeats for each group. Impacts are estimated using a two-stage instrumental variable regression model. Controls include household characteristics (age and gender of the household head, family size), and village-level characteristics (suitability for various cash and food crops, and SPEI). The model also includes three fixed effects: time, district, and remoteness (the interaction between baseline distance and survey year). Robust standard errors are in parentheses. The significance levels *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.

Table A17: Impact of Road on Grazing Share and Feed Purchase using Alternative IV Construction method

VARIABLES	**Grazing Share**	**Feed purchased (1 = Yes)**
Road	-0.064***	-0.007
	(0.009)	(0.022)
Controls	Yes	Yes
Observations	128,320	128,378

Note: This table presents the effects of road access on cattle feeding practice, using an alternative instrumental variable (IV). The IV categorizes kebeles into four groups based on proximity to the baseline road network: the first group includes villages on the baseline network, the second includes those adjacent to the first, and so on. For each group, least-cost paths from village centers to the nearest baseline road are computed, connecting neighboring villages to the nearest baseline or newly constructed road. This process repeats for each group. Impacts are estimated using a two-stage instrumental variable regression model. Controls include household characteristics (age and gender of the household head, family size), and village-level characteristics (suitability for various cash and food crops, and SPEI). The model also includes three fixed effects: time, district, and remoteness (the interaction between baseline distance and survey year). Robust standard errors are in parentheses. The significance levels *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.

Table A18: Impact of Road on Cattle Death and Vaccinated Cattle using Alternative IV construction method

VARIABLES	**Cattle Death (1 =Yes)**	**Share of Vaccinated Cattle**
Road	-0.075***	0.114***
	(0.021)	(0.023)
Controls	Yes	Yes
Observations	128,378	128,378

Note: This table presents the effects of road access on cattle death and the share of vaccinated cattle, using an alternative instrumental variable (IV). The IV categorizes kebeles into four groups based on proximity to the baseline road network: the first group includes villages on the baseline network, the second includes those adjacent to the first, and so on. For each group, least-cost paths from village centers to the nearest baseline road are computed, connecting neighboring villages to the nearest baseline or newly constructed road. This process repeats for each group. Impacts are estimated using a two-stage instrumental variable regression model. Controls include household characteristics (age and gender of the household head, family size), and village-level characteristics (suitability for various cash and food crops, and SPEI). The model also includes three fixed effects: time, district, and remoteness (the interaction between baseline distance and survey year). Robust standard errors are in parentheses. The significance levels *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.

Table A19: Impact of Rural Roads on Cattle Size and Type Using Kebele as Unit of Analysis

VARIABLES	Cattle Size	Share of Exotic or Hybrids Cattle
Road	-0.076	0.012***
	(0.189)	(0.002)
Controls	Yes	Yes
Observations	8,556	8,466

Note: This table presents the effects of rural road access on livestock size and breed composition, with kebele as the unit of analysis. The estimates are derived using a Fixed Effects instrumental variable regression model. The controls include household characteristics (age and gender of the household head, family size), village-level time-varying factors, and the interaction between baseline distance and survey year. Standard errors are shown in parentheses. *** denotes significance at the 1% level.

Table A20: Effects of Rural Roads on Feeding Habits using Kebele as the unit of analysis

VARIABLES	Feed purchased (1 = Yes)	Grazing share
Road	0.053***	-0.035***
	(0.011)	(0.010)
Controls	Yes	Yes
Observations	8,556	8,552

Note: This table presents the effects of rural road access on feeding habits, specifically feed purchasing and grazing percentage, with kebele as the unit of analysis. The estimates are derived using a Fixed Effects instrumental variable regression model. The controls include household characteristics (age and gender of the household head, family size), village-level time-varying factors, and the interaction between baseline distance and survey year. Robust standard errors are in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table A21: Effects of Rural Roads on Cattle Health using kebele as the unit of analysis

VARIABLES	Share of Vaccinated Cattle	Cattle Death (1 =Yes)
Road	0.075***	-0.015*
	(0.016)	(0.008)
Controls	Yes	Yes
Observations	8,556	8,556

Note: This table presents the effects of rural roads on cattle health outcomes, specifically the share of vaccinated cattle and cattle death incidence using kebele as a unit of analysis. The estimates are derived using a Fixed Effects instrumental variable regression model. The controls include household characteristics (age and gender of the household head, family size), village-level time-varying factors, and the interaction between baseline distance and survey year. Robust standard errors are in parentheses. *** p<0.01, ** p<0.05, * p<0.1.