Rural Roads, Agricultural Extension, and Productivity

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JOB MARKET PAPER

October 2018

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Abstract

Low agricultural productivity is a persistent challenge for developing economies. Two policy innovations that have attracted significant attention include the expansion of rural roads and agricultural extension services that facilitate access to technologies and inputs. However, the studies that examine each of these policies in isolation provide mixed evidence on their effectiveness. This paper shows that it is important to consider roads and extension simultaneously due to the strong complementarities between the two factors. I study the concurrent but independently implemented expansion of rural roads and extension in Ethiopia to examine how access to markets and technologies affect productivity when available in isolation and together. Using geo-spatial data combined with large surveys and exploiting the staggered roll-out of the two programs, I show that there are strong complementarities between roads and extension. While ineffective in isolation, access to both a road and extension increases productivity by 11%. I find that roads and extension improve productivity by facilitating the take up of agricultural advice, credit and modern inputs such as chemical fertilizers. Furthermore, households adjust crop choices and shift across occupations in response to their changing comparative advantages in access to markets and technologies. Overall, while extension and roads increase farm income on average, the gains are concentrated in the villages that have access to both factors.

Keywords: Rural Roads, Extension, Productivity, Ethiopia, Market Access, Agricultural Management

JEL Codes: O12, O13, O18, Q12, Q16, R23, R42

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1 Introduction

Improving agricultural productivity is a policy concern in developing countries. In 2017, while 60% of the population in the least developed economies were engaged in agriculture, the sector accounted for only 24% of the GDP. Expansions in the rural road network and agricultural extension have been considered as solutions to raise productivity. The evidence on the effectiveness of extension and road programs, in isolation, is mixed (Asher and Novosad, 2018; Anderson and Feder, 2007; BenYishay and Mobarak, 2018; Dercon et al., 2009; Krishnan and Patnam, 2013; Van de Walle, 2009). However, there could be important interactions between access to extension and roads. Extension provides farmers with the technologies and inputs that enable them to capitalize on market access. Rural roads facilitate the provision of extension and increase access to market opportunities that incentivize the take up of technologies recommended by extension. This paper shows that it is critical to consider roads and extension simultaneously due to the strong complementarities between the two factors that can modulate their efficacies in different contexts.

I investigate the complementarities between access to markets and technologies by considering the simultaneous but independently implemented expansion of extension and rural roads in Ethiopia. In the first program, the government expanded access to extension, starting in 2004, with a goal to provide every village with a farmer training center and three extension agents that advise farmers and facilitate access to modern inputs. Since 2004, the share of farmers who received advisory services increased from 25% to 74%, and it continues to expand. The second program, the Universal Rural Road Access Program (URRAP), was commenced in 2011 to connect every village with an all-weather road. By 2017, URRAP has doubled the share of villages with an all-weather road to over 76%. Since 2004, the Ethiopian GDP has increased by 262% and value added per worker in agriculture has increased by 94% (WBG, 2018). The massive scale, concurrent timing and uncoordinated expansions of these two programs and Ethiopia's striking growth over the same period present an ideal context to study the role of access to markets and technologies at the early stages of structural transformation.

Combining administrative geo-spatial data with large surveys and exploiting the staggered roll out of the roads and extension, I find that, while ineffective in isolation, extension and roads have strong complementary effects on agricultural productivity. I show that in villages with access to both extension and roads, farmers are more likely to use agricultural advice, credit and modern inputs. In addition, farmers specialize in crops and trade across villages in line with their relative advantages with respect to access to markets and technologies. In the villages that get a road without the technologies provided under extension, households reduce total area cultivated and are more likely to shift to non-farm occupations. While extension and roads increase farm income on average, the improvements are concentrated in the villages that have access to both factors. However, comparing consumption and living standards across villages, the effects of the changes in farm income are mitigated by labor reallocation across sectors.

Access to a road and extension can have strong complementarities because poor connectivity or unavailability of technologies constrain the other factor's efficacy. Improvements in the road network may increase agricultural productivity by changing farmers' access to markets and public services such as extension. Access to roads may also decrease productivity if non-farm opportunities reduce the effort put into farm work or select the more skilled individuals out of agriculture. On the other hand, extension can improve productivity by advising farmers on best technologies, facilitating access to inputs, mobilizing the community to address common problems, and helping households deal with shocks. However, farmers may not benefit from market access without the relevant know-how and support provided under extension. Poor roads limit the ability of extension agents to reach farmers. Farmers may not undertake costly investments in technologies without profitable market opportunities. Hence, extension and road together have a stronger effect on productivity because they relax two interdependent rural constraints, access to markets and technologies, simultaneously.

Until 2004, the provision of extension in Ethiopia was very limited. The current regime, which has been in power since 1995, considers the agriculture sector central in its overall development strategy and has adopted extension as a key instrument to improve productivity. A farmer training center equipped with three development agents is the focal point for the delivery of extension in a village. Since 2004, over 15,000 farmer training centers have been built and 72,000 agents have been staffed. Cereals which are the main staple crops, receive the lion share of the extension coverage. While cereals account for 67% of the cultivated area, they constitute more than 84% of the area under extension. The expansion of extension is implemented by the regional bureau of agricultural and rural development. The main factors that determined the roll out of extension across villages are remoteness, agro-climatic suitability and the regional budget constraints.

In addition to expanding extension, the government has invested over $2 billion in the road network under URRAP. While there are national guidelines regarding the implementation of URRAP, there is no single formula for determining the prioritization of roads across villages. In each region, the district road authority identifies a potential road project, and for each road, the regional administration hires engineering consultants to design a cost-effective route given the topography (mainly gradient and rivers) and the national road design standards. When possible, the route selection circumvents river crossings and builds along flat slopes to reduce costly bridge construction and improve stability. The length of roads to be built in each region was set in the five year URRAP plan at baseline and relatively fixed across years. The timing of which roads are built is determined by the regional authorities considering the remoteness of each village, cost of construction and the regional budget.

I link annual agricultural sample surveys from the Central Statistical Agency with a novel administrative road network data from the Ethiopian Road Authority. I supplement the network data with road level information using the work progress reports I compiled from the regional authorities. The final sample is balanced panel comprising of 1670 villages with over 30,000 farmers in each year for 2010-16. The main outcomes are three alternative measures of productivity: production value per hectare, value added per hectare and TFP calculated following Levinsohn and Petrin (2003). I also use surveys on consumption and employment from the 2010/11 and 2015/16 waves of the Household Consumption and Expenditure Surveys and Welfare Monitoring Surveys.

The critical challenge to identify the effects of expansions in roads and extension is the potential endogenous placement of the programs since policymakers may consider economic and political factors. In my setting, the roll out of each program is mainly determined by baseline remoteness, topography and the regional budget constraints. Furthermore, the two programs are implemented independently by two separate government agencies. The timing of which village gets a road, extension or both is often beyond the purview of the village. I provide causal estimates on the impact of access to rural road and extension by employing generalized difference-in-difference (GDD) and instrumental variable (IV) strategies that leverage the constrained but staggered roll-out of both programs.

In the GDD design, I exploit the variation in the timing of a village's access to a road or extension. In every specification, I include village, year and the interaction between remoteness (distance to baseline network) and year fixed effects. Village fixed effects control for any characteristics, such as natural productivity potentials, that may influence the timing of access to extension and road. Year fixed effects flexibly control for any trends. Given the roll out of roads and extension from the nearest to the most remote, the remoteness by year fixed effects control for any factors that also change overtime by remoteness. Hence, the identification strategy compares two villages that are identical in time invariant characteristics and similarly affected by remoteness, but one of them gets access to the road, extension or both while the other does not due to factors - topography and regional budgets - exogenous to the villages. Using an event study specification, I provide evidence for the identifying assumption that there are no differential pre-trends by timing of treatment.

I adopt two approaches to measure road access. The first approach uses a binary indicator on whether the village is intersected by a URRAP road. URRAP is the main source of variation in road access during my study period, and the binary variable provides estimates on the direct impact of the expansion under URRAP. In the second approach, I use a market access measure which considers the full road network and distribution of economic potential at baseline to construct a continuous measure of connectivity. The market access approach has two key advantages over the binary measure: it allows for continuous treatment intensity and accounts for potential increases in market access from indirect connections.

To allay concerns about omitted variables, I use a second identification strategy that combines the GDD design with an IV based on the predicted optimal road network. To construct the IV, first, I predict the least cost path that connects every village to the baseline network or the nearest connected village accounting for the construction costs implied by land gradient and rivers. Second, I take the regional road authority's perspective and determine the network in each year by building the roads closest to the baseline network until the regional annual budget is exhausted. Using the predicted network, I calculate the market access which serves as an IV for the actual market access. The main advantage of the IV is that it isolates the variation in road access due to only the factors that are exogenous to the village.

The finding that is consistent across the different approaches is that road and extension have strong complementary effects on productivity. While ineffective in isolation, in villages that gain access to both a road and extension, productivity increases by 10-12%. Furthermore, I show that both the OLS and IV results are robust to a battery of controls that account for differential trends by region, agro-climatic suitabilities and baseline proximity to over 45 rural services and facilities which could affect both productivity and timing of access to extension and road.

The novel contribution of this paper is that I study of a unique natural experiment considering two concurrent and uncoordinated national programs to provide causal estimates on the complementarities between access to extension and road. Using model calibrations, Gollin and Rogerson (2014) show that a simultaneous 10% increase in agricultural TFP and 10% reduction in transport costs can lead to 62% improvements in consumption. Furthermore, the studies on take up of technologies and the mixed evidence on the efficacy of roads and extension, in isolation, suggest that it may be valuable to consider the two factors together (Asher and Novosad, 2018; Shamdasani, 2018; Suri, 2011; Michler et al., 2018). For instance, Asher and Novosad (2018) find that expansion of rural roads India has no impact on agricultural outcomes, and conclude that "rural growth is constrained by more than the poor state of transportation infrastructure." In this paper, I show that while road access is ineffective in isolation, it improves productivity when complemented with extension.

In its objective to understand the determinants of agricultural productivity, this paper relates to literature on two puzzles about the developing world: the productivity gap between the agriculture and non-agriculture sector and the low take up of productive technologies. Gollin et al. (2013) document that value added per worker is much higher in the nonagricultural sector, suggesting severe misallocation of labor. Despite poor agricultural productivity, a related strand of the literature has documented another puzzle - low take up of productivity enhancing technologies (Suri, 2011; Foster and Rosenzweig, 2010; Conley and Udry, 2010; Duflo et al., 2008). Suri (2011) shows that farmers do not adopt technologies that could dramatically increase their productivity because of heterogeneous net benefits to the technology. Michler et al. (2018) find that chickpea farmers in Ethiopia adopt improved seeds because it improves economic returns despite its lack of effect on physical yield. In both studies, poor access to markets is a hindrance to the adoption of modern technologies. This paper provides further evidence that there are heterogeneous benefits to technologies based on access to markets.

The paper also contributes to the literature on how rural road expansions affect agricultural production.[1] Jacoby (2000) shows that rural access to markets confers substantial benefits to poor households, but may not be sufficient to reduce income inequality. Aggarwal (2018a) finds that in districts with greater paved road construction, households benefit from cheaper non-local goods, higher consumption variety and increased use of agricultural technologies. Shamdasani (2018) shows that farmers in remote villages that get new road switch to market oriented farming, increase hiring of farm labor, and invest more in complementary modern inputs. Shrestha (2017) finds similar effects considering highway expansion in Nepal. On the other hand, Asher and Novosad (2018) show that while access to new rural feeder roads result in labor reallocation to non-farm work, they find no effects on agricultural outcomes. My paper contributes to the literature by providing additional evidence in a new context. Furthermore, a village's access to a road has general equilibrium (GE) effects since it changes the comparative advantage of the other villages in the network and thus affects the patterns of specialization and trade across villages. I add to the existing studies by exploiting the geo-spatial data and distribution of population across all villages to provide a measure of market access that accounts for variations in treatment intensity and indirect connections to capture the GE effects.

While there are studies that have examined the effect of access to roads on rural welfare in Ethiopia, this paper is the first to provide causal estimates of the impact of road expansions under URRAP. Dercon et al. (2012) find that access to a good road reduces the likelihood of chronic poverty by 36%, and Stifel et al. (2016) show that gravel roads have internal rates of return of 12 - 35%. My paper complements these studies in three key dimensions. First, I hone in on the impact of access to all-weather roads on agricultural productivity and crop choice to assess the channels by which road access affects rural welfare. Second, while the two papers study road access in pre-URRAP period, I consider a time period over which the share of villages that had all-weather roads in Ethiopia doubled to 76%. Third, both

[1] Given the focus of this paper, I limit my discussion of the literature to the studies on rural roads. See Redding and Turner (2015) for a detailed survey of the literature on different types of transport infrastructure, including rails, colonial roads and recent highway expansions.

papers study areas with limited scope: Dercon et al. (2012) use a longitudinal sample of 15 villages while Stifel et al. (2016) consider a sample of 850 households in one district. In this paper, I use the full road network and large surveys that allow me to examine the impact of changes in access to all-weather roads with a panel of over thousands of villages across Ethiopia from 2010-2016.

Finally, this paper relates to the literature on the efficacy of agricultural extension. Several of these studies have found weak or no evidence for the effect of extension on agricultural production across different settings (BenYishay and Mobarak, 2018; Birkhaeuser et al., 1991; Evenson, 2001; Owens et al., 2003; Anderson and Feder, 2007; Feder et al., 2010; Larsen and Lilleør, 2014; Udry et al., 2010). In the Ethiopian context, there have been several studies that have examined the relevance of extension for rural welfare. Dercon et al. (2009) use longitudinal data from 15 villages over 1994-2004 and finds that receiving at least one extension visit during the last cropping season reduces headcount poverty by 9.8%. Bachewe et al. (2018) show that extension agent visit is associated with increased adoption of improved seeds and fertilizer for the main cereals. On the other hand, Krishnan and Patnam (2013) find that while extension agents had initial effect on the use of modern inputs, adoption mainly takes place through social learning in the latter periods. Furthermore, Buehren et al. (2017) study households in 85 villages in 2010 and 2012, find that while access to a farmer training center increases cultivation of marketable crops, it has no effects on productivity, use of fertilizer or income.

My paper adds to the existing studies on the role of extension by providing detailed evidence on its impact using a panel dataset of 1670 villages during a period of massive expansion in extension services in Ethiopia and showing how the effectiveness of the program is modulated by access to markets. Consistent with Buehren et al. (2017), I find that access to extension, in isolation, has no effect on overall productivity. However, I show that access to extension increases cereal productivity, which had been the focus of the program. Furthermore, while ineffective in isolation, extension does increase overall productivity and farm income when combined with improved market access.

The rest of this paper proceeds as following: Section 2 provides the policy background on the road and extension programs, Section 3 offers a simple conceptual framework to understand how roads and extension affect agricultural production, Section 4 discusses the data, Section 5 presents the empirical strategy, Section 6 discusses the results and robustness checks, Section 7 explores the mechanisms that explain the main findings, and Section 8 concludes with the key lessons from the main findings.

2 Policy Background

In this section, I provide a brief overview of institutional context on the expansion of the rural roads and extension services.

2.1 Policy Background: The Universal Rural Road Program

Over 80% of Ethiopia's 105 million population live in the rural areas with seasonally and spatially variable climate and rugged topography. However, in 2010, close to 48 million people lived more than 2 kilometers way from the nearest all-weather road (ERA, 2010a). While the government has heavily invested in the road sector, the focus was on federal trunk and link roads until 2010.

The government commenced the Universal Rural Road Access Program (URRAP) in 2010 with the mission to connect every village by an all-weather road that would provide the community year round access to public, economic and social services. The first implementation phase of the program (2010-2015) aimed to build 71,523 km of all-weather roads throughout the country at an estimated cost of over $1 billion . As Figure A.1 shows that while the lion share of the expenditure on roads were initially dedicated to federal roads, the government has heavily shifted resources towards investing in rural roads through URRAP. Consistent with the expenditure patterns, Figure 1 demonstrates that the roads built under URRAP account for a significant share of the recent expansion in the total road network length. Figures A.2 shows the expansion of the road network since the commencement of URRAP. This study focuses on access to URRAP roads precisely because URRAP is the main driver of the recent increase in the network density and the most relevant road type for the rural population.

The implementation of URRAP is decentralized by design. Ethiopia is organized as a federal system, and the constitution grants each of the eleven regions extensive autonomies to conduct their internal affairs. Furthermore, each region is further decentralized into districts (*weredas*) in a similar fashion. In line with the federal structure, while the full cost of URRAP is borne by the federal government, the implementation of the program is left to the discretion of the regional and subsequently wereda (district) administrations. The program has been implemented in all the regions except in Afar and Somali regions which had opted out of the program.

While there are national priorities and guidelines that inform the implementation of URRAP, there is no single formula for determining the targeting of URRAP across villages. Table 1 presents the plans for the length of kilometers to be built under URRAP in each region and year as established in the official planning documents. As annual work plan shows, across regions and overtime, there is no strategic allocation of the length of roads to built. Rather, the planning reflects the fact that a total number of road length has to be constructed in each region and the timing of how many kilometers is built in a given year is a function of budget constraints. The district level road authorities in each region are tasked with the selection and implementation of URRAP projects. For each potential URRAP road, the regional administration hires engineering consultants that undertake feasibility studies in order to produce the most cost effective routes taking the topographical constraints and national design standards into account. Then, the regional level road authorities are responsible for the approval, coordination and monitoring of the selected projects factoring in the ease of implementation, cost of construction and budget constraints.

To meet the challenges of seasonal weather variability and diverse topography, the federal standards for URRAP specify that the road design has to account for the influence of local climate, hydrology, terrain and available materials in a manner that is cost effective to construct and maintain. Under the program, new all-weather roads are constructed or existing dry weather roads are upgraded. With few exceptions, the vast majority of roads built under URRAP are unpaved gravel roads with appropriate drainage structure and a capacity of 25-75 annual average daily traffic (ERA, 2011).

Typically, the roads built under URRAP are low-volume feeder roads, with an average length of 10 kilometers, that connect village centers to the nearest major regional and federal road or the nearest town which is often placed along the major road. In few instances, URRAP roads can be as long as 80 kilometers, transversing multiple villages. Figure 3 (a)-(d) demonstrates the gradual roll out of URRAP from the villages that are closest to the baseline network to the most remote. I exploit these features of the program roll out in the baseline identification strategy as well as to construct an instrumental variable based on least cost path that connect every village to the baseline network.

2.2 Policy Background: The Expansion of Agricultural Extension

The provision of agricultural extension in Ethiopia dates back to 1953 with the establishment of the Imperial Ethiopian College of Agriculture and Mechanical Arts. In this section, I present a brief overview of the policy background on extension services with a focus on the recent expansion across the country. Berhane et al. (2018) provide a detailed account of the history of extension programs in Ethiopia.

While agricultural extension has gone through various changes since 1953, the scope of the program was limited to areas with high agricultural potential that are also easily accessible until 1995,. The recent expansion of extension across Ethiopia is driven by two factors. First, the current government, which has been in power since 1991, adopted an overall development strategy known as Agriculture Development Led Industrialization that emphasized improvements in smallholder agricultural productivity as the key to transform the economy. Accordingly, the government has invested heavily in the rural sector, and expansion of public agricultural extension services is a significant component of the investment.

Second, a pilot extension program undertaken by nongovernmental organization, Sasakawa Africa Association and Global 2000 (SG-2000) in collaboration with the Ministry of Agriculture, demonstrated the potential for dramatic improvements in productivity under an extension program. In particular, the pilot study showed that under a program that provided farmers with best farming technologies, subsidized inputs and close supervision, farmers could more than double their yields for maize and wheat (Davis et al., 2010). Following the pilot study, in 1995, the government adopted the packages tried under SG-2000 into a national extension services program called Participatory Demonstration and Training System (PADETES), and expanded the availability across the country.

While the extension program has gone through several iterations since 1995, the main components are still the same. Using trained development agents (DAs), the program aims to improve agricultural productivity through the transfer of knowledge on best farming practices, provision of subsided inputs and credit, and community mobilization. The delivery of extension can vary from the simplest provision of advising services to the most comprehensive packages where farmers set aside a plot of land (0.25 to 0.50 hectares) and apply prescribed inputs and practices.

After the assessment of PADETES revealed severe human capital bottlenecks in the extension system, the government implemented a policy to increase the number of development agents through Agricultural Technical and Vocational Education and Training (ATVETs) starting in 2004. In addition, the government put forth a policy to establish a farmer training center in every village equipped with three development agents that would serve as a focal point for the delivery of extension. The farmer training centers, which are equipped with classrooms and trial plots, serve as central locations for farmers to receive advice and learn from demonstrations on trial plots. Starting in 2006, through the Rural Capacity Building Project, the government further strengthened the extension programs by investing in the technical, physical, and managerial capacity of the extension system (Berhane et al., 2018).

The massive investment in the extension program is reflected both in the expansion of access and take up of extension. The number of development agents increased from 2,500 in 1995 to 15,000 in 2002, and to over 72,000 in 2016. Since 2004, more than 15,000 farmer training centers have been built across the country. Figure 4 maps the location of farmer training centers and development agents office in 2007 and 2014, and demonstrates the enormous expansion in the availability of extension over the period.

Similarly, the use of extension has also increased significantly over this period. Figure A.5a (a) shows that the share of area covered under extension package has doubled between 2010 and 2016. However, as Figure A.5a (b) demonstrates, most of the increase in the use of extension is concentrated in cereals, which are the main staple crops. In 2016, over 36% of of the area under cereals is covered by extension while only 13% of the non-cereal area is under extension package. As Figure A.5a (c) shows, despite cereals accounting for only 67% of total cultivated area, they account for over 80% of the area under extension. Thus, access to extension may have heterogeneous effects on agricultural production across crop groups.

3 Conceptual Framework

In this section, taking the existing literature and the Ethiopian context into account, I outline a simple conceptual framework to explain how changes in rural road network and access to extension may affect agricultural production, and highlight the potential complementarities between the two factors.

3.1 Rural Roads and Agricultural Productivity

The expansions in the rural road network may affect productivity and crop choice by changing farmers' access to input markets, agricultural output markets, non-farm opportunities and public services.

Improvements in rural road network provide farmers with easier, and perhaps cheaper, access to markets for inputs as well as private services such as credit that are often available only in neighboring towns. Rashid et al. (2013) study the distribution of fertilizers in Ethiopia, and find that the final subsidized retail prices of fertilizers are 15-20% higher than the prices at the port of entry and transport costs alone account for 64-80% of the differences. Hence, better transport infrastructure can boost productivity by facilitating access to cheaper modern inputs such as chemical fertilizers and improved seeds.

The literature on the economic impact of remoteness has highlighted that rural isolation hampers development by limiting the access to critical public and social services (Bryceson et al., 2008; Linard et al., 2012; Porter, 2002; WBG, 2004). Improvements in the road network can affect agricultural productivity by facilitating the transfer of technological know-how through extension. Furthermore, increased rural connectivity can affect agricultural productivity indirectly by improving access to public services such as health care, education and safety net programs. Aggarwal (2018b) shows that road construction under PMSGY results in higher rates of institutional antenatal-care and deliveries that improve maternal health. To the extent that improvements in health affect workers efforts and time allocation, increased rural road access can have indirect effects on agricultural productivity.

Even with improved access to knowledge and inputs, farmers may not undertake costly investments in modern inputs and practices unless they also have access to output markets that would make such investments profitable (Suri, 2011; Michler et al., 2018). This may be particularly important for crops that perish unless sold within reasonable time or cash crops that are not as needed for subsistence. Improved market access also enables farmers to get better producer prices by allowing them to arbitrage across connected output markets. Hence, increased market access can improve productivity by providing farmers with profitable opportunities that could incentivize costly productivity enhancing investments.

In contexts where subsistence consumption does not justify the production of commercial crops, improvements in market access may incentivize farmers to cultivate profitable crops, such as cash crops and oils, that are predominantly utilized for the sale. Increased rural connectivity may also affect market participation even for crops, such as cereals, that are often produced for own consumption. Furthermore, access to markets may increase the profitability of producing using marginal fallow lands or those previously used for suboptimal purposes such as grazing. In combination, better rural connectivity can increase total land cultivated and encourage production of commercial crops.

In addition, given the seasonality and riskiness of agricultural production, improved rural connectivity can affect agricultural production by providing opportunities for non-farm work that could mitigate the effects of seasonality or shocks. For instance, Asher and Novosad (2018) find that new paved roads result in the reallocation of labor to non-farm sector by facilitating the access of rural labor to external employment. To the extent that households can supplement their income through non agricultural work, they may have the requisite resources need to invest in costly productivity improving investments such as purchasing chemical fertilizers and improved seeds.

Nonetheless, taking the general equilibrium effects into account, it is possible that expansion of the rural road network can reduce agricultural productivity. A substantial reallocation of labor to non-farm secondary employment could adversely affect productivity if farmers are not investing as much time and other resources in productivity improving practices on the farm. Labor reallocation may also negatively affect productivity if the more skilled and able farmers switch to the non-farm sector. In addition, in the long run, market incentivized over-cultivation or use of less productive marginal lands may also result in reduction in agricultural productivity. For instance, Asher et al. (2018) show that while expansion in rural road network did not affect deforestation, the highway upgrades programs resulted in substantial forest losses that could have long term detrimental effects on agricultural productivity.

Due to the network structure, a village's road access may be best considered in relation to the other villages. First, the change in connectivity when a village gets a new road is a function of the characteristics (such as population or level of development) of the new potential destinations. A village that gets connected to a set of more developed villages and towns would have a bigger change its access to markets than one that gets connected to an isolated and less developed cluster. Second, a village's access to a new road has spatial spillovers since it also alters the connectedness of all the other villages in the same network. The relative connectivity of a given village, and thus its evolving comparative advantage with respect to access to markets or extension, determines changes in the patterns of specialization and trade. To account for these two features of expansion of the road network, in the empirical analysis, I show that the results are robust to using the market access approach that accounts for the variations in treatment intensity and the increases in access due to indirect connections.

3.2 Access to Extension and Agricultural Productivity

Extension services can affect agricultural production by providing farmers with best technologies, facilitating their access to inputs, and helping them deal with shocks.

Extension agents are the liaisons between agricultural research and practice. Figure A.5d presents the average development agent's allocation of time during a typical work week. More than 35% of the agent's time is dedicated to advising and training farmers either through field visits to farmers' homes or using demonstrations at the farmer training centers. The main channel through which extension can affect agricultural productivity is by improving farmers knowledge of best farming technologies .

Extension agents are also in charge of facilitating farmers access to modern inputs such as improved seeds and chemical fertilizers. Development agents spend over 10% of their work week to bring inputs from the source, inform farmers about their availability and distribute them to farmers. Furthermore, development agents are tasked with administering loans to farmers who buy the government subsidized inputs on credit. Hence, access to extension can affect agricultural productivity by facilitating knowledge and take up of credit and productivity enhancing modern inputs.

In addition, extension workers play a role in mobilizing the community to address issues that require coordinated effort such as watershed management or address shocks such as pest infestations. As Figure A.5d shows, DAs spend over 15% on community mobilization and data collection. Development agents also play a role in collecting agricultural data and discussing pertinent issues with other stakeholders, such village officials, who may not be directly engaged in agricultural related issues. Thus, access to extension can affect agricultural production by helping farmers mobilize, assist them to cope with adverse shocks and serve as liaisons to different stakeholders at the village and district level.

3.3 Complementarities Between Access to Roads and Extension

As the discussions of the mechanism by which improved access to roads and extension separately affect agricultural production demonstrate, there could be strong complementarities between the two factors.

An in depth review of the public extension service in Ethiopia found that the poor rural road network was one of the main constraints that limited the provision of agricultural extension services to farmers (Davis et al., 2010). As Figure A.5d, extension agents spend significant amount of their time visiting farmers, bringing in inputs and mobilizing the village community. A recent study on the state of extension also found that the poor transport infrastructure limits the ability of DAs to contact a large number of farmers within a given area (Berhane et al., 2018). Hence, access to an all-weather road complements the provision of extension by facilitating DA's ability to visit farmers fields, mobilize the community and bring in the requisite inputs into villages, particularly during the rainy seasons.

In addition, the adoption of modern technologies may not be a profitable if farmers can not take their produce to the market. In particular, with crops that are perishable or difficult to transport under poor road conditions, but potentially profitable given local agro-climatic similarities, farmers may not be willing to cultivate such crops or invest in the requisite modern inputs. The improvements in access to output markets complement extension services by providing farmers with additional incentives to take up the productivity enhancing advices and inputs recommended by the development agents.

Access to a new road on its own may not be beneficial to farmers unless they have the know-how, access to inputs and market information they need to capitalize on new opportunities. Extension complements improved market access by facilitating farmers' knowledge of best farming technologies and subsidized inputs. Furthermore, integration of villages into the larger network could expose farmers to potential import competitions from producers in connected village. Access to extension services can enable farmers in villages that gain road access to position themselves, through choice of crop varieties or targeting of particular markets, in order to cope with the potentially negative effects of import competition. Hence, access to extension complements improvements in the road network by enabling farmers to capitalize on the economic benefits and mitigate the potential adverse effects of economic integration.

Overall, while access to extension may increase agricultural productivity on its own, its efficacy may be limited in the absence of good transport infrastructure. Even if improvements in rural road network provide farmers with increased access to markets that incentivize productive investments, farmers may not benefit from the improved access without access to the relevant know-how and access to inputs and credit that are provided under the extension program. The presence of both extension services and an all-weather road in a village relaxes the two main constraints on agricultural production, access to markets and technologies, simultaneously. Hence, there may be strong complementaries between the expansion of extension and rural road network under URRAP in transforming agricultural productivity.

4 Data

In order to examine the impact of village level access to an all-weather road or extension, I combine administrative data on the road network with various survey datasets that have information on variables of interest pertaining to availability of extension, agricultural production, employment, consumption and other welfare measures. In this section, I provide details on the three main data sources.

4.1 Road Network

I use a novel and previously unused geo-spatial data on the road network that was complied by the Ethiopian Road Authority (ERA) in 2016. The GIS data covers all roads in Ethiopia and the corresponding attribute table provides detailed road level information, including road class, ownership, surface type and construction year. The data on construction commencement and completion year is not available for all the roads in the GIS data. Hence, I supplement the network data with road level information using the work progress reports I compiled from the four main regional road authorities (Amhara, Oromia, SNNP and Tigray). As the Figure 1 and A.2 show, the rural roads constructed under URRAP account for the lions share of the recent expansion in the road network recently.

Almost all of the URRAP roads were commenced between 2011 and 2014. Figure 2 provides the number of villages where road construction was commenced for each year. Since the data on the completion year of URRAP roads is not comprehensive, I use the construction commencement year compiled from the regional progress reports to construct the road access measure. For the roads where both the construction start and completion year is available, the average length of the project is around 2 years.

Therefore, in the analyses, I impute a village to have access to a URRAP road two years after the commencement of a road in that village. The calculation of road access using the construction commencement year is advantageous since the completion year maybe correlated with endogenous factors, such as changes in district capacity, that can also affect agricultural production. Furthermore, using an instrumental variable strategy, I show that measurement error is not important in driving the results.

4.2 Annual Agricultural Sample Surveys

The main source of data on outcomes of interest is the Annual Agricultural Sample Survey (AgSS) for main growing season (*Meher*) that is undertaken by the Central Statistical Agency (CSA). The AgSS is a large survey covering more than 40,000 private peasant holders engaged in growing crops or raising livestock in private or in combination with others. The survey covers the entire rural part of the country except for select zones comprising of the non-sedentary population in Afar and Somali regions.

The CSA follows a stratified two-stage cluster design to determine the AgSS sample. In the first step, a random sample of about 2000 enumeration areas (EAs), which are sub-village level geographical units consisting of 150-200 households are selected, and in the second stage, around 20 agricultural households are selected from each EA. On average, CSA subdivides each village in to around 4 EAs and often only one EA is surveyed within each village. For each agricultural holder, the AgSS provides holder level data on demographics, field level data on crop cultivated, area and use of inputs and services like extension. While the AgSS also provides field level production data, the quantity is imputed based on EA level crop yield that is calculated using a selection of three to five crop cuts in the EA.

Starting in 2010, the same set of EAs are covered in each wave of the AgSS but households are re-sampled every year. Hence, the AgSS allows for the construction of a balanced panel at the EA level and a repeated cross section at the holder level. I aggregate all the variables on production to the EA level and I take that to be representative of village level variables so as to construct a balanced panel over 2010-2016. Hence, in the following sections, I use the term enumeration area and village interchangeably.

In addition, for all the analyses, I consider the data from the four main regions (Amhara, Oromia, SNNP and Tigray) which comprise of more than 90% agricultural holders in the full sample. Figure A.6 shows that there is significant spatial variation in distribution of the EAs in the balanced panel sample. The wide coverage and representativeness of the sample is critical in the empirical strategy given the large diversity in agro-clamatic suitability across locations in Ethiopia.

I impute that a village has extension if there is at least one holder with a field under an extension package. While it would have been ideal to have data on the exact year a village gets access, the data is not available. However, while the imputation may introduce measurement error, the approach also has several advantages. First, in the AgSS, households are randomly selected within each village and thus there is no systemic bias in terms of selection into the sample by extension use. Second, the fact that the imputation uses a criteria of at least one extension user in a village helps avoid potential endogenous issues related to the share of holders in the village that use extension. Finally, this study focuses on access to extension and the binary measure is a good proxy for the availability of extension in a village.

4.3 Welfare Monitoring Surveys & Household Consumption and Expenditure Surveys

For the outcomes on household level employment, consumption, asset ownership and other measures of welfare, I use two complementary household level surveys – the Welfare Monitoring Surveys (WMS) and Household Consumption and Expenditure Survey (HCES) undertaken by the CSA in 2010/11 and 2015/16. The WMS and HCES are household level surveys covering all rural and urban areas of the country except select non-sedentary zones in Afar and Somali regions. Similar to the AgSS, the WMS and HCEs use a two-stage stratified cluster design where EAs are randomly selected in the first stage and then household are randomly selected within the households.

Each survey covers around 30,000 households in each wave. The two surveys are designed to complement each other to provide socioeconomic data. While the WMS provides data on employment, ownership of assets, living standards, use of public facilities, shocks, cultural practices and other measures of socioeconomic wellbeing and the HCES provides data on consumption and expenditure of households.

Figure A.7 shows the distribution of enumeration areas from the WMS rural sample from the four main regions. As the figure shows the WMS has a wide spatial coverage across the four regions.

4.4 Additional Data Sources

I supplement the administrative and survey data with census data on village level population in from the 2007 census. Furthermore, I use novel geo-spatial data on village boundaries, the centroid of enumeration areas, and the location of rural facilities and services (farmer training centers, village office, markets, banks etc) in 2007 and 2014 that were compiled by the CSA in preparation for the 2007 census and the upcoming 2020 census, respectively.

In addition, I construct village level rainfall measures, averages and deviation from the long run mean, for annual and growing season rainfall using monthly rainfall data from Climate Hazards Infrared Precipitation (CHIRPS) dataset. Funk et al. (2015) demonstrate that the CHIRPS dataset performs well for drought monitoring in Ethiopia. For the robustness analyses, I also construct village level agro-climatic suitability measures for over 20 crops using the FAO GAEZ v3.0 dataset on crop specific attainable yields calculated assuming intermediate input use and rainfed cultivation (IIASA/FAO, 2012).

5 Empirical Strategy

The identification of the causal impact of transport infrastructure or access to extension on economic development are challenging for various reasons. First, the timing and placement of a road or an extension service is often non-random because the decision on when and where to build a road or a farmer training center may be strategic. Given the high costs of constructing roads or establishing farmer training centers, policymakers may target places that have higher economic potential. In contexts where political, ethnic or other forms of favoritism are salient, policymakers may build roads or expand extension in areas already benefiting from other, perhaps unobserved, advantages. On the other hand, pro-poor policymakers may also build roads or farmer training centers in locations that are under performing. In addition, placed-based policies, such as roads and extension, in developing contexts often come in packages and make it difficult to disentangle one policy from the other.

I address these identification challenges by considering the plausibly exogenous variation in access to markets and technologies from the concurrent and independent expansion of agricultural extension and rural road network. In particular, while there is no unique formula that dictated prioritization of road construction or expansion of extension, the main factors that determined which villages received the roads or extension earlier are the ease of implementation and the budget constraints at the regional levels that are beyond the purview of the villages.

In the case of the road expansion program, as Table 1 shows, there are specific regional annual work plans, set before the commencement of URRAP, that established the total length of road to be built in each region and year. The annual work plans show that, at least at the regional level, there is no strategic allocation of where and when to build roads. The annual plans are based on the total length of roads to be built to connect every village in each region divided roughly equally across the five year period. The roll out of URRAP roads across villages in a region is mainly determined by three factors: baseline proximity of a village to the existing road network, costs of road construction implied by geographical factors (mainly land gradient and location of rivers), and the annual regional budget limits.

District road authorities are tasked with identifying potential URRAP projects. For each road, the regional road authority hires engineering consultants to design a cost-effective route given the local topography and the nationally determined road design standards. The road design manual emphasizes that the route selection should take ease of topography, particularly slope stability, as a critical factor in the design process (Ethiopian Road Authority, 2011). For instance, in the project inception report by the consultants for the URRAP road from Sandabo to Ejersa Mecha, the feasibility study states that the route selection is undertaken considering "length, terrain type, number of major crossing, intermediate villages, and availability of construction materials" (ORA, 2016). The regional road authorities are responsible for the approval, coordination and monitoring of the selected projects factoring in the ease of implementation, cost of construction and budget constraints.

Figure 3 (a)-(d) show that the villages that are closest to the baseline network are connected first and the road network is gradually expanded to the most remote villages through sequential roll out. In addition, Figure 8 (a) demonstrates that the route selection of URRAP roads is limited by rivers and the land gradient of the terrain. Topography is strong constraint in the construction process because the planners aim to circumvent river crossings as that would require costly bridge construction and build roads along a flat slope so as to improve stability and avoid costly construction in rugged areas.

I provide causal estimates on the impact of access to rural roads and extension by employing a generalized difference-in-difference (GDD) design with OLS and in combination with an instrumental variable (IV) that leverages the constrained and staggered roll out of URRAP. I provide evidence on the identifying assumption that there are no differences in trends by treatment status. In the robustness checks, I also test the stability of the OLS and IV the findings to additional controls for potential confounders.

5.1 Generalized Difference-in-Difference: OLS

The first empirical specification is a generalized difference-in-difference design that exploits the variation in the year that a village gets access to a URRAP road or an extension. I focus on URRAP roads because it is the main source of variation in rural access to an all-weather roads during my study period. To examine the effect of village level access to a URRAP road, extension or both, I consider the following specification:

$$Y_{vt} = \alpha Road_{vt} + \beta Extension_{vt} + \gamma Road_{vt} X Extension_{vt} + \delta_t + \eta_v + \Phi \mathbf{X}_{vt} + \epsilon_{vt} \quad (1)$$

where $Y_{v,t}$ is an outcome variable such as log value added per hectare, $Road_{vt}$ and $Extension_{vt}$ are indicators on whether the a village v has a URRAP road or extension by year t, respectively. η_v is village FE and δ_t is year FE, **X** include time varying village level controls such as growing season season rainfall.

Access to a road may be correlated within a district because new URRAP roads sometimes transverse multiple villages within a district. In addition, all the survey datasets used in this study use a two stage clustered sampling design, where the primary sampling unit is the enumeration area (sub-village units). Following Abadie et al. (2017), the standard errors are clustered at the district level to account both for the sampling design and the correlation in treatment within district.

In equation 1, α captures the effect of access to only a URRAP road, β captures the effect of access to only extension, and γ captures the effect of having access to both a URRAP road and extension. A positive γ indicates complementarities between access to a road and extension.

The empirical strategy addresses several of the main identification concerns. Given that the strategy exploits variation in the timing of treatment, one may be concerned that early treated villages may be different from late-treated. Village fixed effects account for any time-invariant characteristics, such as underlying productivity potentials, that affect both the timing of access and the outcomes of interest. Given the roll out of road program and extension from nearest to remote areas, the interaction of baseline distance to the network with year fixed effects accounts for any potential confounders that are correlated with remoteness. Year fixed effects flexibly control for any trends. In addition, I control for annual and growing season rainfall that can affect both the provision of roads, extension and agricultural outcomes.

Hence, the main identification strategy essentially compares two villages that are identical in observable characteristics and face similar trends by remoteness but differ in their access to a URRAP road or extension as a results of the exogenous budget constraints that determined which village obtained a road or extension in a given year. The remaining identifying assumption is that there are no differential pre-trends between early and late treated villages.

To examine the lack of pre-trends as well as assess the dynamic response to road access, I consider an event study specification of the following form:

$$Y_{vt} = \sum_{j=-3, j\neq -1}^{5} \beta_j \mathbf{1}(\text{years since URRAP Construction Started = j}) + \delta_t + \eta_v + \Phi \mathbf{X}_{vt} + \epsilon_{vt} \tag{2}$$

where the j indicates the number of years since or before access to URRAP. I consider a similar specification for access to extension or both a road and extension. The absence of pre-trends, i.e. all the pre-treatment coefficients (β_j) are zero, would provide supportive evidence for the identifying assumption that the there are no differential trends by timing of treatment.

5.2 The Market Access Approach

In the baseline specification, I consider a measure of a village's road access using a binary indicator on whether the village is intersected by a URRAP road. During my study period, URRAP is the main source of variation in the rural road access. While helpful to obtain an easily interpretable estimate on the impact of access to a URRAP road and carry out the event study specification to test the identifying assumption, the binary variable has two main shortcomings. First, it assigns every connection the same weight. However, given the geospatial distribution of the road network, a village that gets connected to a sparse network may not have the same level of increase in market access as one that is close to a more developed and populated network. Second, the binary measure treats all villages that are not intersected by a road as untreated. Nonetheless, a given village's level of connectivity can increase through indirect connections. If there are strong connection spillovers, the binary measure can lead to an underestimation of the treatment effects as indirectly treated villages are considered as controls.

To address these concerns, I use the market access approach that measures a village's connectivity taking the full network and population distribution into account. In particular, following Donaldson and Hornbeck (2016), I use the reduced-form expression for market access derived from general equilibrium trade theory:

$$MarketAccess_v = \sum_d \tau_{vd}^{-\theta} Population_d \tag{3}$$

where τ_{vd} is the transport cost from village v to d, and θ is trade elasticity. Hence, the market access measure is the sum of the population of all potential destination that the village is connected to (directly and indirectly) weighted by the trade elasticity.

I calculate the cost of transport from each village to all possible destinations using standard tools in ArcGIS in the following four steps. First, I construct the road network for each year based on all the roads that have been constructed by that year. Second, for each year, I construct a link from every village centroid to the nearest road that is within 2km. I adopt the 2km cutoff to be in line with other studies such as the World Bank's Road Access Index WBG (2016). However, the results are robust to relaxing the cuttoff to 5km. Third, I assign each road in the network a national level per kilometer cost of transport, from 2001, based on the road type and quality. This achieves two objectives: it accounts for the fact that it is costly to transport goods on rural gravel roads compared to highway asphalts and it avoids the potential endogenous evolution of transport costs as the network expands. Fourth, given the full road network in each year and the per km cost of transport for each road, I calculate the cheapest cost of traveling from each village to all the villages it is connected to by the network.

Following equation 3, I generate the market access measure for each village by summing the population of all reachable destinations where each destination is weighted by the transport cost from the village to that destination and the trade elasticity. In the calculation of the market access, I take the population distribution of all populated villages in Ethiopia except for Somali region ($\approx$ 15,600 villages) from the 2007 census. I consider the pre-URRAP population data since the population distribution can be endogenous to changes in the road network. Following Allen and Atkin (2016), I set the trade elasticity ($\theta = 1.5$) based on the average gravity coefficient for developing country sample in Head and Mayer (2014). In the robustness checks, I show that the results are robust to varying θ from 1 to 26.83 considered in the literature (Donaldson, 2018; Head and Mayer, 2014).

Figure 7 shows the market access measure in 2012 for a select area, where the darker red villages indicate higher market access. As the figure illustrates, the key advantages of the market access approach is that it allows for continuous measure of treatment intensity and accounts for changes in overall connectivity through indirect connections.

5.3 Instrumental Variable Strategy: Least Cost Network Predicted By Topography

To allay any concerns regarding omitted variables, in this section, I provide an IV strategy that isolates the variation in village road access determined solely by constraints that are exogenous to the village. In the absence of data on the exact criteria followed in the roll out of extension, the IV strategy focuses on the instrument for the expansion of rural roads. In the robustness section, I show that both the OLS and IV results are robust to controlling for differential trends by village characteristics, such as agro-climatic suitability and proximity to rural services and facilities, that may confound the effect of extension.

The main idea behind the IV strategy is that it captures the variation in road access using only factors predetermined at baseline (geography and annual plans) to avoid the fact that some of the variation in the actual road network may be affected by endogenous unobservable factors. I take the perspective of a cost minimizing planner in each regional road authority and construct the optimal road network based on remoteness of villages, topography and the annual budget.

I predict the optimal road network using tools in ArcGIS that allow for construction of least cost paths between locations. First, for each of the 15,600 villages, I use data on land gradient and location of all river streams in Ethiopia to create a cost raster that assigns each pixel with the cost that would be accumulated for any path originating from the given village. I sort the villages into four groups based on their proximity to the baseline road network. The first group comprises of villages that are transversed by the baseline road network, the second group consist of the villages that share a border with the first group, the third group share a boarder with the second group and so on.

Starting with the first group, I construct the least cost path from each village's administration office, a central location from which most URRAP roads originate, to the nearest baseline network. Figure 8 (b) shows the first set of roads predicted. I then consider the second set of villages and generate the least cost path from each village to the baseline network or the roads constructed in the earlier step. Figure 8 (c) shows the roads predicted starting from the first and second set of villages. I apply the same procedure to connect the third and fourth group of villages. Figure 8 (d) shows the full predicted network.

To generate the temporal variation in the predicted road network, I follow the regional budget constraints set forth before the commencement of URRAP by the national road authorities. Table 1, taken from a national planning document, presents the annual work plans in terms of kilometers of roads to be built under URRAP in each region and year. For each region and year, I rank the predicted roads yet to be built based on their proximity to the baseline network. Then, I construct all the roads from the closest to the most remote until the cumulative length exhausts the regional annual budget. This process of construction aims to capture the fact that the URRAP roads are rolled out gradually from the easiest to the most remote villages. Finally, using the predicted road network for each year, I construct market access IV using the procedures outlined in Section 5.2.

The four key factors considered in the construction of the instrument - rivers, gradient, baseline remoteness and the regional work plans - may affect agricultural outcomes on their own. The presence of a river and flat land gradient may be correlated with agricultural suitability. Baseline remoteness and the regional work plans may also be correlated with village or regional characteristics that affect productivity. However, all of these factors are fixed at baseline and exogenous to the village, and their relevance would be washed out by the village, year and remoteness by year fixed effects used in all the regressions. I also show that the results are robust to controlling for differential trends by region, agro-climatic suitability and proximity to rural services and facilities.

As Figure 8 (d) shows, the road network predicted using only predetermined topographical and budget constraints is very similar to the actual road network. This is formally shown in the first stage regression of actual market access on predicted market access in Table A.2- the instrument has a strong first stage. The striking similarity between the predicted and actual road network provides further evidence that the roll out URRAP is mainly determined by factors exogenous with respect to each village and corroborates the baseline identification strategy.

6 Results

In this section, I present the results on the effects of access to extension and road on agricultural productivity considering the three sets of empirical strategies. First, I discuss the findings using the generalized difference-in-difference strategy where I exploit the variation in the timing of access to a road or extension using a binary measure of road access. Second, I provide results on the same set of outcomes where I measure rural connectivity using the market access approach. Third, I present another set of evidence on the main findings using an instrumental variable strategy that isolates the variation in market access due to factors, topography and regional budget constraints, that are exogenous to the villages. Finally, for each of the identification strategies, I provide evidence on the robustness of the results to a demanding set of controls on potential confounders.

6.1 Results Using with Binary Measure of Road Access

Table 2 presents the estimates on the effects of roads and extension on productivity aggregating across the main crops (cereals, pulses and oils) and considering three alternative measures of productivity. The first outcome, log production value per hectare, is the log of total value of production of main crops, calculated using national crop prices, divided by the cultivated area for main crops. For a single crop, log production value per hectare is analogous to physical yield. Similarly, log value added per hectare is the log of total production value after subtracting costs of fertilizers and seeds divided by the total area of main crops. Log TFP is calculated using the Levinsohn and Petrin (2003) approach using the same set of revenue and cost variables along with additional controls for rainfall. The variable of interest, road, is an indicator that takes 1 if a village is intersected by a URRAP road in that year. I focus on access to a URRAP road because, as shown in Figure 1, URRAP is the sole driver of the variation in the rural road network since 2010 and I exploit the variation in the timing of road access for identification.

Across the three different measures of productivity, access to a road on average increase productivity by 4-5%. Columns 2, 5, and 6 show that while access to extension on average increases yield by 2%, the effects considering log value added per hectare and log TFP are not significant. The key result that is consistent across the three measures of productivity is that there are strong complementarities between access to roads and extension. In villages that have access to an all-weather road and extension, farmers are more productive by 9-13%. Columns 3, 6, and 9 show that the gains in productivity from increased connectivity and extension are concentrated in the villages that have access to both – access to a road or extension in isolation has no significant effect on agricultural productivity.

The results in Table 2 show that extension in isolation increases production value per hectare, but it has no significant effect on value added per hectare. The differences in these results suggest that while the extension program improves physical yield (as captured by production per hectare), in isolation, extension may not have a significant effect on the profitability of overall production. As I show in Section 7.3, farmers in villages with extension invest in modern inputs such as chemical fertilizers and improved seeds. While such modern inputs may increase physical productivity, they are costly investments, especially in the villages without road access, and may turn out to be economically unprofitable if the gains in productivity do not outweigh the costs of investments.

6.1.1 Checking for Pre-Trends Using Event Study Specification

The identifying assumption for the estimated effects in Table 2 to be causal is that there are no differential pre-trends. In this section, I discuss the evidence on the lack of differences in pre-trends by treatment status using the event study specification defined in equation 2. In addition, access to a road or extension may have dynamic effects on productivity since it would take time for farmers to adjust their crop choice and farming practices to changes in access to markets and technologies. The event study analysis would provide evidence on the timing of when the programs have significant effects on the outcomes of interest.

Figure 5 plots the coefficients from the regression of log value added per hectare on a set of dummy variables indicating the number of years since road construction started in the village. Similarly, Figure 6 plots the coefficients from the regression of log value added per hectare on a set of dummy variables indicating the number of years since a village had access to both a road and extension.

First, Figures 5 and 6 demonstrate that there are no differential pre-trends with respect to access to a road or access to both a road and extension. The event study results provide further evidence that the estimated effects of access to a road and extension are causal. Second, both figures show that the effects of access to road and extension on productivity are dynamic. There is no immediate effect on productivity following access to a road or extension, but there is a gradual and persistent positive effect. The event study results are consistent with the fact that it would take time for farmers to make use of access to technologies and markets since they need to experiment, learn and adjust their farming practices to make use of new opportunities.

6.2 Results Using the Market Access Approach

While the binary road access approach is useful to get a reduced form estimate of the effect of a village's direct access to a URRAP road, the approach does not allow for treatment heterogeneity and spillover effects. The binary measure of road access can underestimate the effect a new road since villages whose connectivity increases via indirect connections are considered untreated. In this section, I present the results using the market access approach discussed in Section 5.2 that takes the full road network and distribution of economic potential at baseline (as proxied by village population in the 2007 census) to construct a continuous measure of market access that accounts for the intensity of treatment and changes in market access through indirect connections.

Panel A of Table 3 reports the main results where a village's connectivity is measured using the market access approach. The market access variable is normalized so as to capture the fact that it is the relative change in a given village's connectivity that matters for production and trade across villages. The measure captures a given village's comparative advantage with respect to its integration into the larger network. Hence, in Panel A of Table 3, the coefficients on the market access variable indicate the percent change in in productivity estimated for one standard deviation increase in market access.

Comparing the estimates in Panel A of Table 3 with the baseline results in Table 2, the main findings are robust to the use of the market access approach. One standard deviation in market access improves productivity by 2-3%. Column 5 and 6 show that there are strong complementarities between market access and extension. While changes in market access or extension on their own have no effects on overall productivity in isolation, in villages with extension service, a one standard deviation increase in market access improves productivity by 3-5%. Hence, the gains in productivity due to changes in access to markets and technologies are concentrated in the villages with access to both a road and extension.

In Tables A.3 and A.4, I show that these results are robust to changing cutoff at which I consider a village connected to the network from 2km to 5km and to varying the trade elasticity θ from 1 to 26.83 used in the literature (Donaldson, 2018; Head and Mayer, 2014).

While the GDD results in Table 3 and Table 2 are similar in patterns and signs, it is informative to compare the magnitude of the estimated effects. Ex ante, the direction of the bias of the binary measure relative to the market access approach is ambiguous. The binary measure could underestimate the effect of access to a new road since it considers villages that are indirectly treated as controls. On the other hand, the market access approach, which considers all villages within 2km of the road as connected to the network, may take villages that are not treated (e.g. if there are barriers such rivers) as treated. In addition, it may be the case that connection in the extensive margin and to the nearest village/town, as captured by the binary measure, may be more salient than incremental connections to farther places that is included in the market access approach. Hence, the direction of the bias is unclear.

To compare the two estimates, I first calculate by how much a direct connection increases a village's market access. In the appendix, Table A.1 shows that when a village gets a road, its market access increases by 0.8 standard deviations. Hence, taking the 3% productivity gain estimated for a one standard deviation increase in market access (Column 4 and 7 in Panel A of Table 3), direct access to a URRAP road on average improves productivity by 2.4%. Similarly, considering the estimated complementarity effects, the results using the market access approach imply that a given URRAP connection in a village with an extension service increases productivity by 4%. Comparing these estimates with those from Table 2, the magnitude of the effects using the market access approach are smaller than those obtained using a binary measure of road access.

6.3 Results Using Instrumental Variable Based on Predicted Road Network

While the tests for pre-trends demonstrated the lack of differential pre-trends by treatment status, there may still be concerns regrading omitted variables. In this section, I provide another set of evidence on the main results using an instrumental variable strategy, detailed in Section 5.3, that isolates the variation in the road network solely due to topography and budget constraints that are exogenous to each village.

I begin by discussing the relevance of the instrumental variable. In the appendix, Table A.2 presents the first stage regression results of actual market access on predicted market access. The instrument has a strong first stage - with a F-statistic equal to 91.28 in the baseline specification. While predicted market access does not perfectly capture actual market access, its strong relevance indicates that the factors considered in the prediction of the network are indeed followed by policymakers on the ground. Given that I can predict a significant part of the variation in the actual market access solely using topography and budget constraints also provides further credence to the preceding identification strategy that posits that timing of which villages obtained the road are beyond the purview of the village.

In Panel B of Table 3, I report the instrumental variable estimates on the effects of market access and extension on the three measures of productivity. The IV findings on the complementarities between access to extension and road are robust and comparable in magnitude to the corresponding OLS results in Panel A. While extension in isolation increases overall yield, as measured by production value per hectare, it has no effect when considering value added per hectare or TFP. Similarly, increases in market access in isolation has no effect on productivity across the three outcomes. However, in villages with extension services, a one standard deviation increase in market access improves productivity by 4-6%.

Given the potential measurement error of road access, it is possible that the IV estimates may be higher than the OLS estimates. Indeed, in Table 3, while the effects estimated using the IV approach in Panel B are slightly larger than the OLS estimates in Panel A, the coefficients are not statistically different.

Overall, the results from the IV estimation corroborate the main OLS findings. While access to extension or a road in isolation has no effect on productivity, the two factors improve productivity significantly when they are present in village simultaneously.

6.4 Robustness of Main Findings to Additional Controls

The results so far paint a consistent picture regarding the effects of access to a road and extension – despite the two programs being ineffective in isolation, they have strong positive effects on productivity when they are present in a village simultaneously. In this section, I discuss the evidence on robustness of the main findings from the three empirical strategies to additional controls for potential confounders.

Table 4 reports the results from the fully interacted model (Equation 1) with sequential addition of controls in each column. Panel A presents the OLS results using the binary road access measure, Panel B reports the OLS results using the market access approach, and Panel C provides the IV results using the predicted market access instrument. In each of the panels, Column 1 presents the baseline results.

Since the implementation of the road and extension programs are decentralized to the regional government, one may be concerned that the estimated effects of access to extension or road may be confounded by differential regional trends. In column 2, I show that the results are robust to controlling for region by year fixed effect that allow for flexible trends for each region.

One may also be concerned that villages with better agro-climatic suitability get earlier access to a road or extension and growing more productive over time due to other unobserved factors. In column 3, I find that the results are robust to the inclusion of differential trends by village level agro-climatic suitability for the 20 main crops using FAO GAEZ data on crop specific attainable yields.[2]

Finally, policymakers may target villages to receive a road or extension based on characteristics, such as proximity to towns or district capitals, that may also put them on differential productivity trend for other reasons. In column 4, I show that the complementarity between access to a road and extension is robust to allowing for differential trends by proximity to over 45 rural services and facilities that could affect the provision of road and extension and the growth of agricultural productivity. [3]

[2] I consider the agro-climatically attainable yields with intermediate input use and rain-fed cultivation. The list of crops considered are: barley, millet, maiz, rice sorghum, wheat, sunflower, coffee, groundnut, oils, rapeseed, chickpea, pulses, sweet potato, potato, beetroot, carrots, onions, tomato.

[3] The controls included year fixed effects interacted with the log distance from the enumeration area to the locations of places or rural services and facilities in 2007: Village Office, National Capital (Addis Abeba), Zone Capital, District Capital, Town, Market, Flour Mill, Factory, Hotel, Mountains, Bridges, Forrest, Banks, Gas Stations, Post Office, Quarries, Coffee Washing Sta-

6.4.1 Heterogeneous Effects on Productivity of Cereals vs Non-Cereals

Across specifications, there is strong evidence that access to extension, in isolation, has no effect on overall value added per hectare or TFP. However, cereals have been the main focus of the extension program, and we may expect that access to extension has heterogeneous effects across crop groups. As Figure A.5c shows, cereals constitute over 84% of the area under extension package despite accounting for only 67% of the cultivated area. Within cereals, close to 35% of the area is under the extension package program. Hence, access to extension may be more beneficial for cereal cultivation relative to other crops.

Table 5 presents the estimates on the effects of the road and extension programs for log value added per hectare for cereals and non-cereals (pulses and oils).[4] Consistent with the overall effect, access to a road increases the productivity of both cereals and non-cereals by 4% and 5%, respectively. However, unlike the findings in Table 2, access to extension on average improves cereal productivity by 2%, but it has no significant effect on the productivity of non-cereals.

In line with the results in Table 2, there are strong complementarities between the road and extension program for both cereals and non-cereals - each program in isolation has no effect on productivity on cereals or non-cereals. However, villages that have access to both road and extension become 13% and 9% more productive for cereals and non-cereals, respectively. As Table A.6 shows, the results are similar when considering production value per hectare or TFP. The stronger complementarity effects on cereals compared to non-cereals is consistent with the fact that the extension program emphasized packages that are geared towards improving cereal productivity.

Column 3 of Table 5 shows that cereal productivity declines in the places that have access to a road but not to extension. There is no such effect for non-cereals. These findings suggest that the expansion of roads and extension could have negative general equilibrium effects since a given village's access to a road or extension may affect the comparative advantage of the other villages in the network. Villages with access to only a road become less competitive in cereal production compared to the villages that have access to both a road and extension given the emphasis of extension on cereals. On the other hand, households in villages with only a road also have better options for cultivation of non-cereals or non-farm work compared to those without a road. In the discussion of potential mechanisms, in Section 7.1, I show that farmers in villages with access to only a road shift out of cereal cultivation into non-cereal crops and non-farm occupations. Furthermore, farmers in villages with only a road are less like to use chemical fertilizers for cereal cultivation. Hence, the decline in cereal productivity in these villages could reflect the reduction in efforts and quality of inputs used for cereal cultivation.

Overall, the results in Table 2-5 shed light on the literature's mixed evidence on the effectiveness of extension programs. The null effect of extension on value added per hectare and TFP is consistent with the findings of Buehren et al. (2017) who show that the extension program had no overall effect on productivity. However, my findings provide further evidence on the heterogeneous effects of access to extension. First, extension increases physical yield, as measured by production value per hectare, but does not affect value added per hectare and TFP. This highlights the importance of differentiating the

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tions, Sawing Mills, Police Stations, Airports, Animal Husbandry, Dams, Meteorology Stations, Cooperatives, Radio Stations, Micro-finance , Electric Power Lines, Trails, Swamps, Flooded Areas, Irrigation, Telephone Stations

[4]Cereals include maize, millet, oats, rice, sorghum, teff and wheat. Pulses and Oils include chickpea, haricot bean, horse bean, feild pea, lentil, vetch, soyabean, fenugrk, lineseed, ground nut, neug, rapeseed, sesame, and sunflower.

effects on physical yield, economic profits and TFP. Second, although extension does not affect overall agricultural productivity, I find that it has a significant effect on the productivity of cereals, which constitute more than 80% of the area under extension in Ethiopia. Third, I show that extension has a strong effect on overall productivity in villages that also have access to an all-weather road. The robust complementarities between extension and road access across specification demonstrates that it is informative to evaluate the efficacy of each program by accounting for the availability of complementary factors.

7 Mechanisms

The key and robust result so far is that while access to a road or extension in isolation have no effect on agricultural productivity, the two factors have substantial effects in improving productivity when they are available in a village simultaneously. This section explores the underlying channels through which rural connectivity and access to extension can have complementary effects on productivity.

I first show that farmers specialize in crops across villages in a manner that reflects their comparative advantages with respect to access to markets and the technologies provided under extension. Then, I provide evidence that road and extension affect agricultural productivity by facilitating the take up of advising, credit and modern inputs such as chemical fertilizers and improved seeds. In addition, I present evidence, consistent with the changes in cultivation patterns, showing that households reallocate their labor across sectors in response to their changing comparative advantages. Finally, I present evidence on the overall impact of the road and extension programs by considering the changes in food consumption and household's perspective on their living standards.

7.1 Farmers in Villages With Extension Specialize in Cereals

As Figures A.5a and A.5b show, cereals are disproportionately covered under the extension program. While cereals account for 67% of the cultivated area, they account for more than 84% of the area under extension. Given the focus of the extension program on cereals, all else equal, farmers in a village with extension have better access to technologies suitable for cereal cultivation and thus have a relative advantage in the cultivation of cereals. Furthermore, in places that have extension, improved rural connection facilitates farmers ability to specialize in cereals since they can sell their cereal production to other markets and import non-cereal crops and other goods. Hence, in this section, I examine whether farmers adjust their cultivation patterns in response to changes in the availability of road and extension. I also provide suggestive evidence that shows trade patterns reflect the patterns of specialization.

Table 6 shows that in villages with extension farmers are more likely to cultivate cereals both in the extensive and intensive margins. Columns 3 show that farmers are more likely to cultivate cereals, and the effect is stronger in the places that also have a road. However, in villages that get only a road, farmers are 2.3% ($\approx 0.02/0.88$) less likely to cultivate cereals. Furthermore, Column 5 and 6 shows that access to extension induces farmers to specialize in cereals. On average, farmers in villages with extension dedicate a 2.2% higher share of their area cultivated to cereals, and this is even higher (by 2%) in villages with access to both a road and extension.

In order to corroborate the findings regarding the changes in crop choice, I investigate whether the crop specialization patterns are also reflected in patterns of trade across villages. In the absence of data on trade across villages, I consider how the ratio of average production to consumption varies across village by availability of extension and road. A higher production to consumption ratio can reflect excess output at the village level that is either stored or potentially sold to other villages.

In Table 7, I provide suggestive evidence showing that the patterns of production and consumption across villages corroborate the specialization patterns documented above. Column 1 shows that in villages with both a road and extension, farmers produce more cereals than they consume. Column 2 shows that the same villages produce significantly less pulses and oils compared to their consumption. On the other hand, column 2 shows that in villages that only get a road, farmers produce pulses and oils more than they consume. While insignificant, the results in Column 1 also indicate that the villages with only a road, farmers produce less cereals than they consume.

The results in Table 5 demonstrate that extension and road have a greater complementary effect on the productivity of cereals compared to non-cereals. Table 6 shows that access to extension increases farmers specialization in cereals with a greater effect in villages that also have a road. The patterns of production and consumption across villages documented in Table 7 are consistent with the results on crop choice - farmers in villages with both extension and road specialize in cereals while those with only a road shift to non-cereal cultivation and trade accordingly. The results in Table 5, 6 and 7 together suggest that the complementary effects of extension and road on productivity are partly due to farmers' increased specialization in cereals to take advantage of the technologies provided under the extension program and the trade facilitated by the improvements in the road network.

7.2 Access to Roads and Extension Facilitates Use of Advising and Credit

As Figure A.5d shows, extension agents spend over 35% of their time to advise and train farmers either through field visits to farmers' homes or using demonstrations at the farmer training centers. Farmers also need to travel to training centers or the development agent's office to receive advice or get the credit they may need to purchase inputs. A review of state of extension in Ethiopia has argued that poor transport infrastructure limits the ability of development agents to contact a large number of farmers within a given area (Berhane et al., 2018).

In Table 8, I show that access to extension and road increase the take up of agricultural advising and credit. Columns 1 and 2 show that access to road and extension on average increase take up of advising by 2% and 10% respectively. Column 3 demonstrates that, while extension on its own increases take up of agricultural advising by 9.2%, the effect is 6.2% higher in the villages that also have an all-weather road. In column 4, shows that access to a road has no effect on take up of credit. However, as shown in columns 5 and 6, the availability of extension increase take up of credit by 4%.

The results in Table 8 demonstrate that one of the channels through which the expansions in the road network and extension affect productivity is by facilitating the use of advising and credit that provide farmers with the requisite skills and capital needed to invest in productive practices and inputs.

7.3 Access to Roads and Extension Increases Adoption of Modern Inputs

Access to roads and extension may also affect the use of modern inputs since agricultural advising increasing farmers knowledge of best practices and the provision of credit provides farmers with the loans they need to make productive investments.

Indeed, in Table 9, I show that extension and road access have strong complementary effects on the application of chemical fertilizer, improved seed and herbicide. Columns 3, 6, 9, and 10 show that while extension on its own does increase take up of modern inputs, the effects are much larger in the villages that also have an all-weather road. Another striking result in Table 9 is that farmers are much less likely to use modern inputs in villages with access to only a road. These results are consistent with the earlier discussion that farmers in villages with only a road face import competition with a relative disadvantage with respect to access to inputs, advising and credit. As I show in the subsequent discussion in Section 7.4, households in villages with a road but without extension, reduce total area cultivated and are more likely to switch out of skilled agriculture into non-farm occupations. Hence, the decline in use of modern inputs in these places could reflect the reduction in skills, efforts and quality of inputs applied to agricultural production.

7.4 Households With Access To A Road But Not Extension Shift Out Of the Farm Sector

Beyond adjusting the choice of crops, households can also respond to changes in access to markets and technologies by reallocating their labor to non-farm sector. In this section, I provide evidence that changes in rural connectivity and extension also affect agricultural production through the reallocation of labor across sectors.

Table 10 shows, in the villages with only a road, individuals shift out of skilled agriculture into crafts and trade occupation. Extension in isolation has no effect on occupational choice. However, there is a 22% increase in the share of individuals engaged in crafts and trades occupations in the places with only a road with an equivalent increase in the share of skilled agricultural workers in villages with road and extension. Columns 1-3 in Table 11 corroborate the patterns of labor reallocation documented in Table 10. As column 3 shows, in the villages with access to both extension and road, farmers increase the total area cultivated where as those in villages with only a road decrease the total area cultivated.

The patterns of labor reallocation are consistent with the earlier findings on productivity, crop choice and trade across the villages. Villages that gain access to both an extension and a road have a relative advantage in the cultivation of crops, especially for cereals, given their improved access to agricultural advice, credit, inputs and markets. While the villages that get only a road gain access to markets, they lack the complementary factors provided under the extension program. Furthermore, as shown in the trade patterns data, producers in villages with only a road face increased import competition, particularly in cereals, without the requisite support from the extension program. Hence, individuals in villages with only a road have more incentives to switch out of agriculture into other sectors while those in the villages with both extension and road are likely to deepen their engagement in agriculture.

7.5 Complementarities and Farm Income

The findings so far indicate that increased rural connectivity and the expansion of extension have improved overall productivity, particularly in the villages that have access to both factors. The investigation of the underlying mechanisms demonstrated that extension and road access facilitate take up of advising, credit and modern inputs. Furthermore, households across villages respond to changes in access to extension or road by adjusting their crop choices or by reallocating their labor across sectors. In this section, I attempt to provide a summary of the total effect of the two programs by considering their effect on farm income, food consumption and perceptions on the changes in living standards.

Expansion in the road network and agricultural extension could affect rural welfare in several ways. Changes in rural connectivity and extension could benefit consumers (through changes in prices, quality and variety of goods), increase household non-farm income, or provide non-pecuniary benefits such as improved access to education and health service. Given the scope of this paper, I will focus the discussion in this section on the effects of the two programs on farm income and summary outcomes that could provide suggestive evidence on overall effects.

Columns 1-3 in Table 11 present the results on the effects of extension and road access on the average farmer's income as proxied by total value added per farmer. Column 1 and 2 show that access to road and extension on average increase farm income by 5% and 7%, respectively. However, the gains are concentrated in the villages that have access to both an all-weather road and extension services. Even though access to a extension in isolation no effect on farm income, it increases value added per farmer by 24% in the villages that also have a road. On the other hand, I find that farm income declines by 15% in the villages that only get a road. These findings re-affirim my persistent findings that show the strong complementarities between the two programs. In isolation, extension has no effect on farm income and access to a road, without complementary extension, could have deleterious effects on agricultural production. Nevertheless, when both factors are present in a village simultaneously, they result in large improvements in average farm income.

The changes in the value added per farmer across villages could be driven by changes in productivity, area cultivated or the composition of crops cultivated. Columns 4-6 in Table 11 report results that could shed light on the factors that contribute to the observed changes in value added per hectare. Column 4 shows that in villages that have access to both a road and extension, TFP increases by 10%. Furthermore, villages that have only a road experience negative but insignificant decline in productivity. The results are similar when measuring productivity using value added per hectare.

Column 5 of Table 11 shows that in addition to affecting productivity, extension and road also affect the total area cultivated by the average farmer. In particular, farmers in villages with both access to extension and road increase the area cultivated, by 4%, where as those in villages with only a road decrease the total area cultivated by 6%. These patterns are consistent with the findings in Section 7.4 that households in villages with only a road shift out of agriculture where as those in villages with both road and extension increase their engagement in skilled agriculture.

The results in Section 7.1 showed that villages with both extension and road, the improvements in cereal productivity is greater and farmers specialize in cereals where as those in villages with only roads shift to non-cereal cultivation. Consistent with the changes crop choice, the results in column 5 show that in villages with both extension and road the cereals share of value added increases by 5.5% ($\approx 0.03/0.55$).

Taken together, the results in Table 11 imply that the complementary effects of extension and road on farm income is attributable to increases in productivity, total area cultivated and the shift towards cereals in which the farmers have a comparative advantage in access to technologies provided by the extension program. On the other hand, the reduction in average farm income is mainly due to the reduction in the area cultivated combined with the shift out of cereal cultivation.

7.6 Effect on Food Consumption and Standard of Living

While access to only a road reduces average farm income, it may not necessarily decrease total household income. The discussion in Section 7.4 showed that farmers in villages with only a road shift out of agriculture into the non-farm occupations. The reduction in farm income and area cultivated is consistent with the shift out of agriculture in to non-farm work these villages, and there may not be an effect on total income since households could supplement or substitute farm earnings through non-farm work. To get at the overall welfare effects, in Table 12, 13 and A.7, I examine the effects of access to extension and road on household consumption, access to food and perceptions about their living standards.

In Table 12, I report the results on the impact of access to extension and road on the number of months the household can feed itself using own production or through the purchase of crops. In line with the findings on crop choice, productivity and labor allocation, column 3 shows that in villages that gain access to both extension and a road, households report that they can feed themselves with their own production of cereals and pulses for 2.28 more months (28% increase). Consistent with the shift out of agriculture documented in the villages with only a road, households are less capable of feeding themselves through their own production of cereals and pulses. However, as columns 6 demonstrates, the effects are not statistically significant when we consider the ability of households to feed themselves using their own production or through the sale of their crops.

Table 13 suggests that households in villages with access to both extension and road spend more on total and food consumptions, and have a higher net calorie intake. Villages with extension access on average have a 11% increase in net calorie intake. While the signs of the coefficients are consistent with the patterns and magnitudes documented above, they are not statistically significant.

Similarly, Table A.7 shows that the negative effects on farm income in the places with only a road could be mitigated by the observed reallocation of labor to the non-farm sector. Columns 1 and 2 show that access to a road and extension on average improve households ability to access food by 6% and 13% respectively. Despite the decline in farm income and area cultivated in places with only a road, there is no corresponding decline in the household's ability to access food. The results are similar when considering household's views on the whether the household or community living standard have improved since the previous year. While households in villages with only a road experience decline in farm income, they report positive, but insignificant, improvements in their living standards.

Together, the results in Tables 10-13 and A.7 suggest that, while the places with only a road experience a decline in farm income, the overall effects on consumption and well being may be mitigated by the household's ability to supplement or substitute farm income with non-farm work. Furthermore, the results on cultivation and labor reallocation suggest that access to extension and road hasten the process of structural transformation by facilitating specialization across crops and occupations.

8 Conclusion

This paper shows that it is critical to examine the effects of roads and extension services simultaneously due to the strong complementarities between access to markets and technologies. Exploiting two concurrent and independently implemented programs in Ethiopia that expanded the rural road network and extension, I find that there are strong complementarities between the two programs. Access to a road or extension on its own is ineffective in increasing productivity. Improved rural connectivity and extension improve productivity by facilitating the use of agricultural advice, credit and modern inputs.

I find that on average access to road and extension increase value added per worker by 5.2% and 6.6%, respectively. Over 2010-2016, agricultural value added per worker in Ethiopia increased by 29.4%. Hence, expansions in the road network and extension services accounted for 18% and 23% of the growth in value added per worker, respectively.

Increased rural road access presents both beneficial opportunities and potential risks. While producers in villages that get connected have access to external markets, they also face increased competition from imports. Changes in access to road or extension affect households by changing their competitive advantages depending on the presence of either or both factors in the village. I find that in the villages with a road but without extension value added per worker declines by 17%. However, I find that there are no differences in food consumption and perceptions about standards of living. The results suggest that labor reallocation to non-farm sectors mitigates the negative spatial effects that arise out of differences in access to technologies provided by extension.

The findings in this paper shed light on the heterogeneous returns to road and extension expansion programs documented in different contexts. The results suggest that the inefficacy of roads in boosting productivity could be due to lack of complementary access to technologies and inputs. Similarly, the varying results on the effectiveness of extension programs could be be explained by differences in rural connectivity. Furthermore, the results underscore that policymakers could leverage the complementarities between extension and road programs to enhance the effectiveness of each of the policies. In the absence of a coordinated provision of extension and rural roads, policymakers may need to account for the potentially deleterious spillover effects of connectivity and facilitate solutions that mitigate the impact of the changes in competitive advantages across villages. This paper provided suggestive evidence showing that labor reallocation can reduce the impact of the negative spillover effects, and access to rural roads hastens the process of structural transformation in rural areas. To the extent the occupational changes result in an efficient reallocation of resources, it may be desirable to facilitate such changes.

While this study has focused on how roads and extension affect agricultural productivity, it may be fruitful to examine their role in other socio-economic outcomes. Changes in rural connectivity and extension could affect a myriad of outcomes such education, health, access to consumer goods and deforestation (Aggarwal, 2018a,b; Adukia et al., 2017; Asher et al., 2018). Specific to this study, there are three natural extensions for future work. First, Ethiopia faces persistent drought-induced famines, and changes in access to markets and technologies may affect households' capacity to cope with such shocks. Second, increased market access and the ensuing specialization in crops across villages may expose farmers to volatilities in prices. Extension and rural roads may have complementary effects on farmers' exposure and resilience to such volatilities. Third, given the costliness of investment in technologies and land needed to exploit beneficial opportunities, rural connectivity and extension could exacerbate inequality by favoring those with better access to capital. These additional studies could provide insight into how expansion in the rural road network and extension could, in isolation and together, affect rural welfare beyond the effects on productivity documented in this paper.

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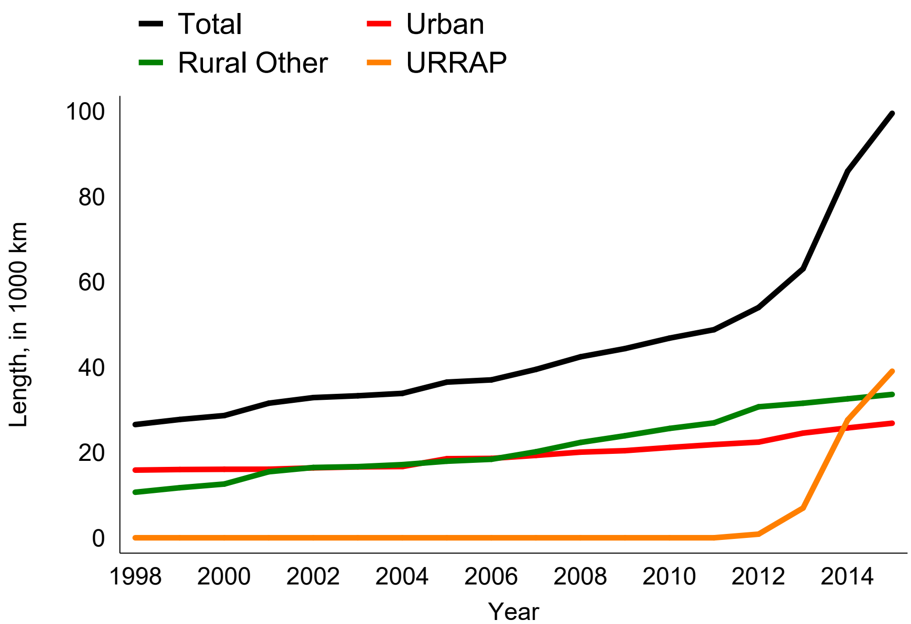
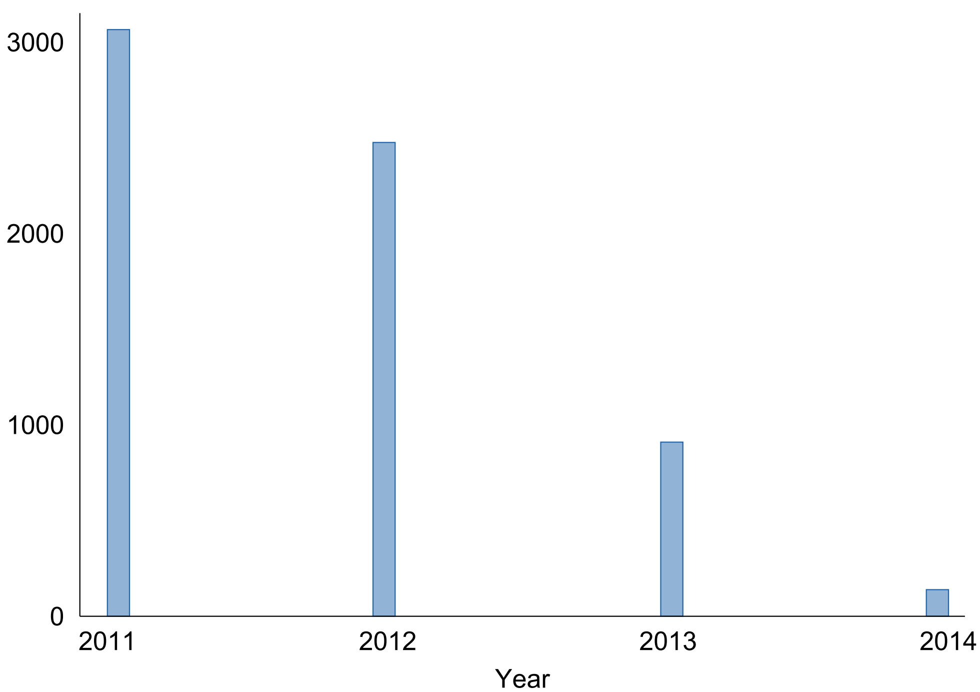
Figures

Figure 1: Road Length by Road Class (in kilometers)



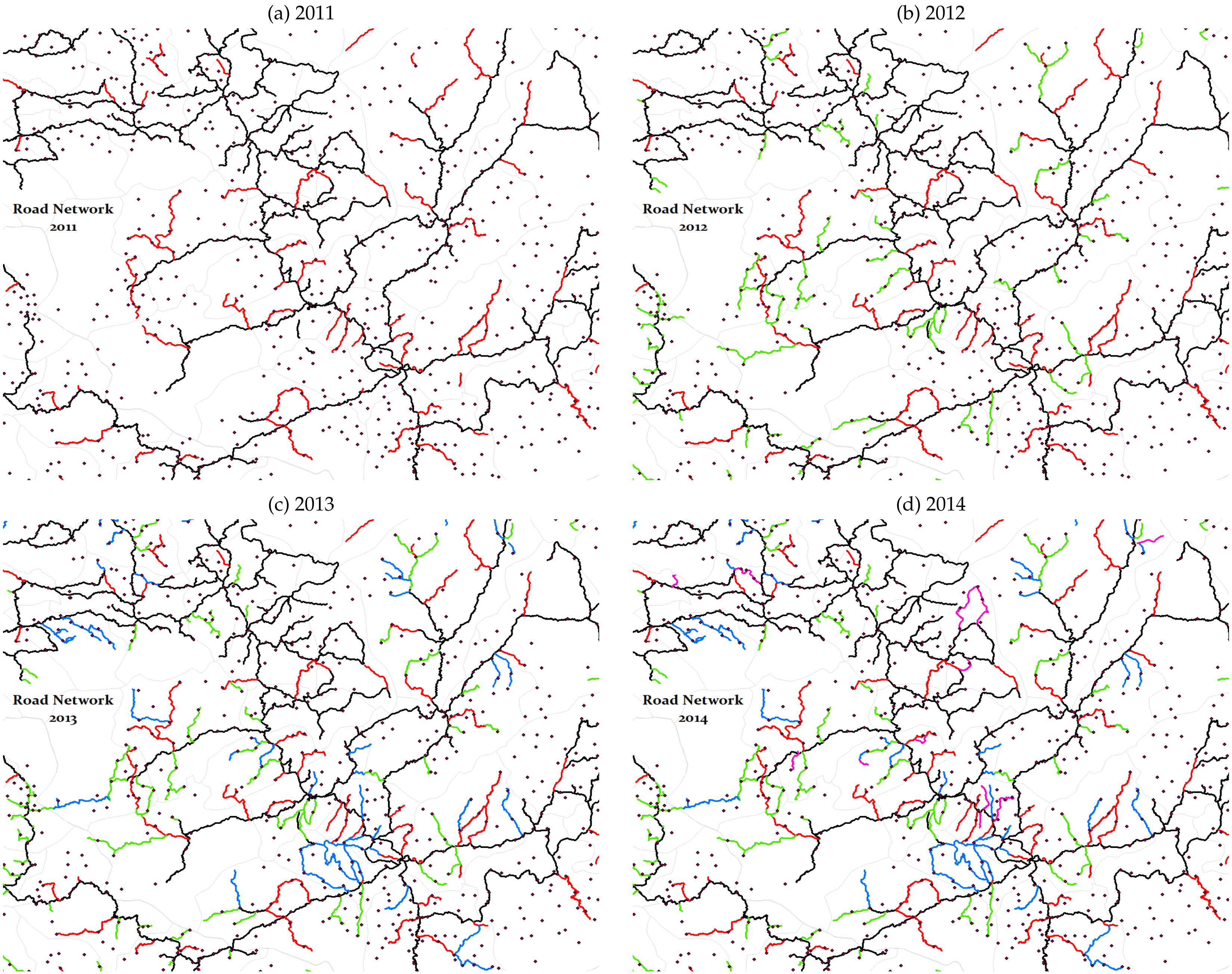
Notes: The figure presents the total length of the road network, in kilometers, by road classes. Source: ERA (2015)

Figure 2: Number of Villages By Construction Commencement Year



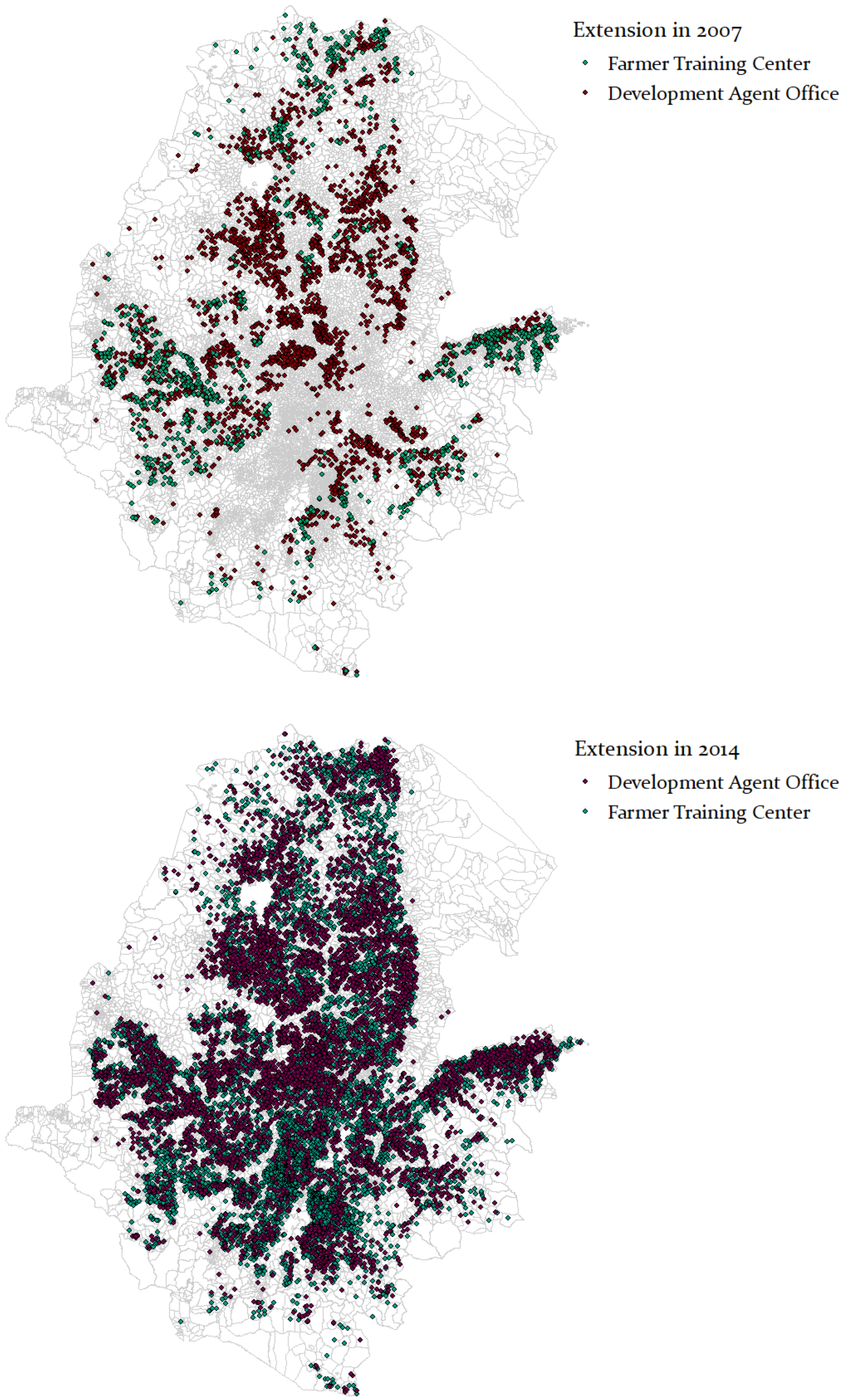
Notes: The figure describes the distribution of villages where new URRAP road construction commenced over 2011-2015

Figure 3: Expansion of the Rural Road Network in Detail



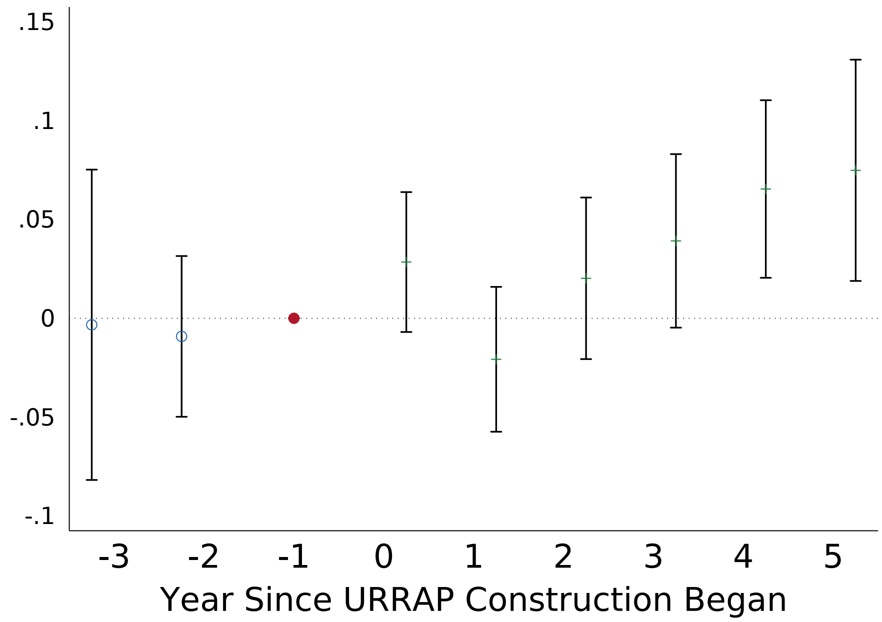
Notes: Using a select area, figures (a)-(d) demonstrate the sequential roll out of the URRAP roads across over 2011-2014.

Figure 4: Expansion of Farmer Training Centers and Development Agent's Office



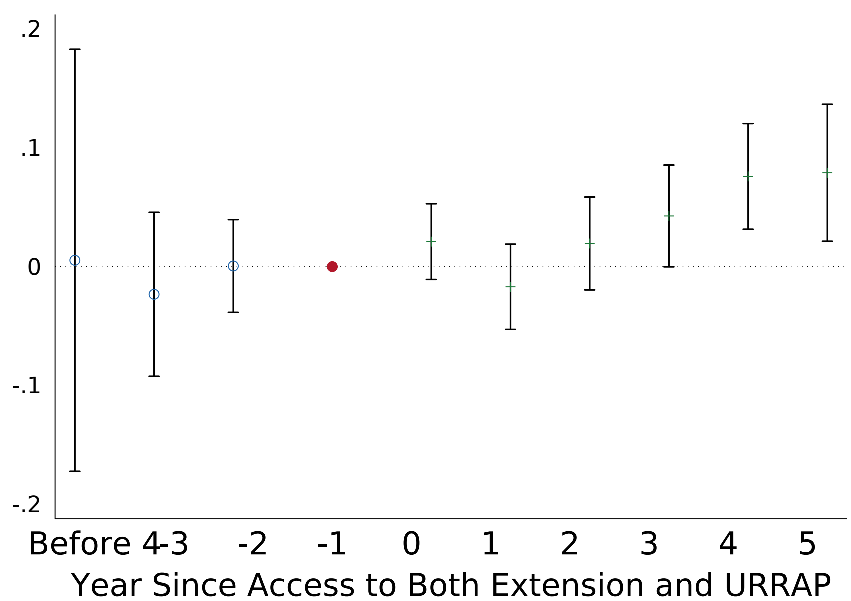
Notes: The two figures present the distribution of farmers training centers and development agent officies that are the focal points for the delivery of extension in 2007 and 2014. The data sources for the 2007 and 2014 are the Rural Facilities and Services GIS data prepared by the Central Statistical Agency in preparation for the 2007 and 2020 censuses, respectively

Figure 5: Effect of URRAP on Log Value Added per Hectare



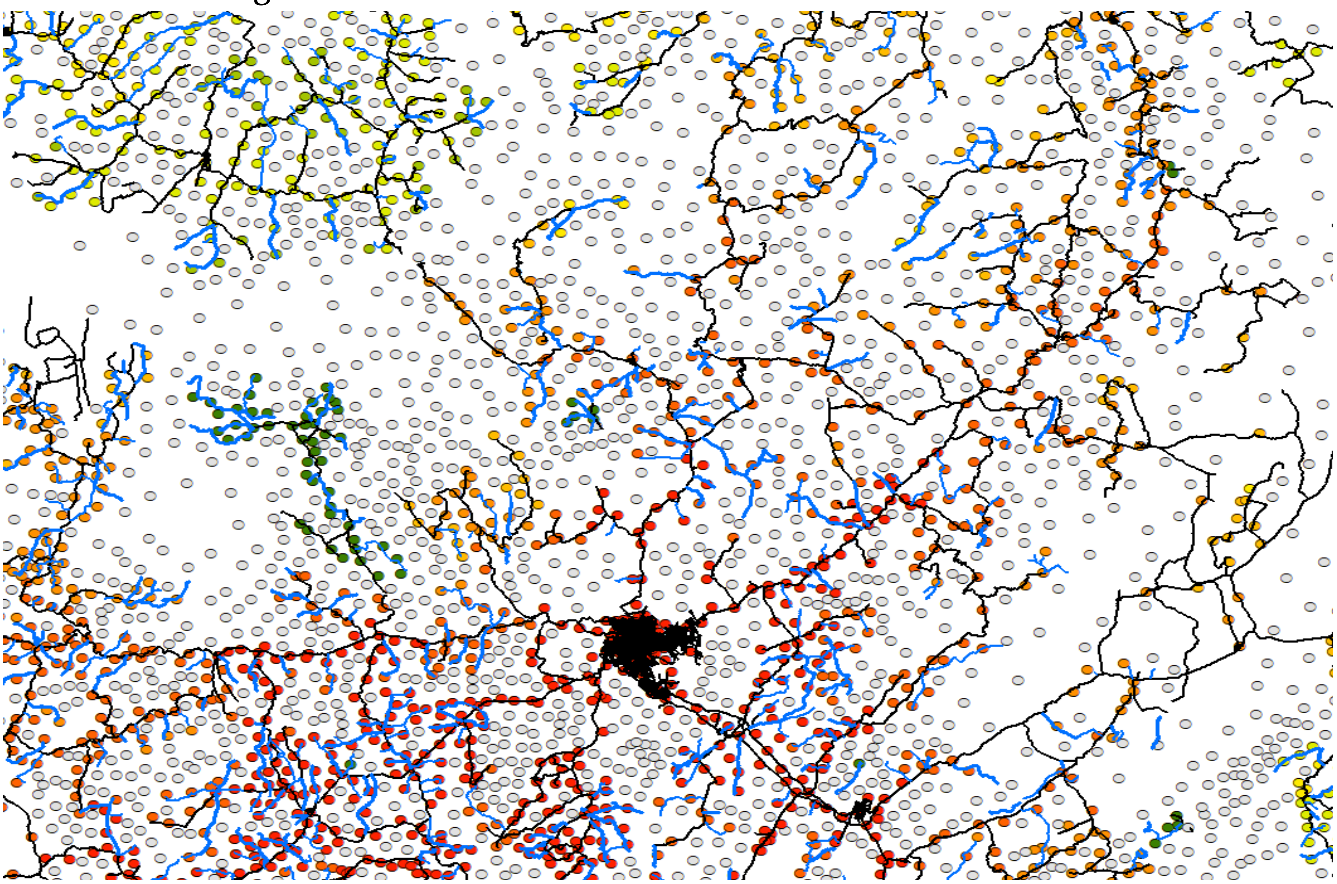
Notes: The figure shows the coefficient estimates from a panel regression of log value added per hectare on a set of dummy variables indicating the number of years before or since a URRAP road construction commenced in a village. The omitted category is a dummy for a year before construction commenced in the village. The regression also include three sets of fixed effects - village, year and remoteness (log distance to baseline network) by year fixed effects - and four sets of rainfall measures, mean and deviation from the long run mean for annual total and growing season rainfall. 90% confidence intervals are displayed around each estimate. Standard errors are clustered at the district (*wereda*) level.

Figure 6: Effect of Access to Both URRAP and Extension on Log Value Added per Hectare



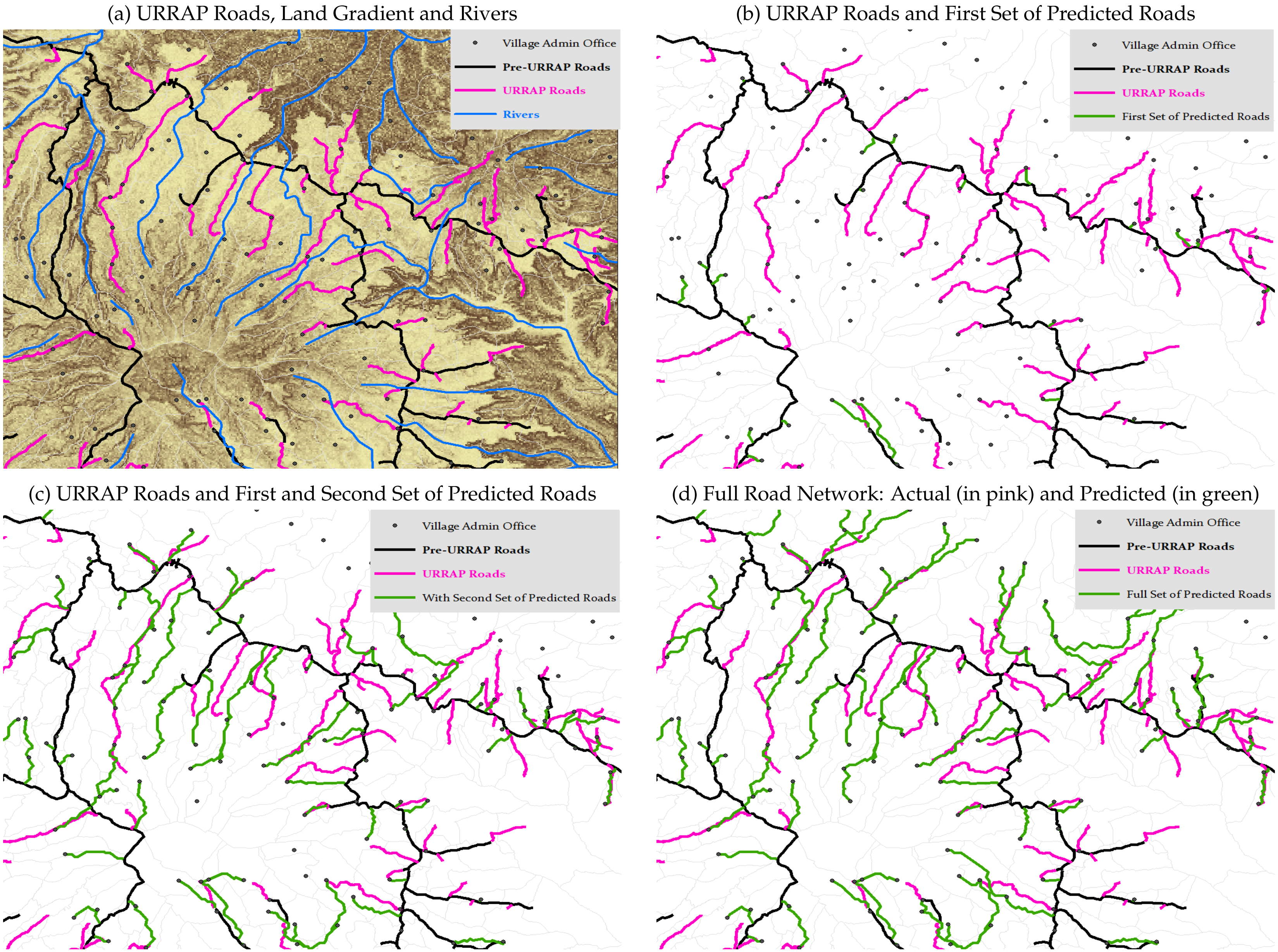
Notes: The figure shows the coefficient estimates from a panel regression of log value added per hectare on a set of dummy variables indicating the number of years before or since a village got access to both extension and started construction of a URRAP road. The omitted category is a dummy for a year before first year the village has extension and construction of URRAP was started. The regression also include three sets of fixed effects - village, year and remoteness (log distance to baseline network) by year fixed effects - and four sets of rainfall measures, mean and deviation from the long run mean for annual total and growing season rainfall. 90% confidence intervals are displayed around each estimate. Standard errors are clustered at the district (*wereda*) level.

Figure 7: Demonstration of the Market Access Measure in 2012



Notes: The figure shows the distribution of market access measures for select area in 2012. The darker red the spots have higher market access value. The figure illustrates that market access approach, discussed in Section 5.2, captures the treatment intensity in road access by showing that the villages that are closest to a dense and more populated network have a higher market access.

Figure 8: Construction of the Instrumental Variable Approach



Notes: The four figures illustrate the steps undertaken in the construction of the predicted road network discussed in Section 5.3. The black lines are the baseline road network and the pink lines are the URRAP roads. In figure (a), the figure overlays the land gradient in shades of brown and the blue lines are river streams. The lines in green in figures (b)-(d) are the roads predicted based on the least cost paths using the methdology discussed in Section 5.3.

Tables

Table 1: Official Plans for the Length of Roads to be Constructed under URRAP

	Annual Work Plans (in kilometers)					
Region	2011	2012	2013	2014	2015	Total for 2011-2015
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	6607	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

Notes: This table presents the annual work plans, set in 2010, for the length of roads, in kilometers, to be constructed or upgraded into an all weather road status under URRAP during the Growth and Transformation Plan over 2011-2015. Source: URRAP/ Wereda Road Development Plan from the Ethiopian Road Authority (ERA, 2010b).

Table 2: Access to Road, Extension and Agricultural Productivity

Dependent Variable:	Log Production Value per Hectare			Log Value Added per Hectare			Log TFP		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Road	0.037**		-0.044	0.043**		-0.054	0.051***		-0.051
	(0.015)		(0.032)	(0.017)		(0.036)	(0.017)		(0.041)
Extension		0.021*	0.005		0.015	-0.004		0.016	-0.003
		(0.011)	(0.012)		(0.013)	(0.013)		(0.015)	(0.015)
RoadxExtension			0.096***			0.114***			0.121***
			(0.030)			(0.034)			(0.040)
Mean of Dep. Var.	9.51	9.51	9.51	9.40	9.40	9.40	7.25	7.25	7.25
N	11773	11773	11773	11773	11773	11773	11773	11773	11773
Village FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Remoteness X Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Rainfall Measures	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: This table reports the OLS estimates on the effects of road and extension on three alternative measures of productivity. Log production value per hectare is the log of total value of production of main crops (cereals, pulses and oils), calculated using national crop prices, divided by total cultivated area for main crops. Similarly, log value added per hectare is the log of total production value after subtracting estimated costs of fertilizers and seeds divided by total cultivated area. Log TFP is calculated using the Levinsohn and Petrin (2003) approach considering the logs of total production value, costs of fertilizers and seeds, number of holders engaged in cultivation of main crops, area cultivated and rainfall measures (mean and long run deviation for annual and growing season). Road is an indicator if a village is intersected by a URRAP road. Extension is an indicator if there is at least one person in the village using extension. All the regressions include three sets of fixed effects - village, year and remoteness (log distance to baseline network) by year fixed effects - and four sets of rainfall measures, mean and deviation from the long run mean for annual total and growing season rainfall.Standard errors are clustered at the district (*wereda*) level. Significance levels: $*$: 10% $**$: 5% $***$: 1%.

Table 3: Effects on Productivity Using the Market Access Approach - OLS and Instrumental Variable Results

Dependent Variable:	Log Production Value per Hectare			Log Value Added per Hectare			Log TFP		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Panel A: Market Access Approach: OLS								
MarketAccess	0.024***		-0.002	0.029***		0.001	0.025***		-0.014
	(0.008)		(0.013)	(0.009)		(0.014)	(0.009)		(0.015)
Extension		0.023**	0.025**		0.017	0.019		0.019	0.022
		(0.011)	(0.011)		(0.013)	(0.013)		(0.015)	(0.015)
MarkeAccessxExtension			0.033***			0.034***			0.049***
			(0.011)			(0.013)			(0.013)
Mean of Dep. Var.	9.52	9.52	9.52	9.40	9.40	9.40	7.25	7.25	7.25
N	11654	11654	11654	11654	11654	11654	11654	11654	11654
	Panel B: Market Access Approach: Predicted Market Access IV								
MarketAccess	0.024		-0.004	0.035		0.007	-0.005		-0.049
	(0.040)		(0.043)	(0.046)		(0.049)	(0.043)		(0.046)
Extension		0.020*	0.024**		0.015	0.019		0.017	0.023
		(0.012)	(0.012)		(0.013)	(0.013)		(0.015)	(0.015)
MarkeAccessxExtension			0.039**			0.038**			0.061***
			(0.015)			(0.018)			(0.017)
First Stage F-Statistic	91.91		45.78	91.47		45.56	91.91		45.78
Mean of Dep. Var.	9.52	9.51	9.52	9.40	9.40	9.40	7.25	7.24	7.25
N	11659	11793	11659	11641	11773	11641	11659	11793	11659
Village FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Remoteness X Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Rainfall Measures	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: This table reports the effects of road and extension on productivity where road access is measured using the market acces approach. Panel A presents the OLS estimates, and Panel B reports the IV estimates. Market access is calculated using equation (3) for each year based on the full road network in that year and distribution of population across villages from the 2007 census. Market access is normalized so that the corresponding coefficient indicates the percent effect on productivity of a one standard deviation increase in market access. Extension is an indicator if there is at least one person in the village using extension. The instrument in Panel B is the predicted market access constructed using the optimal road network as discussed in Section 5.3. All the regressions include three sets of fixed effects - village, year and remoteness (log distance to baseline network) by year fixed effects - and four sets of rainfall measures, mean and deviation from the long run mean for annual total and growing season rainfall. Standard errors are clustered at the district (*wereda*) level. Significance levels: $*$: 10% $**$: 5% $***$: 1%.

Table 4: Robustness of Main Findings to Additional Controls

Dependent Variable:	Log Value Added Per Hectare			
	(1)	(2)	(3)	(4)
	Panel A: OLS with Binary Road Access			
Road	-0.054	-0.052	-0.049	-0.042
	(0.036)	(0.036)	(0.036)	(0.036)
Extension	-0.004	-0.011	-0.010	-0.007
	(0.013)	(0.013)	(0.013)	(0.014)
RoadxExtension	0.114***	0.115***	0.102***	0.087***
	(0.034)	(0.034)	(0.033)	(0.033)
Mean of Dep. Var.	9.40	9.40	9.40	9.40
N	11773	11773	11773	11773
	Panel B: OLS using Market Access			
MarketAccess	0.001	0.002	-0.005	-0.001
	(0.014)	(0.014)	(0.014)	(0.014)
Extension	0.019	0.012	0.010	0.013
	(0.013)	(0.013)	(0.013)	(0.013)
MarkeAccessxExtension	0.034***	0.034***	0.030**	0.026**
	(0.013)	(0.013)	(0.012)	(0.012)
Mean of Dep. Var.	9.40	9.40	9.40	9.40
N	11654	11654	11654	11654
	Panel C: IV using Market Acces			
MarketAccess	0.007	0.001	-0.044	-0.058
	(0.049)	(0.049)	(0.052)	(0.055)
Extension	0.019	0.012	0.010	0.012
	(0.013)	(0.013)	(0.013)	(0.013)
MarkeAccessxExtension	0.038**	0.038**	0.035**	0.031*
	(0.018)	(0.018)	(0.017)	(0.017)
First Stage F-Statistic	45.56	44.47	37.99	35.23
Mean of Dep. Var.	9.40	9.40	9.40	9.40
N	11641	11641	11641	11641
Baseline Controls	Yes	Yes	Yes	Yes
Region X Year FE	No	Yes	Yes	Yes
Crop Suitabilities X Year FE	No	No	Yes	Yes
Proximity to Facilities (in 2007) X Year FE	No	No	No	Yes

Notes: This table subjects the results from the fully interacted model (column 6) in Table 2 and 3 to sequential addition of differential trends by potential confounders. Dependent variable is log value added per hectare. Column 1 presents the baseline results. Column 2 adds region by year fixed effects. Column 3 adds the interactions between year fixed effects and agro-climatically attainable yields for 20 crops, separately. Column 4 adds the interaction of year fixed effects with log distance from village to the locations 45 rural services and facilities. All the regressions include three sets of fixed effects - village, year and remoteness (log distance to baseline network) by year fixed effects - and four sets of rainfall measures, mean and deviation from the long run mean for annual total and growing season rainfall. Standard errors are clustered at the district (*wereda*) level. Significance levels: $*$: 10% $**$: 5% $***$: 1%.

Table 5: Heterogeneous Effects of Roads and Extension on Productivity

Dependent Variable:	Log Value Added Per Hectare					
	Cereals			Pulses and Oils		
	(1)	(2)	(3)	(4)	(5)	(6)
Road	0.036**		-0.076*	0.050**		-0.028
	(0.017)		(0.043)	(0.024)		(0.044)
Extension		0.024*	0.002		-0.017	-0.031
		(0.014)	(0.015)		(0.019)	(0.020)
RoadxExtension			0.133***			0.091**
			(0.041)			(0.043)
Mean of Dep. Var.	9.37	9.37	9.37	9.37	9.37	9.37
N	11688	11688	11688	11289	11289	11289
Village FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Remoteness X Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Rainfall Measures	Yes	Yes	Yes	Yes	Yes	Yes

Notes: This table reports the effects of roads and extension on the productivity of cereals and non-cereals. Cereals include maize, millet, oats, rice, sorghum, teff and wheat. Pulses and Oils include chickpea, haricot bean, horse bean, feild pea, lentil, vetch, soyabean, fenugrk, lineseed, ground nut, neug, rapeseed, sesame, and sunflower. All the regressions include three sets of fixed effects - village, year and remoteness (log distance to baseline network) by year fixed effects - and four sets of rainfall measures, mean and deviation from the long run mean for annual total and growing season rainfall. Standard errors are clustered at the district (*wereda*) level. Significance levels: $*$: 10% $**$: 5% $***$: 1%.

Table 6: Effect on Cultivation of Cereals

Dependent Variable:	Cultivation of Cereals					
	Any Cultivation			Percent of Area Cultivated		
	(1)	(2)	(3)	(4)	(5)	(6)
Road	-0.002		-0.022**	0.239		-0.769
	(0.00)		(0.01)	(0.37)		(0.67)
Extension		0.017***	0.013***		1.409***	1.202***
		(0.00)	(0.00)		(0.27)	(0.31)
RoadxExtension			0.024***			1.245*
			(0.01)			(0.69)
Mean of Dep. Var.	0.88	0.88	0.88	64.84	64.84	64.84
N	238464	238464	238464	237881	237881	237881
Village FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Remoteness X Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Rainfall Measures	Yes	Yes	Yes	Yes	Yes	Yes

Notes: This table reports the estimates on the effect of road and extenion on crop choice. The dependent variable in columns 1-3 is an indicator on whether the holder cultivates any cereals, and the dependent variable in columns 4-6 is a the percent of cultivated area dedicated to cereals. All the regressions include three sets of fixed effects - village, year and remoteness (log distance to baseline network) by year fixed effects - and four sets of rainfall measures, mean and deviation from the long run mean for annual total and growing season rainfall. Standard errors are clustered at the district (*wereda*) level. Significance levels: $*$: 10% $**$: 5% $***$: 1%.

Table 7: Effects of Roads and Extension on Production and Consumption

Dependent Variable:	Log of Production/Consumption	
	Cereals	Pulses and Oils
	(1)	(2)
Road	-0.292	0.907**
	(0.201)	(0.349)
Extension	-0.079	-0.001
	(0.065)	(0.152)
RoadxExtension	0.321	-0.926***
	(0.202)	(0.351)
Mean of Dep. Var.	1.37	2.42
N	982	520
Village FE	Yes	Yes
Year FE	Yes	Yes
Remoteness X Year FE	Yes	Yes
Rainfall Measures	Yes	Yes

Notes: This table reports the estimates of equations (1). Log production/consumption of cereals is the log of the ratio of village level average household production of cereals (from the AgSS 2010 and 2015) divided by the corresponding average household consumption of cereals (from HCES 2010 and 2015). Log production for pulses and oils is defined analogously. All the regressions include three sets of fixed effects - village, year and remoteness (log distance to baseline network) by year fixed effects - and four sets of rainfall measures, mean and deviation from the long run mean for annual total and growing season rainfall. Standard errors are clustered at the district (*wereda*) level. Significance levels: $*$: 10% $**$: 5% $***$: 1%.

Table 8: Effects of Roads and Extension on the Use of Advising and Credit

Dependent Variable:	Any Use of					
		Advising			Credit	
	(1)	(2)	(3)	(4)	(5)	(6)
Road	0.02*		-0.03	-0.01		-0.01
	(0.011)		(0.024)	(0.009)		(0.012)
Extension		0.10***	0.09***		0.04***	0.04***
		(0.010)	(0.010)		(0.006)	(0.006)
RoadxExtension			0.06***			0.00
			(0.022)			(0.014)
Mean of Dep. Var.	0.69	0.69	0.69	0.23	0.23	0.23
N	242147	241794	241794	242147	241794	241794
Village FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Remoteness X Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Rainfall Measures	Yes	Yes	Yes	Yes	Yes	Yes

Notes: This table reports the estimates on the effects of extension and road on use of credit and advising. The outcome in column 1-3 is an indicator if a farmer received any agricultural advice and the dependent variable in 4-6 is an indicator if the farmer obtained credit in the survey year. All the regressions include three sets of fixed effects - village, year and remoteness (log distance to baseline network) by year fixed effects - and four sets of rainfall measures, mean and deviation from the long run mean for annual total and growing season rainfall. Standard errors are clustered at the district (*wereda*) level. Significance levels: $*$: 10% $**$: 5% $***$: 1%.

Table 9: Effects of on Use of Modern Inputs

Dependent Variable:	Share of Cultivated Area Under											
	Chemical Fertilizer			Improved Seed			Irrigation			Herbicide		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Road	0.063		-2.959***	0.248		-1.203***	0.110		-0.180	0.476		-0.978
	(0.47)		(0.76)	(0.28)		(0.32)	(0.14)		(0.49)	(0.44)		(0.89)
Extension		3.943***	3.310***		1.644***	1.347***		0.286**	0.229*		0.754**	0.467
		(0.37)	(0.39)		(0.19)	(0.21)		(0.14)	(0.13)		(0.33)	(0.32)
RoadxExtension			3.721***			1.778***			0.354			1.745**
			(0.81)			(0.39)			(0.50)			(0.89)
Mean of Dep. Var.	35.17	35.17	35.17	6.14	6.14	6.14	1.78	1.78	1.78	13.47	13.47	13.47
N	238464	238464	238464	238464	238464	238464	238464	238464	238464	238464	238464	238464
Village FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Remoteness X Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Rainfall Measures	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: This table reports the estimates on the effects of roads and extension on use of modern inputs. The first dependent variable, Chemical Fertilizer, is the holder level measure of the share of area that is cultivated using the chemical fertilizer. The remaining dependent variables are defined similarly. All the regressions include three sets of fixed effects - village, year and remoteness (log distance to baseline network) by year fixed effects - and four sets of rainfall measures, mean and deviation from the long run mean for annual total and growing season rainfall. Standard errors are clustered at the district (*wereda*) level. Significance levels: $*$: 10% $**$: 5% $***$: 1%.

Table 10: Effects of Roads and Extension on Labor Reallocation

Dependent Variable:	Indicator for Occupation								
	Skilled Agriculture			Manufacturing and Mining			Crafts, Trade and all Occupations		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Road	-0.02		-0.22***	0.00		-0.01*	0.01		0.23***
	(0.028)		(0.078)	(0.002)		(0.006)	(0.028)		(0.079)
Extension		0.00	-0.06		-0.00	-0.00		0.00	0.07
		(0.042)	(0.047)		(0.003)	(0.003)		(0.042)	(0.047)
RoadxExtension			0.22***			0.01**			-0.23***
			(0.080)			(0.006)			(0.082)
Mean of Dep. Var.	0.60	0.60	0.60	0.00	0.00	0.00	0.40	0.40	0.40
Observations	35262	35262	35262	35262	35262	35262	35262	35262	35262
Village FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Remoteness X Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Rainfall Measures	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: This table reports the estimates on the effects of road and extension on labor allocation. Skilled Agriculture is an indicator for individuals whose main occupation is skilled agricultural and fishery worker. Manufacturing and Mining is an indicator for individuals working as plant and machine operators and assemblers and those engaged in elementary occupations in manufacturing and mining. Crafts, Trade and all Occupations is an indicator for any occupation that isnt skilled agriculture or manufacturing/mining. All the regressions include three sets of fixed effects - village, year and remoteness (log distance to baseline network) by year fixed effects - and four sets of rainfall measures, mean and deviation from the long run mean for annual total and growing season rainfall. Standard errors are clustered at the district (*wereda*) level. Significance levels: $*$: 10% $**$: 5% $***$: 1%.

Table 11: Effects of Road and Extension on Average Cultivated Area, Productivity and Farm Income

Dependent Variable:	Farm Income: Log Value Added per Farmer			Log TFP	Log Cultivated Area per Farmer	Cereals Share of Value Added
	(1)	(2)	(3)	(4)	(5)	(6)
Road	0.052**		-0.147***	-0.052*	-0.032***	-0.025*
	(0.021)		(0.042)	(0.031)	(0.012)	(0.013)
Extension		0.066***	0.026	-0.018	0.016***	0.010**
		(0.016)	(0.017)	(0.011)	(0.006)	(0.005)
RoadxExtension			0.239***	0.112***	0.039***	0.029**
			(0.040)	(0.030)	(0.011)	(0.014)
Mean of Dep. Var.	9.42	9.42	9.42	9.52	0.62	0.55
N	11839	11839	11839	11851	11851	11851
Village FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Remoteness X Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Rainfall Measures	Yes	Yes	Yes	Yes	Yes	Yes

Notes: This table reports the estimates on the effects of roads and extension on farm income and the drivers of farm income. In columns 1-3 the dependent variable is the log of the total value added for all crops at the village level divided by the number of holders engaged in agricultural production. In Column 4 the dependent variable is the log of TFP estimated using the Levinsohn and Petrin (2003) approach. In Column 4 the dependent variable is the log of the total cultivated area in the village divided by the number of holders in the village. In column 5, the dependent variable is the share of value added of cereals in total value added. All the regressions include three sets of fixed effects - village, year and remoteness (log distance to baseline network) by year fixed effects - and four sets of rainfall measures, mean and deviation from the long run mean for annual total and growing season rainfall. Standard errors are clustered at the district (*wereda*) level. Significance levels: $*$: 10% $**$: 5% $***$: 1%.

Table 12: Crop Production and Household Ability To Feed Itself

Dependent Variable:	Number of Months Household Can Feed Itself Using Own Current Production of Cereals and Pulses			Using Own Production Or Sale of All Crops		
	(1)	(2)	(3)	(4)	(5)	(6)
Road	-0.143		-2.270**	-0.693*		-0.770
	(0.267)		(0.980)	(0.369)		(1.080)
Extension		0.995*	0.336		-0.187	-0.221
		(0.533)	(0.593)		(0.648)	(0.825)
RoadxExtension			2.284**			0.081
			(1.003)			(1.071)
Mean of Dep. Var.	8.16	8.16	8.16	10.12	10.12	10.12
N	13892	13892	13892	13899	13899	13899
Village FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Remoteness X Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Rainfall Measures	Yes	Yes	Yes	Yes	Yes	Yes

Notes: This table reports the estimates on the effects of road and extension on the number of months a household can feed itself. In column 1-3, the dependent variable is the number of months a household can feed itself using only its own production of cereals and pulses. In column 4-6, the outcome variable is the number months a household can feed itself through consumption or sale of own production. Standard errors are clustered at the district (*wereda*) level. Significance levels: $*: 10\%$ $**: 5\%$ $***: 1\%$.

Table 13: Household Total Expenditure, Food Consumption and Net Calorie Intake

	Log Total Expenditure			Log Food Expenditure			Log Net Calorie		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Road	0.018		-0.005	-0.007		-0.076	0.014		-0.092
	(0.034)		(0.114)	(0.039)		(0.129)	(0.030)		(0.111)
Extension		0.054	0.046		0.092	0.070		0.107*	0.075
		(0.060)	(0.067)		(0.072)	(0.082)		(0.055)	(0.056)
RoadxExtension			0.026			0.077			0.115
			(0.118)			(0.135)			(0.112)
Mean of Dep. Var.	10.34	10.34	10.34	9.56	9.56	9.56	15.15	15.15	15.15
N	14912	14865	14865	14912	14865	14865	14912	14865	14865
Village FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Remoteness X Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Rainfall Measures	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: This table reports the estimates on the effects of access to roads and extension on expenditures and calorie intake. The dependent variable in column 1-3 is the log of total annual household expenditure, columns 4-6 is the log of annual expenditures on food, and columns 6-9 is the log of the net colorie intake for the household. in The data comes from the rural sample of the 2010/11 and 2015/16 waves of the Household Consumption and Expenditure Survey. Standard errors are clustered at the district (*wereda*) level. Significance levels: $*: 10\%$ $**: 5\%$ $***: 1\%$.

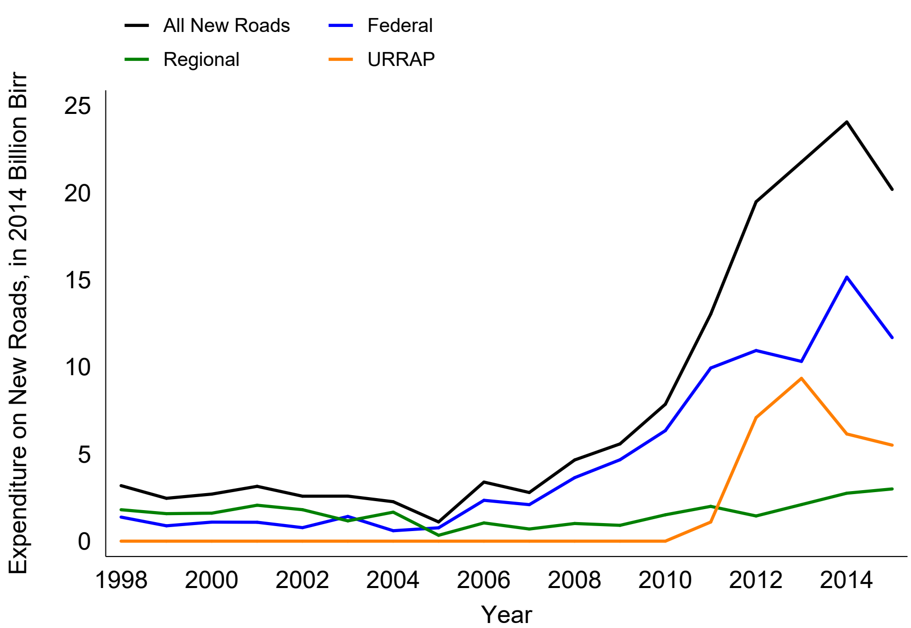
Appendix

Contents

A Additional Results and Robustness Checks

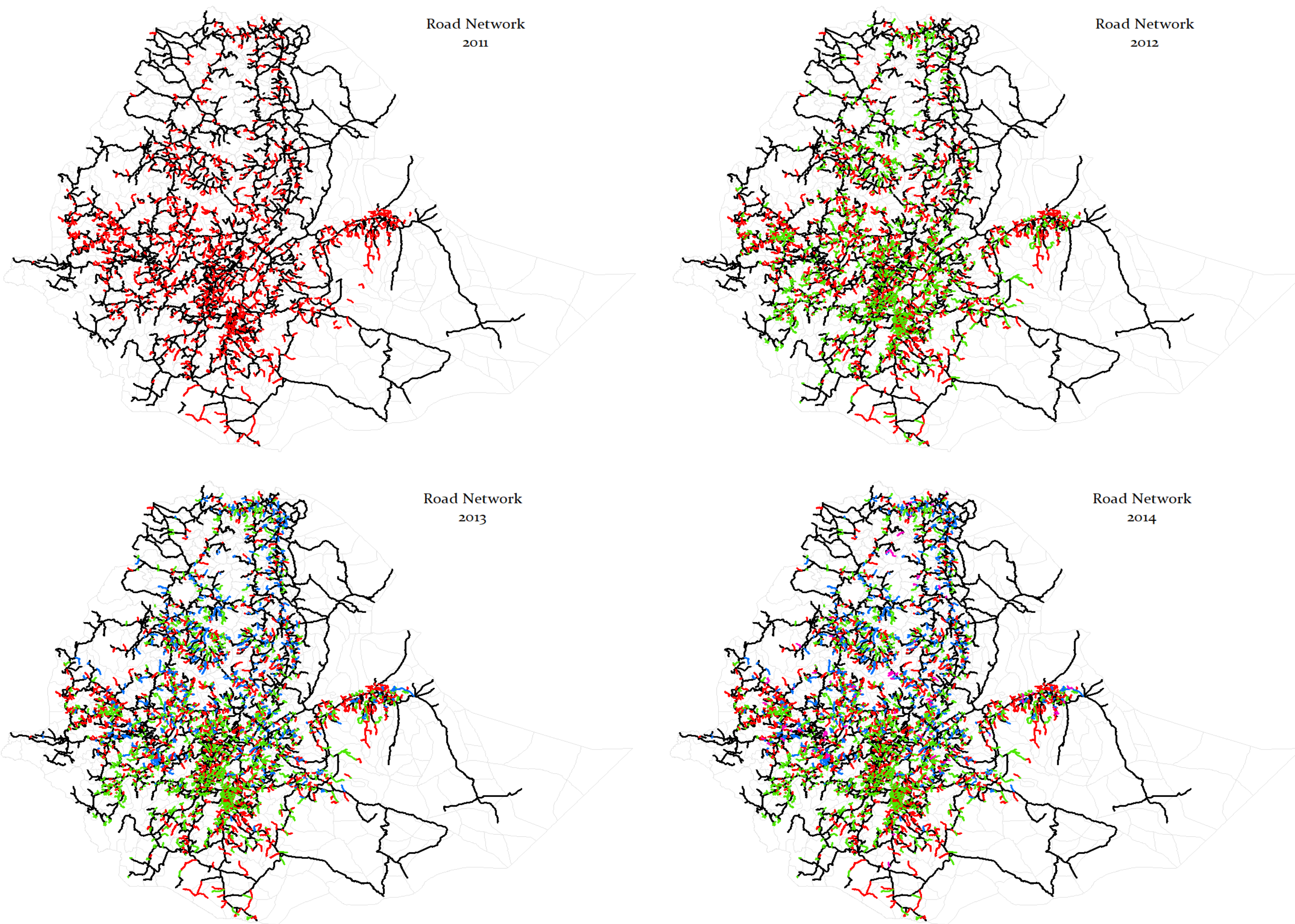
A.1 Additional Figures

Figure A.1: Annual Expenditure on New Roads by Road Class (in Million 2014 Ethiopian Birr)



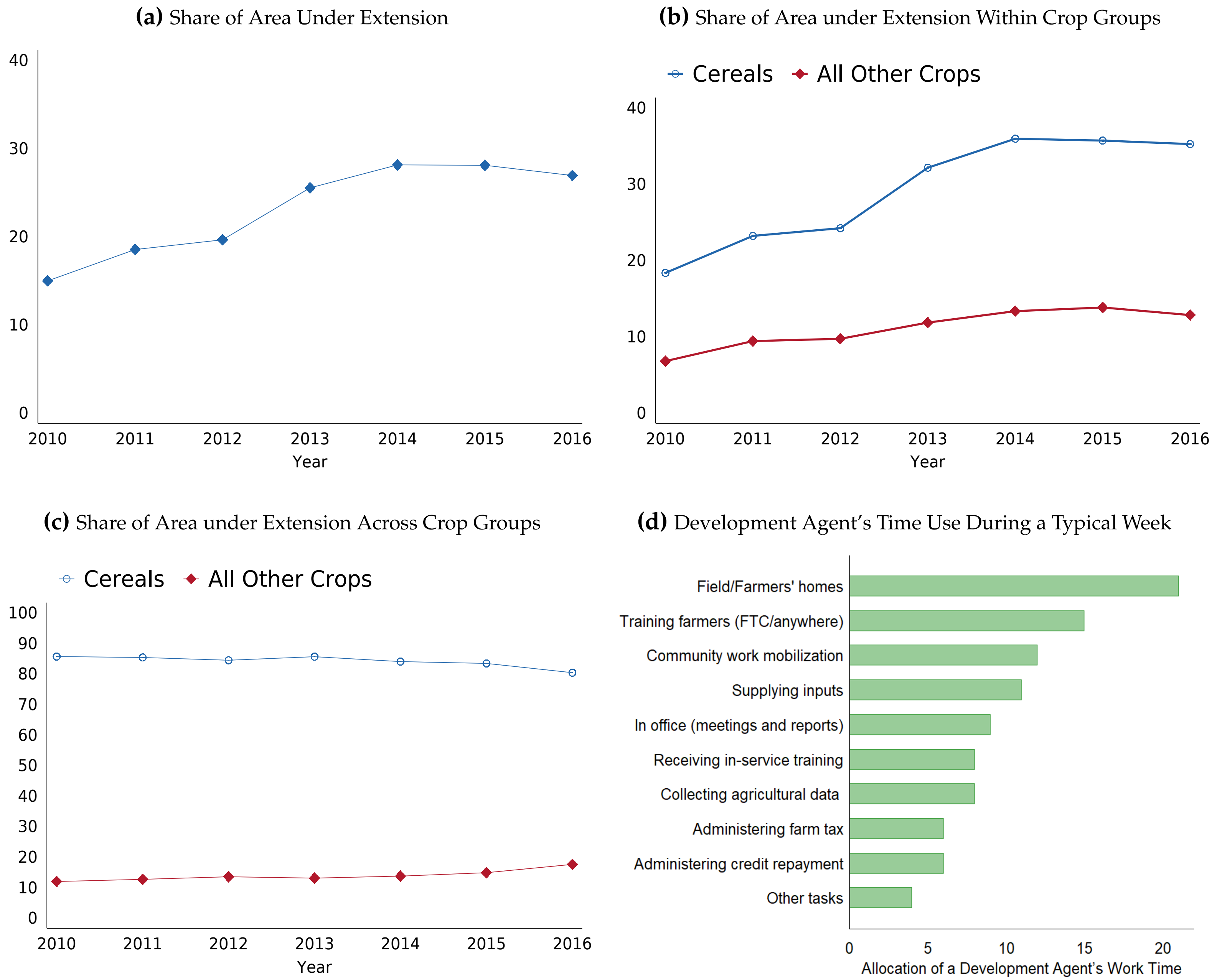
Notes: The figure presents the annual real expenditure, in millions of 2014 Ethiopian Birr, on new roads by road class type. Source: ERA (2015)

Figure A.2: Expansion of the Rural Road Network



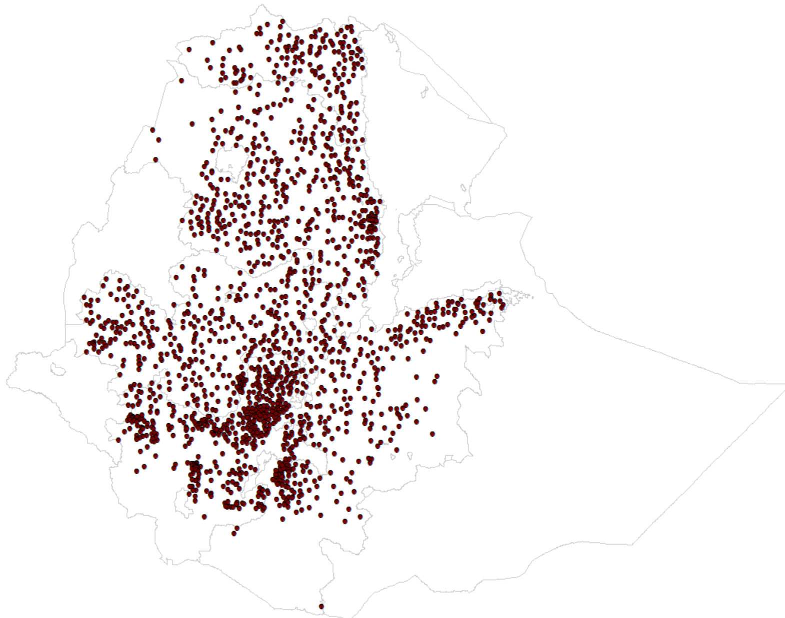
Notes: Figures (a)-(d) demonstrate the evolution of the full road network over 2011-2014 through the addition of the URRAP roads.

Figure A.4: Expansion of Extension Services



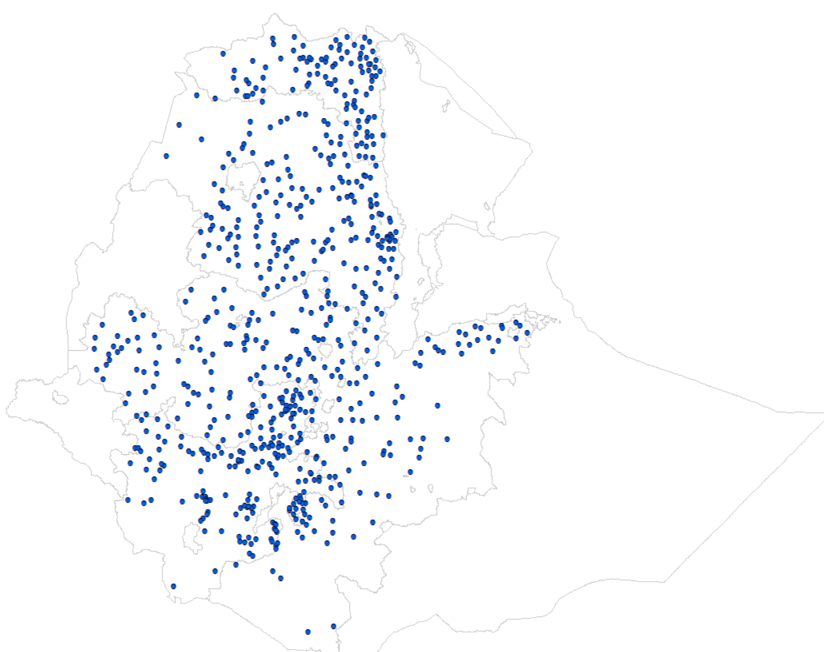
Notes: Source for Figure (d) : Berhane et al (2018) using the 2016 Digital Green DA survey of 896 development agents in Amhara, Oromiya, SNNPR and Tigray regions

Figure A.6: Enumeration Areas in the Annual Agricultural Sample Survey Balanced Panel



Notes: The figure presents the spatial distribution of the enumeration areas (sub-villages) in the balanced panel from the Agricultural Sample Survey (2010-16) from the four regions considered in the main analyses.

Figure A.7: Enumeration Areas in the Rural Sample of the Welfare Monitoring Survey and the Household Consumption and Expenditure Surveys



Notes: The figure presents the spatial distribution of the enumeration areas (sub-villages) rural sample of the Welfare Monitoring Surveys (2010/11 and 2015/16) from the four regions considered in the main analyses.

A.2 Additional Tables

Table A.1: Effect of Direct URRAP Connection on Market Access

Dependent Variable:	Market Access			
	(1)	(2)	(3)	(4)
URRAP Road	0.820***	0.815***	0.801***	0.800***
	(0.037)	(0.036)	(0.037)	(0.037)
N	11744	11744	11744	11744
Village FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Remoteness X Year FE	Yes	Yes	Yes	Yes
Rainfall Measures	Yes	Yes	Yes	Yes
Additional Controls				
Region X Year FE	No	Yes	Yes	Yes
Crop Suitabilities X Year FE	No	No	Yes	Yes
Proximity to Facilities (in 2007) X Year FE	No	No	No	Yes

Notes: This table reports the regression of market access on an indcator on whether the village was intersected by a road. Actual market access is calculated using equation (3) for each year based on the full road network in that year and distribution of population across villages from the 2007 census. The standard errors are clustered at the district (*wereda*) level. Significance levels: $*$: 10% $**$: 5% $***$: 1%.

Table A.2: First Stage Regression: Actual and Predicted Market Access

Dependent Variable:	Actual Market Access			
	(1)	(2)	(3)	(4)
Predicted MarketAccess	0.217***	0.215***	0.200***	0.194***
	(0.023)	(0.023)	(0.023)	(0.023)
F-Statistic	91.47	89.43	77.10	70.69
N	11641	11641	11641	11641
Village FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Remoteness X Year FE	Yes	Yes	Yes	Yes
Rainfall Measures	Yes	Yes	Yes	Yes
Additional Controls				
Region X Year FE	No	Yes	Yes	Yes
Crop Suitabilities X Year FE	No	No	Yes	Yes
Proximity to Facilities (in 2007) X Year FE	No	No	No	Yes

Notes: This table reports the first stage regression of actual market access on predicted market access with sequential addition of robustness controls. Actual market access is calculated using equation (3) for each year based on the full road network in that year and distribution of population across villages from the 2007 census. Predicted market access is calculated similarly but using the optimal network predicted in each year based on topography and the regional budget constraints using the procedures outlined in Section 5.3. Both actual and predicted market access variables are normalized so that the coefficient indicates the standard deviation effect on actual market access of a one standard deviation increase in predict market access. The first-stage F statistics are cluster-robust, and standard errors are clustered at the district (*wereda*) level. Significance levels: $*$: 10% $**$: 5% $***$: 1%.

Table A.3: Robustness of The Market Access Based Results to Varying the Connection Cut-Offs and Trade Elasticity (θ) Value

Dependent Variable:	Log Value Added Per Hectare									
	Market Access Is Calculated Using									
	Baseline, $\theta = 1.1$	$\theta = 1$	$\theta = 1.5$	$\theta = 1.5$	$\theta = 3.6$	$\theta = 3.73$	$\theta = 3.8$	$\theta = 6.74$	$\theta = 12.86$	$\theta = 26.83$
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	
	Panel A: A Village Within 2km of a Road is Connected									
MarketAccess	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.002
	(0.014)	(0.014)	(0.014)	(0.014)	(0.014)	(0.014)	(0.014)	(0.014)	(0.014)	(0.014)
Extension	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.018
	(0.013)	(0.013)	(0.013)	(0.013)	(0.013)	(0.013)	(0.013)	(0.013)	(0.013)	(0.013)
MarketAccessXExtension	0.034***	0.034***	0.034***	0.035***	0.035***	0.035***	0.035***	0.035***	0.036***	0.036***
	(0.013)	(0.013)	(0.013)	(0.013)	(0.013)	(0.013)	(0.013)	(0.013)	(0.013)	(0.013)
Mean of Dep. Var.	9.40	9.40	9.40	9.40	9.40	9.40	9.40	9.40	9.40	9.40
N	11654	11654	11654	11654	11654	11654	11654	11654	11654	11654
	Panel B: A Village Within 5km of a Road is Connected									
MarketAccess	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014
	(0.013)	(0.013)	(0.013)	(0.013)	(0.013)	(0.013)	(0.013)	(0.013)	(0.013)	(0.014)
Extension	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018
	(0.013)	(0.013)	(0.013)	(0.013)	(0.013)	(0.013)	(0.013)	(0.013)	(0.013)	(0.013)
MarketAccessXExtension	0.021*	0.021*	0.021*	0.022*	0.022*	0.022*	0.023*	0.023**	0.024**	0.027**
	(0.012)	(0.012)	(0.012)	(0.012)	(0.012)	(0.012)	(0.012)	(0.012)	(0.012)	(0.012)
Mean of Dep. Var.	9.40	9.40	9.40	9.40	9.40	9.40	9.40	9.40	9.40	9.40
N	11654	11654	11654	11654	11654	11654	11654	11654	11654	11654
Village FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Remoteness X Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Rainfall Measures	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: This table presents the robustness of the main results on productivity (value added per hectare) using the market access approach to different ways of constructing the market access. Column 1 in Panel A presents the baseline result. In panel A, the market access value is constructed assuming any village within 2km of the road is connected to the road. In panel B, I extend the cutoff to 5km. Columns 2-9 in both panels vary the value of the trade elasticity, θ, used to construct the market access. All the regressions include three sets of fixed effects - village, year and remoteness (log distance to baseline network) by year fixed effects - and four sets of rainfall measures, mean and deviation from the long run mean for annual total and growing season rainfall. Standard errors are clustered at the district (*wereda*) level.
Significance levels: $*: 10\%$ $**: 5\%$ $***: 1\%$.

Table A.4: Robustness of The Market Access Based Results to Varying the Connection Cut-Offs and Trade Elasticity (θ) Value

Dependent Variable:	Log TFP									
	Market Access Is Calculated Using									
	Baseline, $\theta = 1.1$	$\theta = 1$	$\theta = 1.5$	$\theta = 1.5$	$\theta = 3.6$	$\theta = 3.73$	$\theta = 3.8$	$\theta = 6.74$	$\theta = 12.86$	$\theta = 26.83$
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	
	Panel A: A Village Within 2km of a Road is Connected									
MarketAccess	-0.016	-0.016	-0.016	-0.016	-0.016	-0.016	-0.017	-0.017	-0.017	-0.018
	(0.015)	(0.015)	(0.015)	(0.015)	(0.015)	(0.015)	(0.015)	(0.015)	(0.015)	(0.015)
Extension	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.022	0.022
	(0.015)	(0.015)	(0.015)	(0.015)	(0.015)	(0.015)	(0.015)	(0.015)	(0.015)	(0.015)
MarketAccessXExtension	0.049***	0.049***	0.049***	0.049***	0.049***	0.049***	0.050***	0.050***	0.051***	0.052***
	(0.013)	(0.013)	(0.013)	(0.013)	(0.013)	(0.013)	(0.013)	(0.013)	(0.013)	(0.013)
Mean of Dep. Var.	7.25	7.25	7.25	7.25	7.25	7.25	7.25	7.25	7.25	7.25
N	11672	11672	11672	11672	11672	11672	11672	11672	11672	11672
	Panel B: A Village Within 5km of a Road is Connected									
MarketAccess	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
	(0.015)	(0.015)	(0.015)	(0.015)	(0.014)	(0.014)	(0.014)	(0.014)	(0.014)	(0.014)
Extension	0.022	0.022	0.022	0.022	0.022	0.022	0.022	0.022	0.021	0.021
	(0.015)	(0.015)	(0.015)	(0.015)	(0.015)	(0.015)	(0.015)	(0.015)	(0.015)	(0.015)
MarketAccessXExtension	0.032**	0.032**	0.032**	0.033***	0.033***	0.033***	0.034***	0.034***	0.036***	0.038***
	(0.013)	(0.013)	(0.013)	(0.012)	(0.012)	(0.012)	(0.012)	(0.012)	(0.012)	(0.012)
Mean of Dep. Var.	7.25	7.25	7.25	7.25	7.25	7.25	7.25	7.25	7.25	7.25
N	11672	11672	11672	11672	11672	11672	11672	11672	11672	11672
Village FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Remoteness X Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Rainfall Measures	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: This table presents the robustness of the main results on productivity (log TFP) using the market access approach to different ways of constructing the market access. Column 1 in Panel A presents the baseline result. In panel A, the market access value is constructed assuming any village within 2km of the road is connected to the road. In panel B, I extend the cutoff to 5km. Columns 2-9 in both panels vary the value of the trade elasticity, θ, used to construct the market access. All the regressions include three sets of fixed effects - village, year and remoteness (log distance to baseline network) by year fixed effects - and four sets of rainfall measures, mean and deviation from the long run mean for annual total and growing season rainfall. Standard errors are clustered at the district (*wereda*) level.
Significance levels: $*: 10\%$ $**: 5\%$ $***: 1\%$.

Table A.5: Robustness of Main Findings to Additional Controls

Dependent Variable:	Log TFP			
	(1)	(2)	(3)	(4)
	Panel A: OLS with Binary Road Access			
Road	-0.057	-0.055	-0.049	-0.023
	(0.042)	(0.042)	(0.041)	(0.042)
Extension	-0.003	-0.011	-0.012	-0.002
	(0.015)	(0.015)	(0.015)	(0.016)
RoadxExtension	0.125***	0.126***	0.113***	0.072*
	(0.041)	(0.041)	(0.041)	(0.040)
Mean of Dep. Var.	7.24	7.24	7.24	7.24
N	11793	11793	11793	11793
	Panel B: OLS using Market Access			
MarketAccess	-0.02	-0.02	-0.02	-0.01
	(0.015)	(0.015)	(0.015)	(0.015)
Extension	0.02	0.01	0.01	0.01
	(0.015)	(0.015)	(0.015)	(0.015)
MarkeAccessxExtension	0.05***	0.05***	0.05***	0.04***
	(0.013)	(0.013)	(0.013)	(0.013)
Mean of Dep. Var.	7.27	7.27	7.27	7.27
N	11672	11672	11672	11672
	Panel C: IV using Market Acces			
MarketAccess	-0.05	-0.06	-0.09*	-0.10*
	(0.046)	(0.046)	(0.049)	(0.053)
Extension	0.02	0.01	0.01	0.01
	(0.015)	(0.015)	(0.015)	(0.015)
MarkeAccessxExtension	0.06***	0.06***	0.06***	0.06***
	(0.018)	(0.017)	(0.017)	(0.017)
First Stage F-Statistic	45.78	44.68	38.25	35.55
Mean of Dep. Var.	7.27	7.27	7.27	7.27
N	11659	11659	11659	11659
Baseline Controls	Yes	Yes	Yes	Yes
Region X Year FE	No	Yes	Yes	Yes
Crop Suitabilities X Year FE	No	No	Yes	Yes
Proximity to Facilities (in 2007) X Year FE	No	No	No	Yes

Notes: This table subjects the results from the fully interacted model (column 6) in Table 2 and 3 to sequential addition of differential trends by potential confounders. Dependent variable is log TFP estimated using the Levinsohn and Petrin (2003) method. Column 1 presents the baseline results. Column 2 adds region by year fixed effects. Column 3 adds the interactions between year fixed effects and agro-climatically attainable yields for 20 crops, separately. Column 4 adds the interaction of year fixed effects with log distance from village to the locations 45 rural services and facilities. All the regressions include three sets of fixed effects - village, year and remoteness (log distance to baseline network) by year fixed effects - and four sets of rainfall measures, mean and deviation from the long run mean for annual total and growing season rainfall. Standard errors are clustered at the district (*wereda*) level.
Significance levels: $*$: 10% $**$: 5% $***$: 1%.

Table A.6: Heterogeneous Effects of Roads and Extension on Productivity: Cereals vs Other Crops

Dependent Variable:	Agricultural Productivity					
	Cereals			Pulses and Oils		
	(1)	(2)	(3)	(4)	(5)	(6)
	Panel A: Log Production Value Per Hectare					
Road	0.027*		-0.077**	0.042*		-0.029
	(0.015)		(0.038)	(0.021)		(0.040)
Extension		0.029**	0.008		0.000	-0.013
		(0.012)	(0.012)		(0.017)	(0.018)
RoadxExtension			0.123***			0.082**
			(0.036)			(0.040)
Mean of Dep. Var.	9.49	9.49	9.49	9.49	9.49	9.49
N	11688	11688	11688	11289	11289	11289
	Panel B: Log Value Added Per Hectare					
Road	0.036**		-0.076*	0.050**		-0.028
	(0.017)		(0.043)	(0.024)		(0.044)
Extension		0.024*	0.002		-0.017	-0.031
		(0.014)	(0.015)		(0.019)	(0.020)
RoadxExtension			0.133***			0.091**
			(0.041)			(0.043)
Mean of Dep. Var.	9.37	9.37	9.37	9.37	9.37	9.37
N	11688	11688	11688	11289	11289	11289
	Panel C: Log TFP					
Road	0.037**		-0.065	0.082***		0.014
	(0.018)		(0.050)	(0.024)		(0.053)
Extension		0.014	-0.005		-0.028	-0.039*
		(0.016)	(0.016)		(0.019)	(0.021)
RoadxExtension			0.120**			0.079
			(0.049)			(0.053)
Mean of Dep. Var.	7.33	7.33	7.33	5.62	5.62	5.62
N	11688	11688	11688	11289	11289	11289
Village FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Remoteness X Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Rainfall Measures	Yes	Yes	Yes	Yes	Yes	Yes

Notes: This table reports the estimates on the effects of roads and extension on the productivity of cereals and non-cereals separatley. Cereals include maize, millet, oats, rice, sorghum, teff and wheat. Pulses and Oils include chickpea, haricot bean, horse bean, feild pea, lentil, vetch, soyabean, fenugrk, lineseed, ground nut, neug, rapeseed, sesame, and sunflower. All the regressions include three sets of fixed effects - village, year and remoteness (log distance to baseline network) by year fixed effects - and four sets of rainfall measures, mean and deviation from the long run mean for annual total and growing season rainfall. Standard errors are clustered at the district (*wereda*) level.
Significance levels: $*$: 10% $**$: 5% $***$: 1%.

Table A.7: Changes in Access to Food and Living Standards

Dependent Variable:	Compared to Last Year Household Indicated Improvements In								
	Access to Food			Living Standard of the					
				Household			Community		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Road	0.057**		0.054	0.010		0.003	0.017		0.032
	(0.029)		(0.065)	(0.030)		(0.074)	(0.036)		(0.114)
Extension		0.133***	0.132**		0.093**	0.090*		0.117*	0.122*
		(0.042)	(0.056)		(0.045)	(0.055)		(0.060)	(0.070)
RoadxExtension			0.005			0.009			-0.015
			(0.068)			(0.078)			(0.119)
Mean of Dep. Var.	0.24	0.24	0.24	0.30	0.30	0.30	0.36	0.36	0.36
N	14947	14947	14947	14947	14947	14947	14943	14943	14943
Village FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Remoteness X Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Rainfall Measures	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: This table reports the estimates on the effects of roads and extension on household access to food and perceptions about the changes in their living standards. All regressions include three sets of fixed effects - village, year and remoteness (log distance to baseline network) by year fixed effects - and four sets of rainfall measures, mean and deviation from the long run mean for annual total and growing season rainfall. Standard errors are clustered at the district (*wereda*) level.
Significance levels: $*$: 10% $**$: 5% $***$: 1%.