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Tracing the Causal Loops Through Local Perceptions of Rural Road Impacts in Ethiopia

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Summary. — To better grasp the interconnected range of socioeconomic impacts from the implementation of rural roads in northern Ethiopia, we have experimented with Causal Loop Diagrams (CLDs), a tool commonly used in systems dynamics, but generally under-used in development research. The expansion of the rural road network in Africa is praised for reducing spatial isolation, lowering transport cost, increasing access to markets, and bringing services closer to home. However, different segments of society will benefit differently from the establishment of a rural road. This difference may lead to dynamics that either exacerbate or reduce existing inequities, which forms the central question for this paper. As part of a broader study on the multiple (in)direct effects of rural roads on productive employment, we undertook oral testimonies in four municipalities to explore how people perceive road impacts on livelihoods, mobility, and work. CLDs were then used to assemble those seemingly loose observations into a systematized view of the whole. The exercise reveals conflicting feedback processes that may dominate system at different times and drive the inequities between surplus food producers and laborer households up or down. The method used can be particularly useful for studying similar infrastructures that seemingly bring benefits to all, but may cause subtle, concealed or delayed effects, and ultimately surprising system behavior.
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Key words — roads, infrastructure, systems, causal loops, feedback, Ethiopia

1. INTRODUCTION

Development policy generally starts by investigating how effects follow causes in the hopes to confront root problems rather than symptoms. In spite of the efforts, poverty and inequity persist partly because of the failure to unravel how effects can also affect causes. Systems can indeed be understood as interconnecting feedback loops where cause and effect chains circle back upon themselves. The principle of diminishing returns, for example, represents a balancing feedback loop with a stabilizing effect on the economy. Systems thinkers have commented that economic models tend to overestimate such balancing mechanisms at the expense of reinforcing feedback loops that might push existing growth and decline patterns away from equilibrium (Arthur, 1999; Bowles, Durlauf, & Hoff, 2006; Meadows & Wright, 2008; Saeed, 2011; Whelan & Msefer, 1996). Dissenting voices from within the discipline of economics also recognize that neoclassical models cannot generate instability (Minsky, 1982 in Keen, 2011). "The dynamic, non-equilibrium social system that is a market economy should be analysed with dynamic, non-equilibrium tools" (Keen, 2011: p. 33).

A promising toolset is provided by the field of system dynamics. Its main technique for tracing cause and effect chains is the Causal Loop Diagram (CLD). The diagrams uncover multiple and conflicting processes of feedback and can therefore help clarify less visible and slower changes in a system. The technique has been developed and applied by Forrester (1968), Meadows, Meadows, Randers, and Behrens (1972), Sterman (2000) and many others in the fields of management, population, industrial and ecological dynamics. It remains a little known tool in development studies despite its potential to complement the descriptive methods commonly used in field research. We illustrate its applicability in the context of the substantial investments in rural roads that took place in Ethiopia in the last couple of decades (Emmenegger, 2012; ERA, 2013).

The disastrous social and ecological disruptions from costly white elephants, such as large hydroelectric dams or nuclear power plants, have long captured the critical eye of development scholars (Robinson & Torvik, 2005). The causal links are quite obvious, especially in hindsight. By contrast, other infrastructures may bring benefits to all, but their distributional effects are subtler, concealed, and delayed. This could lead to "hidden" dynamics that may worsen rather than reduce social inequities. This may indeed be the case for rural roads in Tigray, one of nine regional states in Ethiopia. On the surface, their construction inspires euphoric reactions. Quoting interview respondents: "the road is our bloodline", "roads lead to heaven", "the road is development", "the road is life" (M/66, 19-02-15, Adi Kisandid; F/40, 27-02-15, Hade Alga; M/24, 24-02-15, May Quiha).[1] Beyond these initial praises, however, interviews revealed a wide range of statements about the (in)direct effects of rural roads on development. For example, only farmers with sufficiently high levels of output might be able to afford and benefit from bulk transportation services. A new road could therefore increase their competitive advantage over marginal farmers. Respondents often focused on a specific causality, which would then be complemented or contradicted by other respondents. Going beyond individual statements, the interview data as a whole can be brought together with the use of CLDs to provide a rich and complex picture of economic life and of the function of rural roads.

Approaching the matter in this way is new in a long history of road research. Studies in human and development geography have already suggested that road impacts are distinctly

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distributed among a local population and that this would have long-term adverse effects on distribution (DeGrassi, 2005; Emmenegger, 2012; Gallé, 1989), but those expectations have generally remained unqualified and unquantified. In contrast, economic models in infrastructure impact studies generally endorse road investments by forecasting that these will reduce transaction costs, market volatilities, poverty, and spatial inequalities (see for example Arethun & Bhatta, 2012; Dercon, Gilligan, Hoddinott, & Woldehanna, 2009; Terefe, 2012). In reality, there are several causes for concern. Markets in Tigray show frequent successions of improvements and deteriorations in the local terms of trade (World Food Program, 2016). Every now and then price fluctuations even become volatile (Hadley *et al.*, 2011). At the same time, there is persistent poverty, inequity and malnutrition (Ferede & Kebede, 2015; Hadley *et al.*, 2011; Rajkumar, Gaukler, & Tilahun, 2011). The situation could of course have been worse in the absence of Ethiopia's road investments, but this is hard to establish based on economic models that tend to be primed to generate stability. They also fail to tell us the causes for a particular behavior and therefore how that behavior might possibly change in the future (Meadows & Wright, 2008).

This leads to the following questions: what are the potential and observed economic impacts from rural road infrastructure on different social groups? What does the distribution of those impacts mean for the long-term alleviation or aggravation of existing inequities? CLDs are intended to help understand the nature of these questions by identifying the feedback mechanisms at play. In future work, these could be explored quantitatively, for example through formal dynamic models. We will revert to this in the conclusions.

The focus of the article is on road and transportation infrastructure and its impacts on productivity and employment, even though other dimensions of development such as welfare, culture, health and education might be affected as well. Development is therefore distinguished from economic growth and the article focuses particularly on the qualitative dimension of equity, which is defined as justice and fairness in the distribution of assets and benefits. After a methodological clarification, the results are presented in two distinct sections: the first deals with the local perceptions of the infrastructure's impacts on rural life; the second with the distribution of these impacts.

2. METHODS

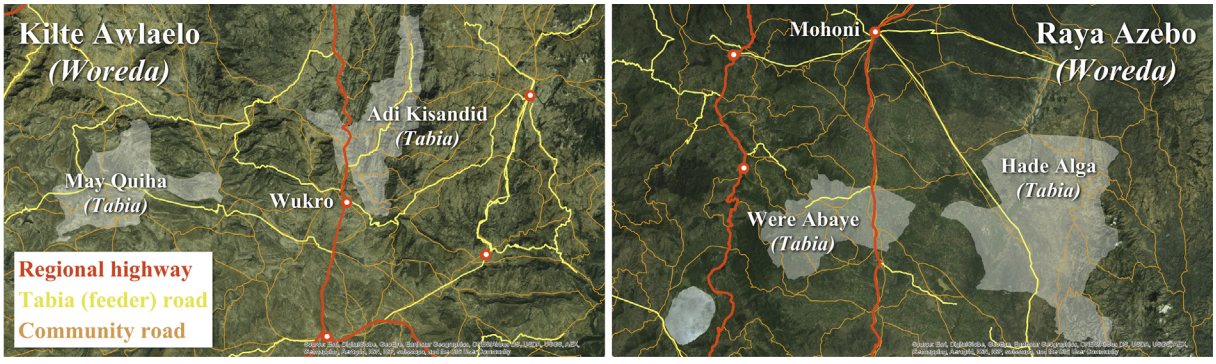
This paper compiles findings from a first step in a larger study[2] on the (in)direct effects of rural roads on productivity and employment in Tigray regional state in northern Ethiopia. The aim of this step was to assess how people experience and represent rural road developments in their direct surroundings. The study sites are in Kilte Awlaelo and Raya Azebo, two of Tigray's 35 *woreda* or districts (see Map 1). The *woreda* centers are Wukro and Mohoni, respectively. Distances from the centers to the study sites varies from about 6 to 40 km. Kilte Awlaelo is situated at higher altitude, features mountainous terrain and is generally intensively irrigated and developed for commercial cropping. Raya Azebo is lower, more arid and includes pastoralist activities. Two *tabias* (rural communities)[3] were selected in each *woreda*. A *tabia* might in turn contain four to six villages called *kushet*. It includes a center for its local administrative headquarters, sometimes with a market place or a school.

The study excludes federal highways between the regions and regional highways between woreda headquarters. Two types of rural roads connect woreda, tabia, and kushet (based on Emmenegger, 2012; ERA, 2013):

1. *Feeder roads:* These are mostly dry-weather unpaved gravel roads[4]. They serve as traffic feeders from tabia centers and facilities of socio economic importance to woreda centers or to the nearest all-weather road[5].
2. *Community roads:* These include the dirt paths and tracks between tabia centers, between kushets and tabia centers as well as between kushets.

A government target has been to establish a feeder road in every tabia. The age of a road is an important variable when studying short- and long-term impacts. The selection therefore included two feeder roads implemented recently in Adi Kisandid and Were Abaye (2010–15) and two older feeder roads, for which construction began in the late 1990s in May Quiha and Hade Alga.

A useful data collection technique to learn about a particular event, such as a conflict, a flood or the establishment of a road, is the oral testimony (Herbert & Rodger, 2007; Slim, Thompson, Bennett, & Cross, 1998). The testimonies involved face-to-face in-depth and unstructured interviews. The checklist included general questions about the respondent, his or her occupation, mobility, and household composition. Other open format questions were directed toward the anticipated and observed effects of the feeder road in terms of costs/benefits or advantages/disadvantages. To enhance the diversity of responses and minimize possible biases, our sampling was accidental (not random). The variables were: time of the interview (various hours of the day), market and non-market days, different kushets, different distances from the road, and different gender and age groups. Out of 40 respondents (~10 per tabia), 16 were female and 24 were male. Women are relatively constrained in their mobility and were therefore



Map 1. *Study sites (tabia boundaries in gray).*

underrepresented in the accidental encounters at first. To correct this, more interview requests were made directly at people's homes. The respondents' age varied between 18 and 70 years old. They lived across a total of 13 kushets (which covered most of them) and included traders, food producers, laborers, herders, students, kiosk owners, household heads and dependents. With this sampling method, the intention was not to make generalizations about the total population; rather, the aim was to collect a range of perspectives on the impacts of the feeder road.

Our data analysis and synthesis technique is the Causal Loop Diagram (CLD). This is a system modeling technique utilized to qualitatively reflect on variables and interrelationships (Forrester, 1968; Meadows & Wright, 2008; Meadows *et al.*, 1972; Sterman, 2000). CLDs consist of nodes and links. In a "positive" causal link, the influenced node changes in the same direction as the influencing node. For example, if *variable_1* in Figure 1 decreases, *variable_2* also decreases. A solid line indicates a positive causal link. A "negative" causal link (dotted line) means the two nodes change in opposite directions. Influences can also be delayed (//) relative to other influences in the system. CLDs can include phenomena by which a process is influenced by its own outcome, i.e., feedback. We refer to balancing feedback (B) when the influence slows down the process and to reinforcing feedback (R) when the influence speeds up the process. These mechanisms largely define the dynamics of systems over time. As suggested in the introduction, there is a need for tools that reveal the structures that potential drive a system away from equilibrium, which is one of the purposes of a CLD.

3. PERCEPTIONS OF RURAL ROAD IMPACTS

Subjective perceptions of rural road impacts from a diversity of respondents were collected through oral testimonies. CLDs were then used to assemble these seemingly loose observations into a systematized view of the whole. Although the CLDs were therefore created by the authors, the individual nodes are based on local perceptions. Figure 2 shows the total picture. The following sections systematically discuss its parts, supported with sample quotes from the oral testimonies.

(a) *Roads, mobility and accessibility*

We will distinguish between two types of impacts: on mobility and/or on accessibility, in other words, on whether someone moves more easily to a service or activity, or the other way around (Bryceson, Bradbury, & Bradbury, 2008). A respondent pointed out that "mobility is not for the sake of mobility; people always move and use transport purposefully" (M/57, 24-02-15, May Quiha). A *mobility_and_accessibility* variable therefore appears several times in Figure 2. The purposes include seeking health services at clinics and hospitals, attending school in a nearby settlement or participating in social or political events elsewhere in the woreda or region. This paper turns to agriculture-related *mobility_and_accessibility* (which will be indicated by a darker color in all the diagrams), as farming remains the dominant economic activity for 88% of all households in rural Tigray (Nega, Negash, G/Mariam, Mohammednur, & Miruts, 2011).

Roads have little meaning without complementing means of transport. Several respondents mentioned an increase in vehicle and animal transportation relative to on-foot transportation. "In the past, we used to walk to [nearby town] Machare on a community road and even sometimes all the way to Mohoni. Nowadays, we are connected to the main [feeder] road from where we can use transportation services" (F/58, 01-03-15, Hade Alga). Other respondents explain that vehicle transportation already existed to some extent before the establishment of the feeder roads, but that its availability has increased. Overall, our responses suggest a positive causal link between *rural_roads* and *transportation_services* (Figure 3).

However, the link is perhaps weak or delayed as transportation services do not automatically materialize after the construction of a road. "We don't have transportation facilities for this kushet. Had there been more bus stops and vehicles up to this point, then you wouldn't see people walking" (M/40, 24-02-15, May Quiha). Even with additional roads and transportation services, economic barriers to use may remain. "Especially those who have money can use public buses" (M/67, 19-02-15, Adi Kisandid). "People who don't have money can go more comfortably on foot" (M/67, 01-03-15, Were Abaye). A transport disadvantage arises, not as a lack of facilities, but as the incapacity to afford the services and linked to that the time that is lost on traveling on foot (Lucas, 2011). Bryceson *et al.* (2008) indeed found a positive correlation between average travel distance and income in several road-improved Ethiopian tabias.

Still, several respondents comment on the time and money they can save following the establishment of a feeder road. "A round-trip to Mohoni in the past would take about four days. Now it is possible to complete all the activities and come back within a day" (M/31, 28-02-15, Were Abaye). "If we had to stay away three or four days in the past, we had to spend a lot of money which we can save now" (M/30, 27-02-15, Hade Alga). A positive causal link therefore connects the *transportation_services* variable to *mobility_and_accessibility* (Figure 3). The total time and money saved on traveling will ultimately

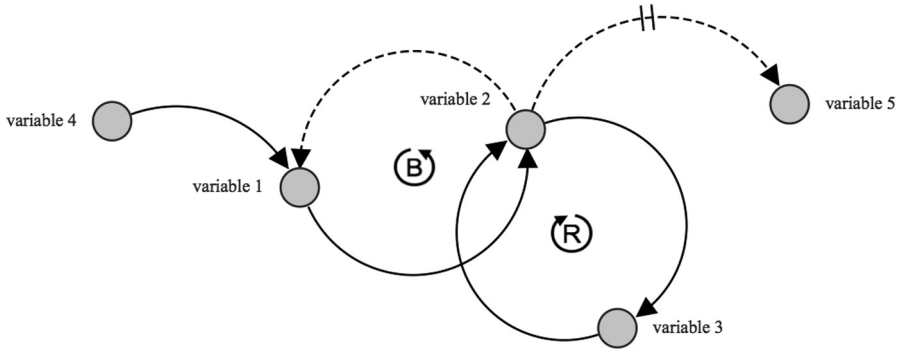


Figure 1. *Example of variables connected by causal links and feedback loops.*

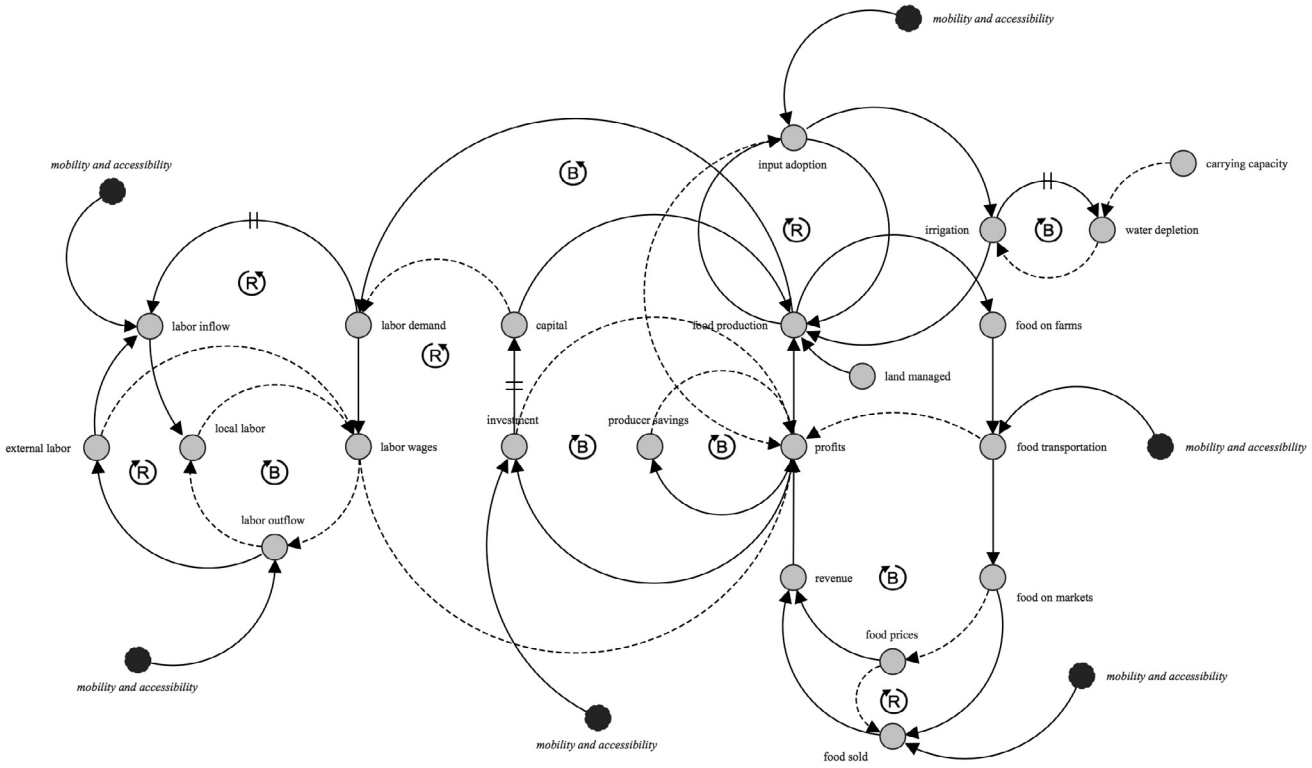


Figure 2. *Total CLD of the perceived system.*

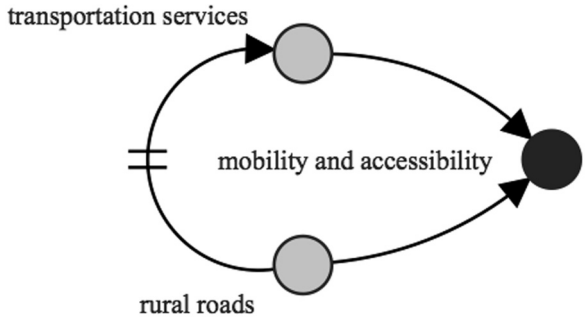


Figure 3. *Partial CLD: roads, mobility and accessibility.*

depend on its frequency. It is also conceivable that feeder roads have increased the number of journeys rather than saved time on a fixed number of journeys. "For my mother it was difficult to travel to the market, even once a month. I travel to markets almost weekly" (F/45, 24-02-15, May Quiha). This does not mean that the older community roads have been abandoned. Respondents explain that reaching the feeder road often still requires crossing considerable distances on dirt paths and tracks.

To what extent vehicles have indeed replaced on-foot transportation is difficult to determine. One respondent observed: "formerly, there was a road, but there were no vehicles and people were travelling on foot. Now it's the opposite" (F/38, 01-03-15, Hade Alga). According to others, this is an exaggeration and traveling on foot has hardly disappeared. In fact, the feeder road quite literally cleared the way for it. "Formerly it was difficult to travel, there were lots of thorns and stones, which would damage our feet. Now the road is smooth and you can travel safely" (F/38, 19-02-15, Adi Kisandid). Even in the absence of *transportation_services*, *rural_roads* therefore also directly link to *mobility_and_accessibility*. A study in four Ethiopian villages estimated that walking still constitutes roughly 90% of all trips; motorized transportation accounts for the remaining 10% (Bryceson *et al.*, 2008). That being said, such a small fraction can still have a significant impact.

(b) *Procuring agricultural inputs*

Past agriculture was almost exclusively rain-fed. Productivity was boosted by expanding cropping into the dry-season through irrigation schemes and by shifting from "traditional" to "improved" high-yielding crop varieties in combination with chemical fertilization (MoFED, 2010). Respondents confirm that this expansion also led to an increase in the cultivation of fruit and vegetables relative to grain. In Figure 4, the total yearly stock of *food_on_farm* is not only larger in size as a result of increased *food_production*; it is also more diverse in content.

Poor road systems and remote market channels in Tigray are said to limit the availability and/or the procurement of agricultural inputs (Meles, Nigussie, Belay, & Manjur, 2009). "Agricultural production has improved. One of the reasons is that the road gave access to fertiliser" (M/43, 23-02-15, May Quiha). This effect is indicated in Figure 4 by the causal links from *mobility_and_accessibility* to *input_adoption* to *food_production*. In line with official policy, formal seed provision was extended from the woreda into the tabia offices of the bureau of agriculture (Almekinders & Louwaars, 1999). However, *input_adoption* still relies on a certain level of mobility, depending on the vicinity of the farm relative to the feeder road and the office. A study in north-western Ethiopia found that 94% of all farming households in the least remote quintile use inorganic fertilizer compared to 70% in the most remote

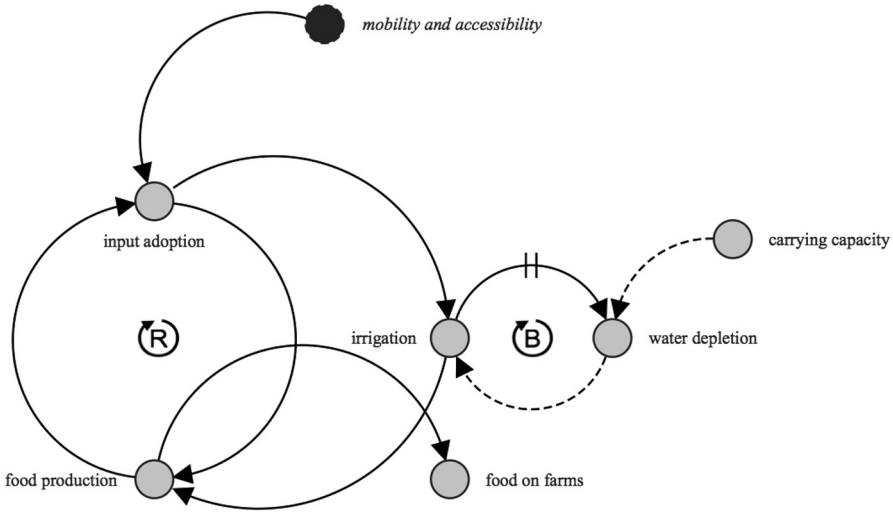


Figure 4. *Partial CLD: procuring inputs.*

quintile (Stifel, Minten, & Koro, 2012). Meanwhile, our respondents confirm that mobility-enhancements remain decisive for procuring other inputs that are not available through extension services within the tabia, such as fuel for irrigation and vegetable seeds.

The reinforcing feedback loop (R) between *input_adoption* and *food_production* in Figure 4 reflects a rising dependency on particular agricultural practices. A characteristic consequence of the hybridization of improved varieties is that seeds need to be re-purchased every season. One respondent explained: "I sometimes buy and use improved seeds in one year and again reuse harvested seeds in the next year. However, new seeds are always better" (M/41, 23-02-15, May Quiha). A study in southern Tigray also reports on seed quality deterioration when harvested and used repeatedly (Meles *et al.*, 2009). Others recognize that high-yielding seeds in combination with fertilizer also increases dependence on water use (the link between *input*_adoption and *irrigation* in Figure 4). "If there is shortage of moisture, the improved seeds are more susceptible to drought than local seeds" (M/41, 23-02-15, May Quiha). This problem was also recognized elsewhere in Tigray (Edwards, Gebre Egziabher, & Aray, 2011).

Experiences in regions where "green revolution" agriculture was adopted decades earlier tell us that such a production system eventually approaches ecological limits to soil nutrient content and water resources (Tilman, Cassman, Matson, Naylor, & Polasky, 2002). This is depicted in Figure 4 by a balancing feedback loop (B) of *irrigation* and *water_depletion.* Most balancing loops have their own goal or purpose. In this case, the "purpose" is to limit *irrigation* whenever it pushes *water_depletion* too close to the natural *carrying_capacity* of the water resource. The feedback includes a delay because the impacts may only be experienced after some time. In some areas, however, irrigation developments are already straining the water resources: "In the past, we used irrigation water from the river that comes down the mountain. Now, people upstream have different crops, especially onion and fruit trees. As a result, the water is not coming to this downstream area anymore" (M/70, 27-02-15, Were Abaye).

While the feeder road stimulated the adoption of the new crops, it was not necessarily the cause for it. Fruit, vegetables and other cash crops were already being produced in the tabias before the roads were established. In Adi Kisandid, for example, the road was constructed a few years ago, but vegetable production already began in 1990 (M/58, 20-02-15, Adi Kisandid). In Were Abaye, "coffee and khat [6] were already here [before the road was constructed in the late 1990s]. The other crops, like fruit, were introduced after that" (M/31, 28-02-15, Were Abaye). It would seem that the feeder road has had a catalytic effect on increasing productivity, but not on introducing entirely new forms of food production.

(c) *Selling food*

Respondents quickly associate feeder roads with the transportation of the output of production (a causal link from *mobility_and_accessibility* to *food_transportation* in Figure 5). They create mobility-enhancements for food producers by opening the way to distant markets. "Formerly, people were mostly consuming what they produced and were not conscious about markets" (M/57, 24-02-15, May Quiha). "These days, if I have customers in town, I rent a horse cart, I come here and dig out the product and transport it to town. The income itself has increased" (M/40, 20-02-15, Adi Kisandid). This last remark suggests reinforcing feedback (R): high *revenue* and *profits* [7] lead to increased *food_production* and *food_transportation* from farm to market, which results in an increase in *food_sold*, higher *revenue* and *profits* (Figure 5). Respondents add that faster *food_transportation* is linked to the earlier-mentioned increase in crop diversity, as they are now able to produce and sell more perishable crops.

Food producers generally rely on wholesalers or retailers and do not sell directly to consumers, which saves time. "Because of the road, I can quickly go to Mohoni, sell my products and come back to my children" (F/25, 28-02-15, Were Abaye). In the opposite direction, the feeder road also brings buyers closer to the farms. This accessibility-enhancement is captured by the effect of *mobility_and_accessibility* on *food_transportation* in Figure 5. *Food_transportation* represents a deduction of *profits*, whether paid for directly by the producer or indirectly to the trader (hence the negative causality between these variables).

As more and more food is produced, transported and sold on the markets (R in Figure 5), a balancing feedback loop (B) is likely to kick in at some point. A growing stock of *food_on_markets* reduces *food_prices, revenue* and *profits* (or slows down their growth), which limits *food_production* and *food_transportation.* This reduces (or slows down) local supply

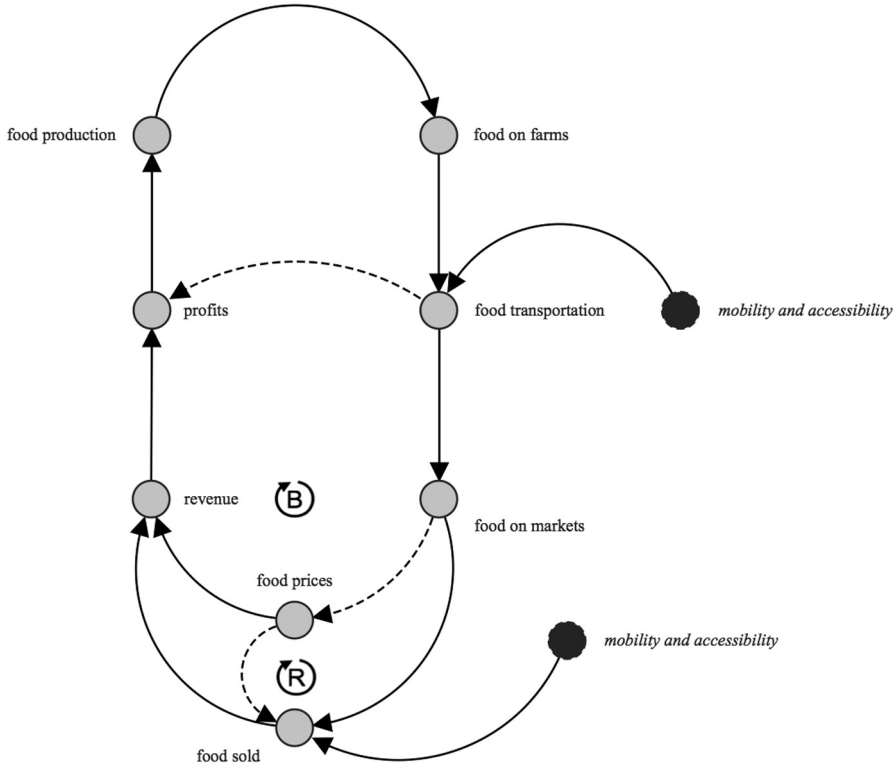


Figure 5. *Partial CLD: selling food.*

into the stock of *food_on_markets*. "Because of road developments and irrigation expansion, people are engaging in growing similar types of crops. This has a negative impact on price" (M/20, 19-02-15, Adi Kisandid). In general, food prices have continued to rise in Tigray (World Food Program, 2016), which implies that the respondent might be referring to relative rather than absolute price declines. He might also be observing faster daily or hourly price fluctuations in an overall rising trend. There may also be other influences not mentioned by the respondents (and therefore not included in the CLD). For example, wholesalers might regulate their stores to keep prices high or wider national or international market forces might draw food out of the region. Demand-side variables, such as wages and consumer mobility, also influence *food_prices* as discussed further below.

The interviews therefore revealed two feedback loops; one is driving the price up and the other is bringing it down. While some have assumed that access to roads in Tigray has a stabilizing effect on food prices (Arethun & Bhatta, 2012), price levels so far continue to fluctuate (Hadley *et al.*, 2011; World Food Program, 2016). The roads can also have a destabilizing effect depending on which feedback mechanism dominates.

(d) *Seeking local employment*

In Tigray, with an average size of 0.91 ha, 92.5% of households possesses the title to a plot of land, whether or not it is under cultivation. An estimated 41% of households also have one or more of their members participating in work outside the family farm (Nega *et al.*, 2011). This includes managing somebody else's land through rental agreements.[8] *Food_production* is therefore undertaken on both the land held and the land rented in by households[9] (the stock of *land_managed* in Figure 6). A survey in Tigray revealed that 24.3% of rural households rent out part of their land, 43.3% are pure owner-operators and 32.4% are tenant-cum-owner households (Gebregziabher & Holden, 2011).

An increased *land_managed* acreage brought under cultivation will typically raise *labor_demand*. A study in Tigray revealed that the demand for hired labor among smallholders occurs in peak agricultural seasons such as harvesting and weeding, but also sometimes in slack seasons (Davis, Reardon, Stamoulis, & Winters, 2002). Tracing the causal links in Figure 6, *profits* are invested in increased *food_production*, which can indirectly lead to higher *labor_wages*, which lowers *profits* and *food_production.* This represents balancing feedback (B). Alternatively, this may trigger (delayed) *labor_inflow* from the outside and a growth of the *local_labor* force inside the tabia. "Compared to other areas, there are more opportunities here" (M/40, 27-02-15, Hade Alga). This *labor_inflow* will depend on the availability (an *external_labor* stock) and mobility of labor in the wider region (*mobility_and_accessibility*). "There is more mobility and there are more people engaged in day-labouring" (F/38, 19-02-15, Adi Kisandid). A growing stock of *local_labor* could lead to lower, not higher *labor_wages*, which in turn raises *profits, food_production* and so on. This represents reinforcing feedback (R). Respondents add that not all tabias face labor shortages and there are also labor outflows.

(e) *Seeking regional employment*

An outlet for dealing with a drop in local *labor_wages* is for members of the affected households to find employment elsewhere, i.e., a *labor_outflow* from the tabia to the region (see Figure 7). "We have farm activities, but we also have those who are in need of jobs. They need to travel to Wukro and

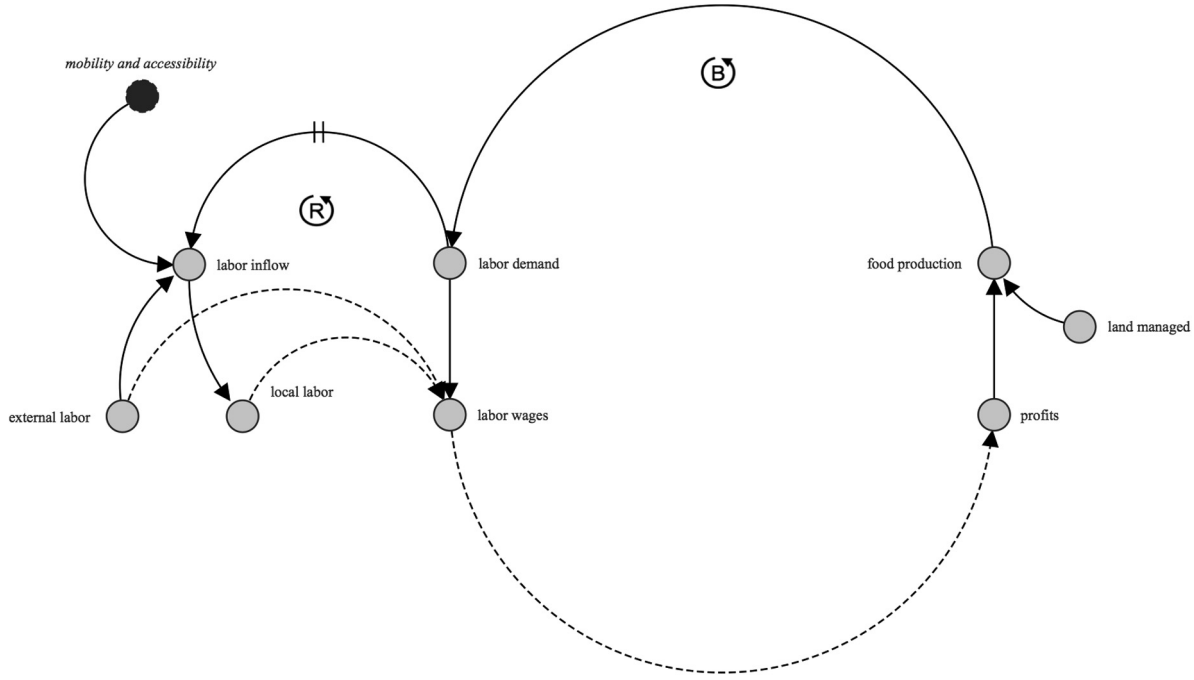


Figure 6. *Partial CLD: seeking local employment.*

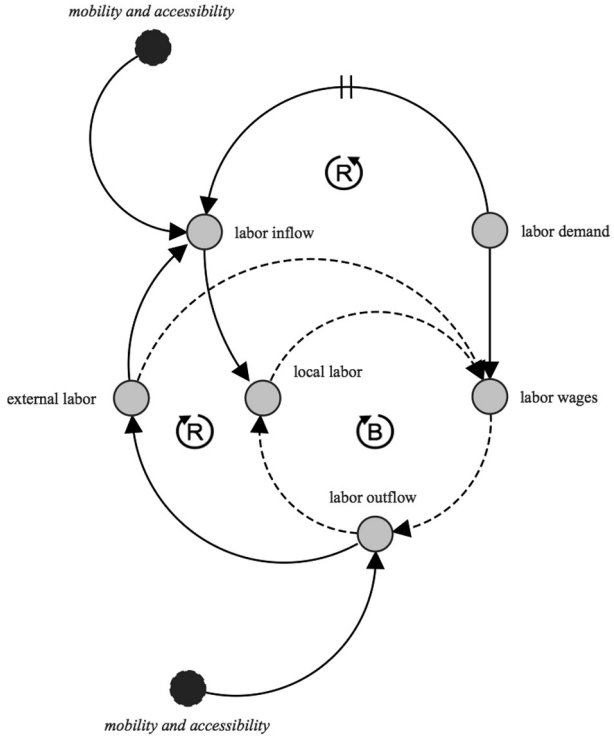


Figure 7. *Partial CLD: seeking regional employment.*

other areas, so the road is important" (M/60, 24-02-15, May Quiha). "When I go to Wukro for work, I will stay there for one or two months... I will try to save some money to bring back to my family" (M/19, 23-02-15, May Quiha). Total *labor_wages* consist of agricultural as well as other wages from trading, salaried employment or food-for-work schemes.[10] These wages are negatively affected by the size of the overall *external_labor* stock (hence the negative causality between these variables).

The decision to seek employment involves an assessment of the relative costs involved. "There are some day-labourers going to Wukro, but if you calculate the transportation cost from here to there, it is not feasible to go only for one day" (M/41, 23-02-15, May Quiha). A *labor_outflow* is therefore triggered by low local *labor_wages* as well as improved or more affordable *mobility_and_accessibility* (Figure 7). Arethun and Bhatta (2012) suggest that better access to roads in Tigray will improve labor force mobility and thereby increase access to job opportunities. Its contribution to *labor_wages*, however, will depend on the size of the *external_labor* force. "Construction work in urban areas is very competitive. There are a lot of workers" (M/20, 20-02-15, Adi Kisandid).

(f) *Investing in household assets*

Important factors affecting *labor_wages* are the intensification and modernization of agriculture. We already mentioned that *profits* are invested to increase *food_production*. *Profits* are actually partly set aside as *producer_savings* and partly spent on *investment*. This is needed to counterbalance the depreciation of the farmer's capital stock and to increase its size. *Capital* includes farming equipment, irrigation pumps, draft or pack animals and other non-land assets. The *investment* represents a cost to farmers—a deduction of *profits* (see balancing loop in Figure 8). "Even though irrigation is more expensive then rain fed agriculture, it is worth it" (M/30, 27-02-15, Hade Alga). The effect of an *investment* on *labor_demand* depends on the type. An ox-drawn plow might reduce the need for hired labor, while irrigation schemes might expand *food_production* and increase *labor_demand*. "In the downstream areas, there is more irrigation production and they always use extra labour" (M/20, 19-02-15, Adi Kisandid).

Tracing the causal links in Figure 8, we see the following reinforcing feedback (R): lower *labor_wages* lead to higher *profits*, *investment* in labor-saving *capital*, lower *labor_demand*

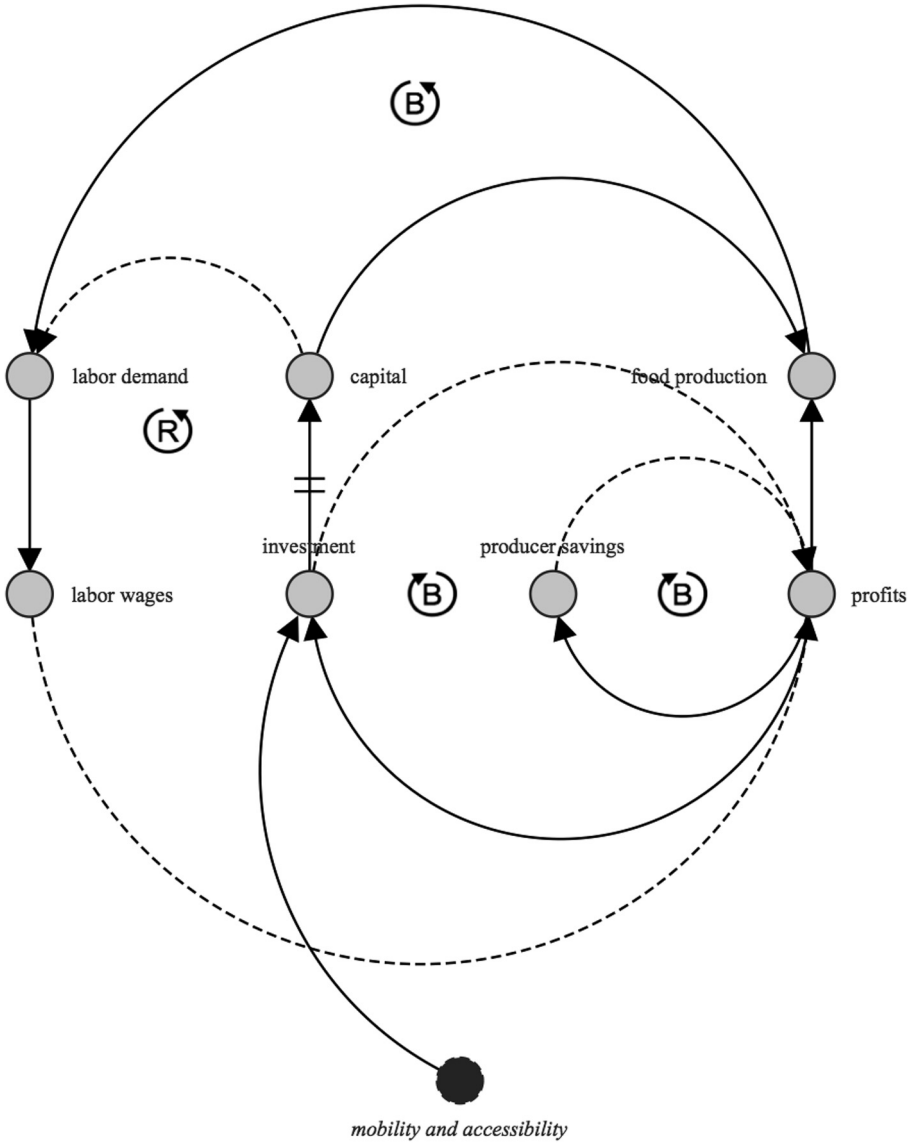


Figure 8. *Partial CLD: investing in household assets.*

and a further reduction in *labor_wages*. When *capital investment* expands labor-intensive *food_production*, on the other hand, it boosts *labor_demand* and *labor_wages*.

Similar to the aforementioned effect of *mobility_and_accessibility* on *input_adoption*, the feeder road may also have a positive impact on household *investment* through access to micro-finance institutions, credit cooperatives or through the government's Household Asset Building Programme, which facilitates the provision of credit, assistance in obtaining livestock, tools, seeds, irrigation schemes and so on (Berhane *et al.*, 2013).

(g) *Purchasing food*

As mentioned, households may work in the food system as producers and/or laborers. They may cultivate their own or someone else's landholding and the harvest may be for direct consumption and/or for trade. The relative weight of these activities in a household affects it dependence on markets for food. "We go to Wukro for buying and selling. We go when there is a shortage of food in the house. We also go to transport our crops" (M/54, 19-02-15, Adi Kisandid). Figure 9 therefore shows an effect of enhanced *mobility_and_accessibility* for consumers on the flow of *food_sold*.

Consumers not only travel to markets; outlets and shops are also established locally. May Quiha and Hade Alga both have a food market at their center; Adi Kisandid and Were Abaye do not. The former two also have relatively old feeder roads, which according to our respondents is not a coincidence. "Before the road, there was only a market in [nearby town] Tsegereda. After the road, another market came in May Quiha" (M/40, 23-02-15, May Quiha). The younger feeder roads on the other hand are associated with the establishment of shops or kiosks. "In my [unconnected] kushet, we always have to go to the shops by the asphalt road... If we had a [feeder] road, we could also get shops here" (F/40, 01-03-15, Were Abaye).

Price fluctuations were already discussed from the perspective of production (supply) in Section 3(c). From the demand side, *food_prices* obviously impact on the flow of *food_sold* (Figure 9), but there are other complexities affecting demand as well: "there are price differences between the different

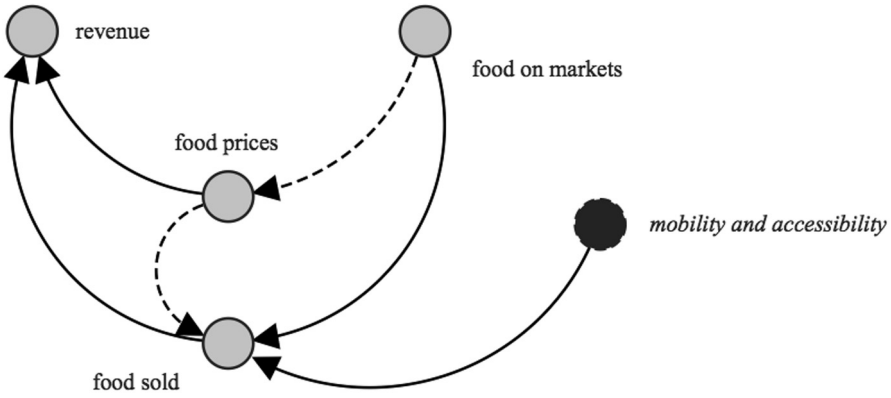


Figure 9. *Partial CLD: purchasing food.*

market centres. When we organise social events, like marriage ceremonies, then we prefer to go to Wukro to buy a lot of things at once. For example, the price of pepper is 50 birr here, and in Wukro it can be 40 birr or less. This is one of the reasons to select different market centres. The second reason is because of the variety of items. You can have a number of choices in Wukro, but here choices are limited" (F/45, 24-02-15, May Quiha).

4. DISTRIBUTION OF RURAL ROAD IMPACTS

Summing up the previous sections, there are several perceived feeder road impacts on *mobility_and_accessibility* in relation to agriculture (see Figure 10):

- Procuring inputs through enhanced *producer_mobility* and *access_to_extension*.
- Investing in household assets through enhanced *producer_mobility* and *access_to_extension*.
- Selling food through enhanced *producer_mobility* and *access_to_traders*.
- Purchasing food through enhanced *labor_mobility* and *access_to_markets*.
- Seeking of employment opportunities through enhanced *labor_mobility*.

Individual perspectives seem to suggest that everyone benefits from the establishment of a feeder road in one way or another. The only direct negative impact mentioned by several respondents was land appropriation for road construction. "We don't complain. We need the road more. Also, the land is from the government and we do not blame them for taking it" (M/54, 19-02-15, Adi Kisandid). Apart from that, the road is associated only with benefits (see Figure 10). However, different segments of society benefit differently and in the long-term this difference might worsen rather than reduce inequities. Before exploring this question, the different segments must first be characterized.

(a) *Wealth categories*

There is little doubt that land is a key biophysical wealth indicator in rural Ethiopia. While the average farm size in Tigray is 0.91 ha, the disparities are pronounced with 2.84 ha for the highest quintile and 0.01–0.14 ha for the remaining four quintiles (Nega *et al.*, 2011). The literature also suggests that heterogeneity in non-land resource endowment (such as labor and oxen) causes inequalities across households. As a result, many households choose to rent out their land. This can lead to a situation where landholders live in poverty and tenants are better off (Gebregziabher & Holden, 2011). The size of the land property "managed", as opposed to "owned", by a household is therefore a better wealth indicator (the *land_managed* node in the above diagrams). This was confirmed in our four study sites during participatory wealth ranking sessions, [11] a well established field method for studying distribution (Chambers, 1994; Grandin, 1988). In all cases, participants identified three major categories ("rich", "middle" and "poor") and selected as a key wealth indicator the total amount of land managed and cultivated, which includes owned and rented properties. The estimates are presented in Table 1.

Another indicator selected by the workshop participants was self-sufficiency in food. There was no strict upholding of a definition of wealth during the workshops. Several indicators, including food sufficiency, are therefore only loosely associated with actual biophysical or financial forms of

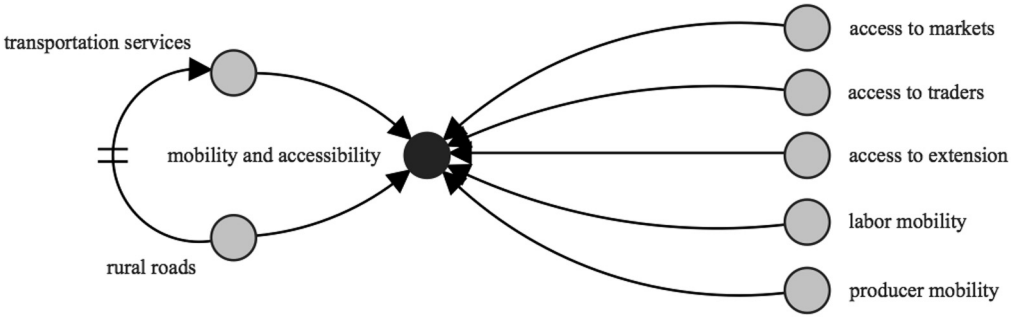


Figure 10. *Mobility and accessibility enhancements from rural roads.*

Table 1. *Managed land and self-sufficiency in food according to wealth group*

Wealth category, as % of the total population across all four tabias	47.5% "Poor"	32.5% "Middle"	20% "Rich"
Average land managed (in hectares)	0.22	1.41	2.34
Food self-sufficiency (in months per year)	2.9	6.9	15.5

wealth. An estimated 20% of the population has the capacity to cover food needs from their own land throughout the year and beyond, for example by storing grain [12] (see Table 1). According to Nega *et al.* (2011) the most food insecure households in Tigray are able to feed themselves adequately for a period of 4.75 months through their own production and/or through markets; they face food shortages for the remaining 7.25 months. We found that the "poor" are able to cover 2.9 months from their own land, including the in-kind return they may receive through sharecropping. There are nutritional differences to consider as well. During those 2.9 months of self-sufficiency, the "poor" may produce only rain-fed crops, which generally means grain. The "rich" may also produce fruit and vegetables through supplementary dry-season irrigation.

Of course, there are exceptions. This very basic categorization reveals a general picture where the better off households manage more land and enjoy lengthier periods of self-sufficiency than those in poverty. On the other hand, a strict division into producer and laborer households is too simplistic. A household may simultaneously generate *profits* (some of which becomes *producer_savings*) and *labor_wages* (financial or in-kind). The relative share of these variables in household income could therefore be taken as a proxy to distinguish between wealth categories. Savings, i.e., financial assets, were also selected as an indicator by participants in the wealth ranking workshops. This will also tell us something about how members of the household depend on and exploit the benefits from feeder roads. Households with higher relative *producer_savings* essentially imply that the road will be used more to procure inputs and sell food; with higher relative *labor_wages*, to seek employment and purchase food.

With different uses and benefits accruing to these broadly defined social categories, what might be the long term outcome for the inequities between them? This will depend on the feedback loops.

(b) *Shifting dominance*

The total CLD of the perceived system from Figure 2 depicts multiple feedback loops. Some of these compete with each other, i.e., feedback loops can drive the system in different directions. An example of this was already discussed in Section 3(c): two conflicting feedback loops act on the rising stock on *food_on_markets* to either increase or decrease *profits*. As with food prices, Section 3(d) presented feedback structures with opposing effects on wages, which could threaten the terms of trade of impoverished market-dependent consumers. In system dynamics, this is referred to as shifting dominance. Meadows and Wright (2008) explain that "when one loop dominates another, it has a stronger impact on behaviour. Because systems often have several competing feedback loops operating simultaneously, those loops that dominate the system will determine the behaviour" (p. 44). We will illustrate the point using different versions of the total CLD from Figure 2. In each version, a different feedback loop dominates either reducing or increasing inequities between *producer_savings* and *labor_wages*. We limit ourselves to three examples only.

Feeder roads facilitate the adoption of inputs, household asset investments and, more generally, the modernization of agriculture. Farmers that manage to follow this path are able to derive a richer advantage from the roads. "In general, those who are actively engaged in irrigation agriculture and working on the land are benefiting more from the road" (F/38, 19-02-15, Adi Kisandid). This group is able to easily access inputs and sell their product, but also to reinvest profits and build capital. "So the mobility itself is development. If I sell at a better price, I can produce more intensively" (M/57, 24-02-15, May Quiha). The road seems to catalyze the productivity of households that are ahead in terms of production. In other words, households with already higher relative *producer_savings* enjoy a competitive advantage at the time a feeder road is established over households with lower *producer_savings*.

A question to ask is therefore whether the spiralling growth of benefits for this group is coupled to decline of benefits for households with higher relative *labor_wages*. Alternatively, those households could also potentially benefit from the rising productivity of households with high *producer_savings*. One particular balancing feedback loop in the system functions to abate or stabilize the gap between *producer_savings* and *labor_wages*. It is highlighted in Figure 11. Lower *labor_wages* will lead to higher *profits* (and *producer_savings*), higher *food_production*, and higher *labor_demand*, which will bring *labor_wages* back up. But then, higher *labor_wages* will lead to lower *profits* (and *producer_savings*), lower *food_production*, and lower *labor_demand*, which will bring *labor_wages* back down again. This loop serves to keep the gap between *producer_savings* and *labor_wages* within bounds. If any of these variables rises too high, the feedback loop will bring it back down, or vice versa.

Another feedback loop pushes toward disequilibrium. Surplus labor exists in crop production in Tigray as a whole (Pender & Gebremedhin, 2008). Rising productivity may therefore not raise rural wages if new roads increase labor supplies (DeGrassi, 2005). In Figure 11, producers hired only locally. When asked about the distribution of benefits from feeder roads, a migrant worker expressed that "the road benefits more the poor. If the road and transportation are available, the poor will have a lot of opportunities to engage in different day-labouring and business activities, to move here and there". When asked whether she felt that this would also benefit the employers, she explained: "Yes, the rich also have a lot of opportunities in terms of employing different people. It actually has a negative impact on labour availability and wage rates. Sometimes, when there is a lot of labour available in this area, some of them may not get jobs. Also, when there are a lot of labourers, the employers decrease the wage rate. Sometimes it's 100 birr and sometimes it's 80 birr per day. In the worst case it can go down to 30 birr per day" (F/40, 28-02-15, Were Abaye).

In Figure 12, a reinforcing loop amplifies the gap between *producer_savings* and *labor_wages*: lower *labor_wages* lead to higher *profits* (and *producer_savings*), higher *food_production, labor_demand*, *labor_inflow* and *local_labor* stock, which will further reduce *labor_wages* and further increase *profits* (and *producer_savings*).

A third feedback loop could make matters worse. Surplus food producers are likely to invest in labor-saving technologies. If the 1960s green revolution in Asia is to provide a lesson here, contrary to expectations, the increased productivity did not lead to a matching growth of employment (George,

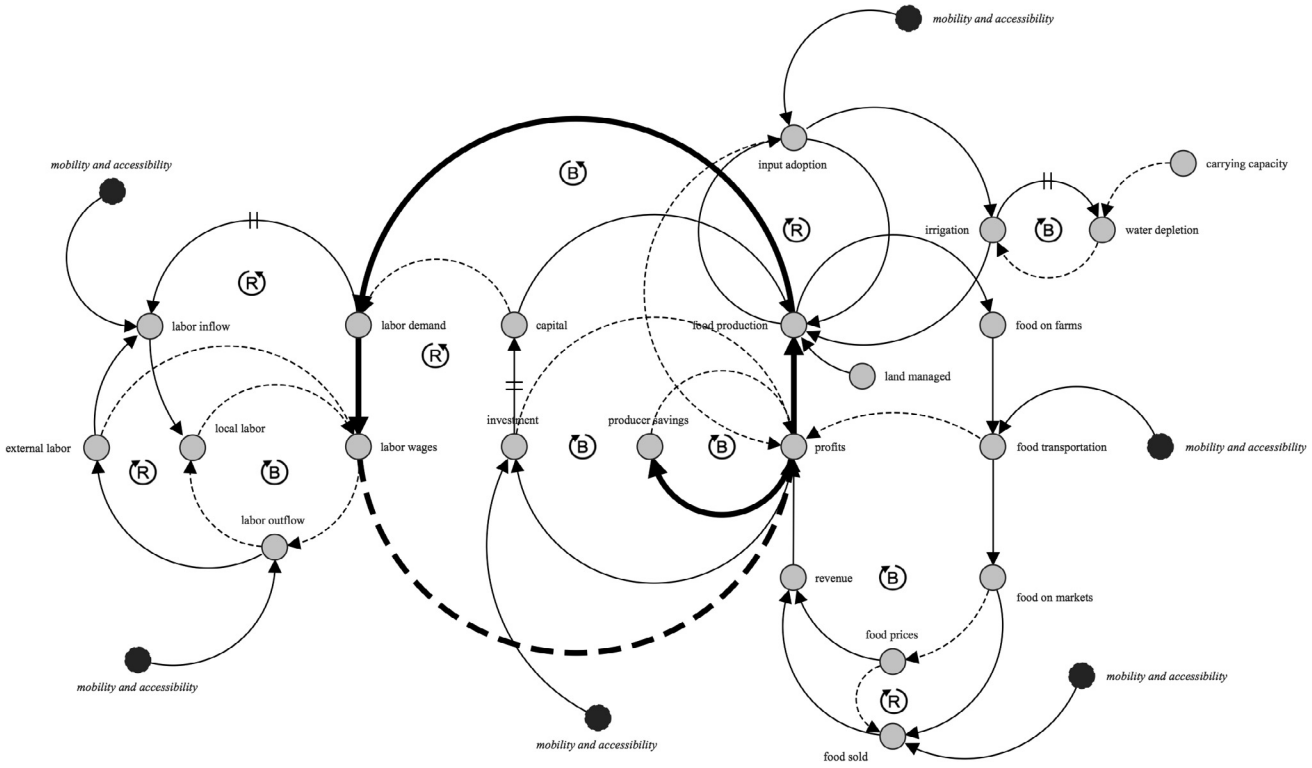


Figure 11. *Balancing feedback loop of labor demand.*

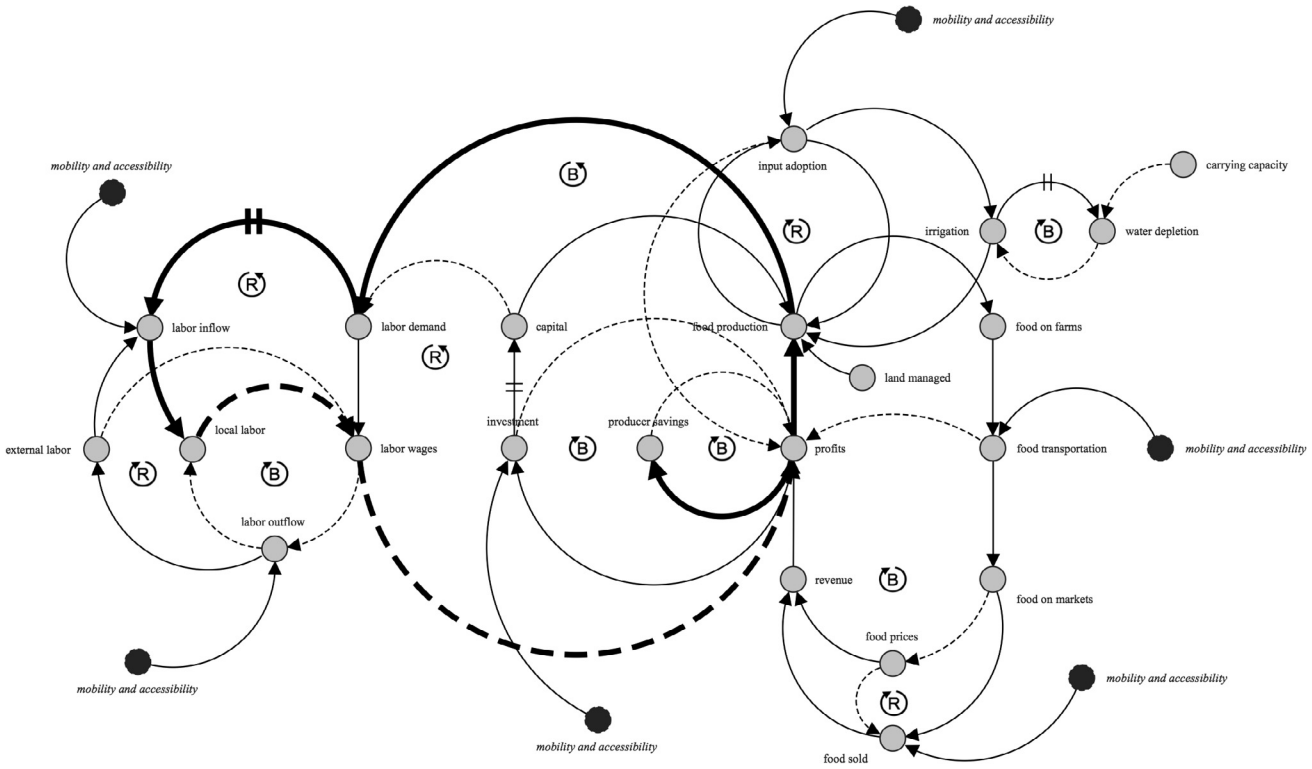


Figure 12. *Reinforcing feedback loop of labor inflow.*

1991). Stifel *et al.* (2012) made a related observation for north-western Ethiopia. Sorghum producers that were well connected to extension services and markets adopted more modern inputs compared to less-connected producers. The more connected farms also required less labor inputs. Such type of research would need to be expanded for different crops and localities, but it places a question mark behind the assumption that by boosting productivity, feeder roads also

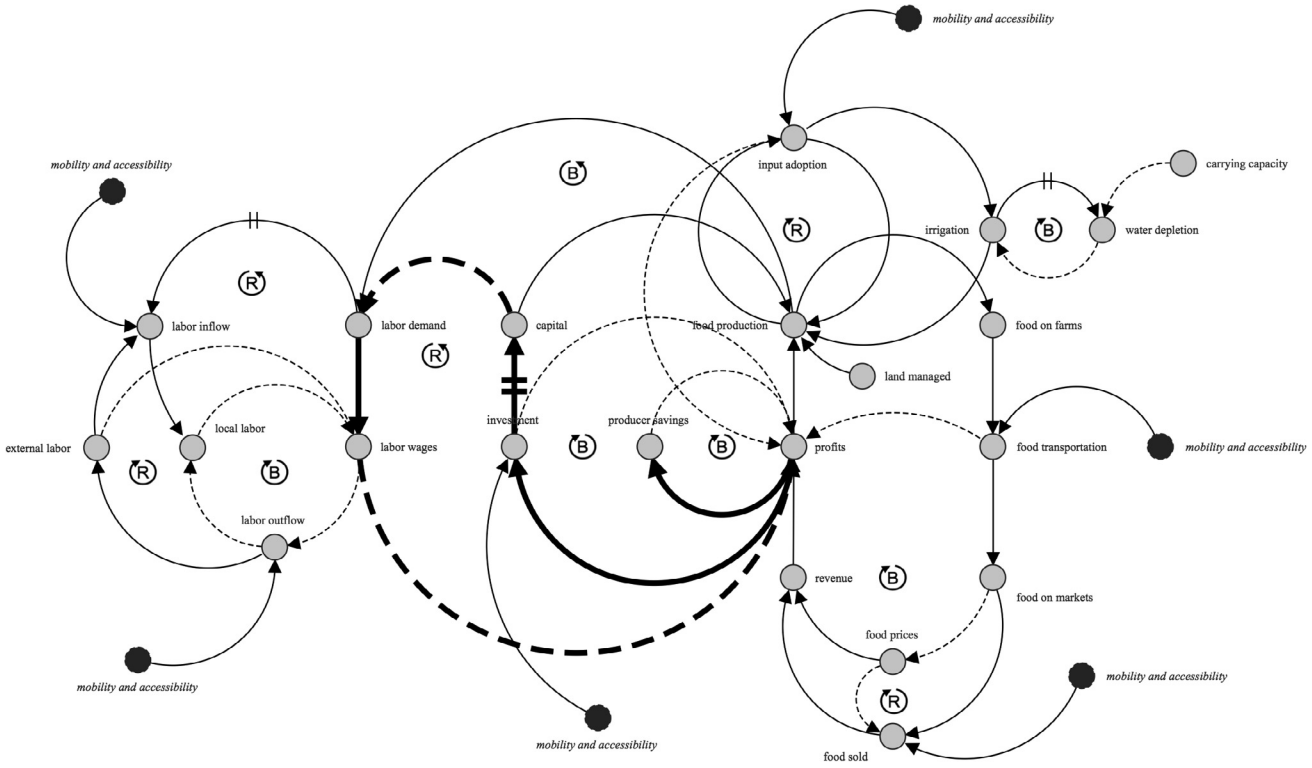


Figure 13. *Reinforcing feedback loop of investment.*

boost labor demand and wages. "If there is no effort to expand job opportunities for them [the poor], there will be problems in the future" (M/57, 24-02-15, May Quiha).

In Figure 13, *investment* goes toward labor-saving *capital*: low *labor_wages*, high *profits* (and *producer_savings*), more *investment* in labor-saving *capital*, less *labor_demand*. This further lowers *labor_wages* and raises *profits* (and *producer_savings*). Alternatively, the *investment* could go toward the expansion of *food_production*, which would pull low *labor_wages* up, but again assuming that producers hire locally.

Agricultural expansion is ultimately limited by the availability of land, water and other resources. Section 3(b) already raised the point. The size of the productive pie cannot grow indefinitely for everyone. In the end, participation as producers in the local economy becomes a zero-sum game and competition becomes competitive exclusion. [13] With local limits to production and employment in the agricultural sector, neoclassical economic arguments suggest that migration (or non-farm employment when this becomes available) should reduce pressure on land and reduce the level of competition among rural wage labor. Here again, we should consider potential inequities. "Some people can go to Wukro and other areas provided their status is a bit up. Otherwise, for day-labourers there is no migration. So only if someone is better educated, they can get better jobs and can go to other areas" (M/67, 19-02-15, Adi Kisandid).

5. CONCLUSIONS

A system with multiple competing loops can lead to surprising outcomes. For long, the dynamics may remain concealed, as suggested in the introduction. There is little controversy in rural road investments at first sight, because everybody enjoys direct benefits. However, the long-term effects aren't necessarily impartial. To better grasp this, we have experimented with a tool commonly used in systems dynamics, but generally under-used in development research.

We started by asking about the observed economic impacts from rural road infrastructure on different social groups. The oral testimonies revealed an overwhelmingly positive attitude toward feeder road developments and associated mobility and accessibility enhancements. The benefits ranged from procuring inputs, investing in household assets, selling food, purchasing food, or seeking employment opportunities. The next step was to enquire into the distribution of impacts and whether this would alleviate or exacerbate inequities. By gathering and connecting the seemingly disconnected causal links mentioned by respondents, a broader systemic picture emerged. It revealed a number of balancing and reinforcing feedback loops. The long-term development outcomes will depend on which feedback loop dominates.

We have seen how even in places where transportation services have improved, access and benefits remain skewed. At the same time, improved mobility is useful for the employment-seeking household, insofar as this occurs in a situation where there is regional labor shortage, which is not the case for Tigray. Increased competition among a more mobile labor force leads to a severe drop in wages. By facilitating mobility, feeder roads therefore both exacerbate and reduce labor competition. This has implications for food security, more specifically in terms of labor wages relative to food prices. The net result is difficult to predict, but quantitative studies will need to consider both types of feedback.

Improved mobility is useful for the individual food-producing household. However, with distinctive starting positions at the time of construction of a feeder road, households

are more or less able to harness its benefits. Enhanced mobility and accessibility contributes to productivity, which leads to further mobility and access to markets in the wider region. Further studies should therefore attempt to quantify whether improved mobility strengthens in the first place the competitive advantage of producer households that are already ahead. If so, it will increase the wealth gap between surplus and subsistence producers. More and more subsistence producers might then be forced to join an already large and competitive labor force, which would put further pressure on government welfare resources.

We can only speculate on the accuracy and relative prominence of individual oral testimonies drawn from a non-random sample. In fact, the method does not aim produce factually accurate details but offers a lens into the respondents' world-views (Herbert & Rodger, 2007). This implies that a causal link may be weak or even altogether missing. Likewise, when applying systems thinking, Meadows and Wright (2008) remind us to "remember, always, that everything you know, and everything everyone knows, is only a model" (p. 172). Regardless of the limitations, it is in this sphere of representation that systems thinking and oral testimonies are complementary. Oral testimonies challenge the modeler's bounded rationality while CLDs help to combine and contrast the seemingly loose or contradictory observations from the oral testimonies. A follow-up activity could be to organize focus group workshops to involve communities in the evaluation and further development of the CLD.

The aim of this exercise was not to predict shifting dominance in the system, but to question the widespread assumption in neoclassical economic models that rural roads will merely stabilize prices, increase wages and reduce inequities. Further research could inquire into the relative importance of the different feedback loops and their implications for income or wealth gaps, for food production and distribution, for employment, and so on. CLDs in fact often serve as a first step toward building quantitative dynamic models and developing response strategies. The variables in a CLD are then first translated into stocks [14] (e.g., food stores, land holding, available labor), flows [15] (e.g., employment, consumption, production) and model parameters (e.g., labor needs per hectare, fertility rate, growth goal) (Costanza & Voinov, 2001). The models can then simulate how the feedback loops previously mapped out in CLDs slow down or speed up the flows.

Building such a model could help to further explore the origin and magnitude of current trajectories for productivity, wages, prices, food security and self-sufficiency, including their possible instabilities. The model can then be used to assess the effects of feeder road investments and additional interventions to counter undesired effects. This can be particularly useful for studying infrastructure that may seem to bring immediate benefits to all, but their distributional effects are subtler, delayed and contradictory.

NOTES

1. To clarify the interview citations: "M/66, 19-02-15, Adi Kisandid" means Male respondent, 66 years of age, interviews on 19-02-15, in the Adi Kisandid rural community. We use these abbreviations throughout the paper.

2. This two-and-a-half year research program, funded by NWO-WOTRO Science for Global Development, aims to investigate (1) direct employment in infrastructure construction and maintenance; (2) indirect effects on employment due to improved mobility and access; and (3) employment change due to different water resource management options linked to the design of roads.

3. The tabia is also the smallest unit of local government in rural Tigray.

4. Dry weather roads are passable to normal motorized traffic in the dry season. They are not usually passable in the wet season, because of a soft and slippery road surface and/or streams after heavy rain (ERA, 2013).

5. All weather roads are passable in all weathers by normal motorized traffic in both wet and dry weather. They are closed only in exceptional weather conditions (ERA, 2013).

6. Khat is an amphetamine-like stimulant cash crop native to the Horn of Africa. Khat chewing is a custom dating back thousands of years.

7. Profit = Revenue – Costs.

8. The Tigray Regional State land policy allows unlimited periods of use-rights for title-holders as long as they maintain their residency in the village. It also permits them to rent out less than half of the land (Teka, Van Rompaey, & Poesen, 2013).

9. The dominant rental form in Tigray is sharecropping. It involves a non-marketed exchange between the household holding the land and the household that sharecrops it, i.e., the right to cultivate land in return for a portion of the harvest (Ghebru & Holden, 2012).

10. Public works are implemented through programs such as food-for-work, cash for-work, employment generation schemes and employment-based safety nets. The Productive Safety Net Programme, for example, has employed the rural poor in building roads and other infrastructure (Ferede & Kebede, 2015).

11. In each tabia, eight participants from different kushets and socio-economic backgrounds were invited to take part in workshops where they were asked to develop their own categorization of "wealth" categories and list of indicators, which resulted in an estimation of the percentage of households in each category.

12. Another survey in Tigray estimated that 24% of rural households have enough food to eat at all times during the year (Nega *et al.*, 2011).

13. This ecological principle states that when two competing life forms attempt to occupy the same niche, one life form will drive out the other. That will usually not happen by direct confrontation, but by appropriating all the resource, leaving none for the competitor (Meadows & Wright, 2008).

14. A stock variable indicates a store or a quantity of material or information that has built up over time.

15. A flow variable produces a change in the stock variable, usually an actual physical flow into or out of a stock. In systems terminology, physical (and information) flows are also called rate variables.

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