

ABSTRACT

Title of Dissertation: AUTOCHTHONOUS AND INTRODUCED STORES OF BIOMASS VALUE: MEASURING RESILIENCE OUTCOMES OF ENSET AND EUCALYPTUS AS GREEN ASSETS IN THREE REPRESENTATIVE SMALLHOLDER FARM SYSTEMS OF ETHIOPIA

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Fundamental shifts in the ability to observe our world with synoptic satellite remote sensing and the profusion of trend tracking longitudinal data sources not only better inform us of the mounting trouble our planet is in but also provide completely new perspectives on basic shared understandings, such as how many trees grow on Earth and where they take root. Observing the dispersed pattern of increasing tree cover across a multidecadal satellite mosaic, developed by Matt Hansen and colleagues at University of Maryland at College Park, sparked an interest in the ramifications of this unanticipated change, marked clearly upon the landscape in Ethiopia. The following chapters explore the relation of changing amounts of autochthonous treelike perennial enset and introduced eucalyptus trees, commonly found on

Ethiopian farms, to smallholder resilience, food security, and well-being. Spatially informed longitudinal models for three representative subnational data sets are used to investigate the central thesis of this dissertation—trees and treelike perennials on farms in rural Ethiopia indicate a fundamental store of value in living biomass, building a household's assets over time through improved biomass management, for resilient small farm livelihoods that ensure food security and related well-being. Green assets acting as biomass stores indicate natural “value,” representing transformed and stored energy of the sun, that Blaikie and Brookfield (1987) considered inadequately captured as a no-cost contribution to the “use value” concept in development economics, economic geography production, and income-focused research, as well as in Marx's (1887/2013) labor-focused value constructs that only briefly acknowledge workers are helped by the transformative “natural forces” at work on the land. Model results presented in Chapters 3, 4, and 5 reveal a lack of on-farm trees and treelike perennials often indicates biomass poverty and energy insecurity. Chronic biomass poverty, measured with spatially aware hierarchal models, is related to an inability to maintain a sufficient level of essential green assets, thereby contributing to poor resilience and well-being outcomes on small farms. On the other hand, medium and longer term asset accumulation supports improved well-being when livelihood strategies make use of farm forests, other on-farm trees, and treelike perennials.

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SYSTEMS OF ETHIOPIA

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Dedication

For Sabrina and our daughters, Eva Lea Pace and Maris Stella.

Acknowledgments

This document is presented with full gratitude to the smallholder farmers of Ethiopia who took the time to participate in the panel surveys analyzed in this dissertation. By sharing their knowledge about and recent innovation on the food and farming systems that coevolved over millennia in these important places, a wealth of information was contributed that is likely germane to improving the discussion of how we may go about sustainably living on this planet. I am grateful to the enumerators that collected the data, the organizations and their personnel that organized and prepared the data for sharing, and the taxpayers who ultimately supported these efforts.

Engaging discussion with colleagues, who subsequently contributed to papers originating from this dissertation, have ensured an added level of professional rigor in this work. In addition to the exacting examination by my committee, I would like to appreciate the tough and probative questions of this thesis from these dear colleagues: Nancy Mock, Andrea Colantoni, Luca Salvati, and Andrea Gatto. Particularly with respect to preparing Chapter 4, I am grateful for the generous sharing of knowledge and enset expertise from James Borrell, Lucie Buchi, and their colleagues, who attended the international workshop and conference, Research on Enset and Its Agri-System, hosted by Wolkite University with the Ethiopian Biodiversity Institute, Addis Ababa University, Hawassa University, Leicester University, and Kew Royal Botanical Gardens.

Chapter 5 makes use of the Ethiopian Rural Household Surveys (1989-2009). The following standard acknowledgment is requested (Dercon & Hoddinott, 2004). These data have been made available by the Economics Department, Addis Ababa University; the Centre for the Study of African Economies; University of Oxford; and the International Food Policy Research Institute. Funding for data collection was provided by the Economic and Social Research Council (ESRC), the Swedish International Development Agency (SIDA), and the United States Agency for International Development (USAID); the preparation of the public release version of these data was supported, in part, by the World Bank. AAU, CSAE, IFPRI, ESRC, SIDA, USAID, and the World Bank are not responsible for any errors in these data or for their use or interpretation.

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List of Abbreviations

CA	Conservation Agriculture
CPD	capacity pathway diagram
CRGE	Climate Resilient and Green Economy
CQuint	consumption quintiles
ERSS	Ethiopian Rural Socio-Economic Survey
ESS	Ethiopian Socio-Economic Survey
FAO	United Nations Food and Agricultural Organization
FDO	functional dependency overview
FFarea	Area of Farm Forest
FIES	Food Insecurity Experience Scale
GPS	Global Positioning System
GTSLs	generalized two-step least squares
HDDS	Household Dietary Diversity Score
INUS	Insufficient but Necessary, Unnecessary but Sufficient
LSMS-ISA	Living Standards Measurement Survey – Integrated Survey on Agriculture
MINS	Months of Food Insecurity
SNNPR	Southern Nations Nationalities and Peoples
TLU	Tropical Livestock Units
TonF	trees on farms
USAID	United States Agency of International Development

Chapter 1: Introduction

In none of its forms does the theory of value take adequate account of the “value” contained in the natural source of all energy in the ecosystem, the sun’s energy and of the stored products of that energy. (Blaikie & Brookfield, 1987, p. 5)

Nearly 1 trillion trees globally are out of forests, or, to be more precise, an estimated 895,500,000,000 trees are estimated to grow in nonforest biomesⁱ (Crowther et al., 2015). Human development and agriculture have brought trees into deserts, grasslands, savannas, and other ecoregions. Trees grow along roads and rivers, around our homes and schools, in parks, on farms, and inside plantations at nearly every latitude, altitude, and environmental condition around the world. Autochthonous and introduced, these trees and treelike perennials have come to be where they are because they have coevolved or become assimilated by serving important functions in socio-techno-natural systems that can take the form of a farm, park, or other place where humans, nonhuman animals, plants, and nonliving elements relate. As humans have manipulated ecosystems and domesticated nature by making trade-offs for different desirable services (Kareiva et al., 2007), incorporating benefits of trees and treelike perennials appears to be synonymous with human settlement outside forests. If stacked at Crowther’s minimum diameter of only 10 centimeters, with a standard forest tree height of 5 meters, these alternative biome tree trunks stacked together would create a wall more than a kilometer wide that

would reach all the way up to the moon or circle the world at the equator as a fence more than 2,235 times. Trees existing in or encroaching on nonforest biomes is perhaps the most obvious sign of anthropogenic environmental modification across the surface of the Earth, so large that it is easily identifiable from space and is also, perhaps, one of the least studied socio-techno-natural phenomena.

In their work outlining the importance of natural assets and, specifically, tree-related stores of biomass to rural livelihoods, Chambers and Leach (1989) noted academic disciplines and associated professions have not been “organized to notice trees in villages or on farmland; agricultural scientists have been concerned with crops, veterinarians and animal husbandry specialists with domestic animals, and foresters with trees in forests and plantations, rather than on private land” (p. 331). Considering that recently updated estimates from satellite earth observation reported more than 43% of agricultural land globally has more than 10% tree cover, this disciplinary blind spot between agriculture and forestry has real-world policy implications, not only for understanding the important role of tall long-lived perennial plants, trees, and treelike stores of living biomass, as a foundational asset to resilient livelihood well-being outcomes like food security, but also for “sustainability” more broadly, such as undercounting the biomass of these trees in accounting for carbon sequestration globally (Zomer et al., 2009, 2014, 2016).

New research in this area is developing quickly and a stupefying number of trees out of forests in the Sahel and Sahara of West Africa was unforeseen and has raised calls for intensification of quantitative monitoring of out-of-forest trees for better characterization of both environmental and human well-being (M. Brandt et al.,

2020). The relatively recent research interest in on-farm and out-of-forest trees has led to some definitional issues related to disciplinary differences. The inclusion of treelike perennials, such as banana, or the banana relative, *Ensete ventricosum* (Welw.) Cheesman, investigated in Chapters 4 and 5 of this dissertation, in the class of trees on farms (TonF), is a grey area also faced by Miller et al. (2020), who argued bananas should be considered a TonF in their study in Uganda, because they serve the same function as other fruit trees. There is great inconsistency for nonwoody but tall plants that would not be classified as trees from a botanical definition, such as palms or bamboo that have functional characteristics, including fiber production, and that are typically included as TonF in official surveys, while bananas that produce food often are not. From a technological and observation perspective, automated classification using coarse resolution satellite remote sensing tends to overestimate tree cover in forested areas and underestimate tree cover in mosaic landscape (Mayaux & Lambin, 1995). Even with higher resolution satellite imagery, tall plants that are not botanically defined as trees and often grown on plantations, such as palms, bamboo, or bananas, are regularly included in estimates of tree cover or classified as secondary forests (Hansen & Loveland, 2012; Hansen et al., 2013; Potapov et al., 2012; Tropek et al., 2014). Distinctions between managed and natural forests, even with higher resolution satellite imagery, often require analyst visual inspection and judgment (Goetz et al., 2015).

In guidance for improved measurement of TonF from The World Bank, Miller et al. (2019) advised the function in context, from a socioeconomic point of view, should be the determining factor for inclusion of these large living stores of biomass

value in surveys and insisted more attention should be paid to a variety of overlooked and often tall perennial plants that contribute in significant ways to rural livelihoods, in spite of disciplinary specific definitional limitations. This is reflected in the use of the term *autochthonous* to indicate plants—such as enset, featured in Chapters 4 and 5 of this dissertation—have coevolved in located systems often through prolonged interaction with humans that may be at the boundary rather than center of agroecological zones or categorically defined land cover types but are to be distinguished from the concept of “natural forests” or “indigenous plants” as used in conservation frameworks.

As part of the United Nations Framework Convention on Climate Change (UNFCCC), that can make resources available to developing countries for reducing atmospheric carbon and conserving forests, the Reducing Emissions from Deforestation and Forest Degradation and the Role of conservation, Sustainable Management of Forests and Enhancement of Forest Carbon Stocks in Developing Countries (REDD+) program makes a distinction between “plantation”-managed treed areas and natural forests in establishing references for forest monitoring but leaves the specific distinction of natural forest up to the national authorities (Committee of Parties of United Nations Framework Convention on Climate Change REDD+ 2014). TonF do not fit neatly into these categories either, because TonF are often not intended or managed as tree crop in the sense or at the scale of a plantation nor are they typically managed as a common property forest. The REDD+ policy statement on “safeguards” narrows consideration of rural livelihoods in conservation activities to focus on indigenous plants of these common property forests by taking

into account “the need for sustainable livelihoods of indigenous peoples and local communities and their interdependence on forests in most countries, reflected in the United Nations Declaration on the Rights of Indigenous Peoples, as well as the International Mother Earth Day” (United Nations Framework Convention on Climate Change Secretariat, 2016, p. 12).

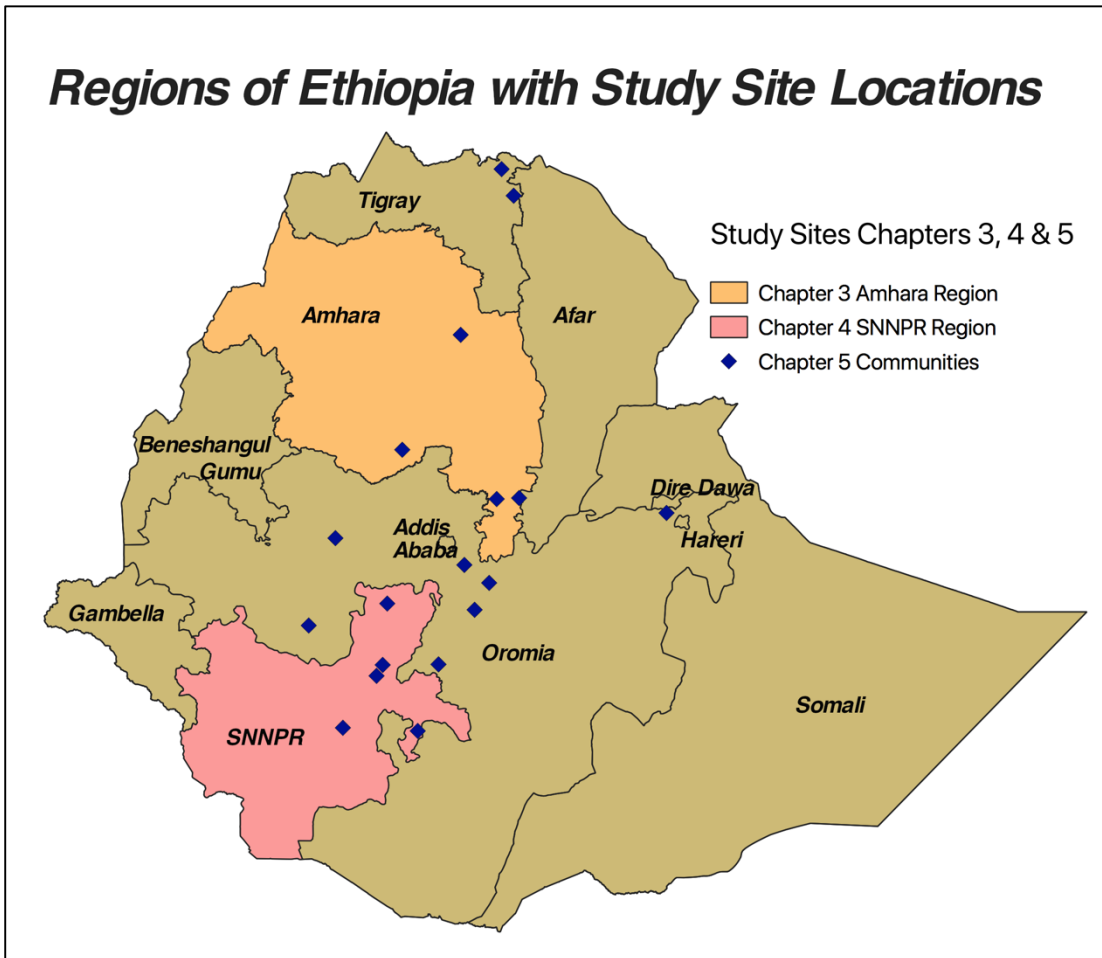
Diverse geography, a long history of cultivation, and location at the boundary of distinct cultural regions adds complication to neatly classifying which areas and which plants designate forests and plantations from agricultural landuse. For example, Ethiopia makes a contextual distinction that bamboo, not botanically a tree but an herbaceous tall perennial, does count for two designated types of natural forest, for REDD+ planning purposes, to be sustainably managed not only as support to local community livelihoods but also as an “industry” (Boissière et al., 2019). Furthermore, a Food and Agriculture Organization of the United Nations (FAO, 2018) publication describing Ethiopia’s REDD+ forest monitoring system features the picture of a woman transporting branches and leaves collected presumably in the large eucalyptus tree-stand surrounding her that is likely a private or community woodlot rather than a forest. Eucalyptus, introduced to Ethiopia in the 1890s, features prominently in private household woodlots and has been a controversial tree regularly banned by local and regional authorities (Mekonnen et al., 2007). Eucalyptus, featured in Chapters 3 and 5 of this dissertation (see Figure 1.1), is also included in the top 30 forest tree species in the Ethiopian forest monitoring reports, although it is noted along with cypress trees as introduced (United Nations Food and Agricultural Organization, 2020b). Adding further to forest and tree-related classification nuances,

smallholder eucalyptus woodlots below the Ethiopian forest definition of 0.5 hectares of continuous tree cover are nonetheless included as plantation forests and large areas where enset farms are located, often with a variety of other indigenous or introduced trees clearly designated as natural forest on the REDD+ 2018-2030 national map (Ministry of Environment Ethiopia, 2018). These tree-covered areas identified as forests, particularly in the SNNPR region of Ethiopia, are intensively farmed with some of the highest rural population densities in Africa (S. A. Brandt et al., 1997).

In this dissertation, the focus is narrowed to privately managed treed areas that include eucalyptus and enset rather than common areas or designated protected forests where these species also are located. Although wild enset grows across not only Ethiopia but also a large part of Africa, it is only cultivated for domestic use in Ethiopia (Borrell et al., 2019). Context and function do seem to guide the labelling of areas with different plant cover, such as that seen in Ethiopia with bamboo forests without trees, plantation forests that are actually smallholder woodlots, and still other forests full of farms that center around the tall perennial enset that is also not a tree as defined botanically. The dissertation, in this way, focuses on function in context and investigates species at the historical bookends of trees and treelike perennials featured prominently in Ethiopian farming systems, from the autochthonous enset cultivated over millenia, to the relatively recently introduced eucalyptus. In doing so, this dissertation seeks to demonstrate enset and eucalyptus' shared strategic use as stores of value serving a resilience function, perhaps similar to the functional role of TonF in other farm systems, despite their different classifications or history in Ethiopia.

Figure 1.1

Study Site Locations for Chapters 3, 4, and 5



Explored in this introduction and throughout the dissertation, the historically located and contested spaces for trees and crops frames the arguments, modelling, and measurement approaches intended to contribute original findings to this understudied middle ground of TonF. Germane to understanding how TonF research became neglected, concepts arising in the late 19th century still resonate in discourse and research programs. Such programs became popular at the time when higher education programs in forestry and agriculture were first being established with increasing prominence from the founding of land-grant universities and research-focused

institutions, such as Johns Hopkins University, that elevated and disseminated research models of primarily deductive, reductionist, and experimental methods in the United States.

Framing the approaches and tools in their historical and geographic context allows for use of a broad set of powerful analytical tools and approaches while examining and updating assumptions that might be more appropriate in one place and less so in an alternative cultural, social, and ecological situation. Depending on geography for example, different types of trees may grow at different rates and be maintained for different reasons in different places, and this may vary over scales from one household, community, country, or region from another. The underlying logic of one food or farm system cannot be assumed to function in exactly the same way as any other, although some functional dependancies or capacities may rematerialize across contexts. There remains a great deal of diversity in these mechanisms out in the world yet to be investigated, but it is essential to develop an understanding of how different disciplines and their history can promote this exploration or otherwise have the potential to propagate disciplinary blind spots.

Believing forests originally covered the Earth, the 19th-century geographer George Perkins Marsh (1864/2013), reasoned the nonforest landscapes he observed were the result of tree cutting to make way for farms and pastures, because forests do not produce food. Marsh (1874) argued deforestation led to land degradation that, in turn, was the cause for the arid wastelands he saw during travels in the Eastern Mediterranean, and, by extension, any remaining trees are simply remnants of the once great forests (Marsh, 1874). Latter-day geographers influenced by Marsh

updated his thesis, focusing on the more recent past in *The Earth as Transformed by Human Action: Global and Regional Changes in the Biosphere Over the Past 300 Years*.

B. L. Turner (1990) and other authors, including prominent members of the Academy of Sciences, substantiated and expanded on Marsh's presupposition that human action can transform local environmental and climate conditions in present-day socioecological systems and human-nature coupled systems research that are foundational to current research and policy-relevant debates on the nature and direction of the Anthropocene.

Despite protestations and caveats in the forward of Turner's book, the basic question of whether a growing human population can be supported by what Rockström et al. (2009) characterized as the Earth's "ecological life support systems" (p. 473) is the underlying theme for the variety of sectoral perspectives presented in the edited volume and ultimately boils down to the question of whether Boserup's (1965/2017) induced intensification will provide for dignified global food security, or does the world become locked in a pathway to inevitable Malthusian disaster (Malthus, 1798). This question has been central to much of Turner's foundational work on resilience and the broader sustainable intensification debate (Turner & Ali, 1996).

Yet, the foundational Marshian misunderstanding quietly promulgates a persistent unexamined assumption in socioecological systems research, seemingly without historical evidence before the relatively recent past. Rather than global forests, ice sheets and deserts dominated the Earth's surface at the end of the Last

Glacial Maxim (LGM), preceding the establishment of agriculture, and there were dramatically smaller areas of today's most common tropical and boreal forests (Shao et al., 2018). Fossil and lake pollen records from Ethiopia, notable for its landscape reflecting dramatically variable biomes at different altitudes, indicate climate was a major driver in slowly bringing shrubs and trees to post-LGM grasslands during wetter and warmer periods in the Bale mountain central highlands, with juniper-podocarpus forests only taking root after BP 4500 (Umer et al., 2007).

Furthermore, biomes defined by their natural lack of trees (e.g., grassland and desert) were in fact most common at the beginning of the Holocene in the subtropical and tropical highland regions where eight origin sites for agriculture are located (Vavilov, 2009). Diffusion models of agriculture, spreading at fairly slow rates out from arid semitropical centers of origin, have been confirmed by radiocarbon dating, for example, in the case of the sheep and barley being introduced into Europe from the Fertile Crescent over a period of approximately 5,000 years (Ammerman & Cavalli-Sforza, 1971).

As a paradigm of biogeography that resonates with Darwin's earliest observations, center-periphery theory holds that less diversity and less abundance is observed further away from the point of origin for plant or animal species, but this maxim has been qualified by research over the years that points to coevolution, symbiosis, and other factors as contributing to determining limits of ecosystems and the distribution of species within them (Pironon et al., 2017). The center-periphery theory and Vavilov's (2009) approach to identifying agricultural origin sites are consistently reflected in the remarkable diversity at genetic, farm, and farm system

levels found in Ethiopia and is exemplified in Chapter 4 of this dissertation focused on the intrinsically interesting and understudied enset growing area. Trees and treelike perennials that are both autochthonous or more recently introduced are the current hallmarks of these Ethiopian food systems, located at the center of origin of many globally important crops, in locations that did not have them at the beginning of this geological era.

A diminished version of Marsh's (1874) intuition of agriculture-related deforestation may have been detected thousands of years after agriculture began, after more than half of the Holocene had passed, in a relatively small corner of north western Europe, as corroborated in pollen records reflecting a measurable decline in mixed deciduous forests starting about 4000 BP and then slowly progressing to the mixed agriculture mosaic found across the European continent today (Fyfe et al., 2015; Roberts et al., 2018). Radiocarbon dating of Neolithic site establishment, with cultivation of cereals or domestication of sheep, does confirm the diffusion of agriculture from the semiarid tropics into that part of Europe between 4000 and 5000 BP (Ammerman & Cavalli-Sforza, 1971).

The suspected European deforestation episode is earlier than potential anthropic deforestation between 2000 to 3000 BP in Central Africa (Malhi, 2018), or famously contested societal collapse in the Central America around 1000 to 1200 BP that is chronologically much later than peak deforestation in pollen records from the area also occurring there between 2000 to 3000 BP (McNeil et al., 2010). In northern Ethiopia, pollen records indicate the earliest evidence of fire-related reduction of the shrub-like *podocarpus* beginning at 2500 BP (Darbyshire et al., 2003) and in southern

Ethiopia at 1850 BP. There are also concurrent reductions of *podocarpus* with the first signals of selective felling or anthropic afforestation leading to increases in a potentially preferred species *juniperos procera* (Bonnefille & Hamilton, 1986).

If Umer et al.'s (2007) estimate of expansion of Afromountaine forest for the southern Ethiopian highlands of BP 4500 is accurate, then forests arrived chronologically later than autochthonous agricultural systems and subsequently have been undergoing pollen-measurable deforestation and reforestation for approximately half of the time these forests have existed. Although there is greater evidence of total ecosystem disruption by domesticated animals overrunning the fauna on island colonies during Roman expansion across the Mediterranean (Zeder, 2008), available writings from Greece and Rome, at 2000 to 3000 BP, indicate forests as common resources were carefully governed to ensure sustainability of cities, although forests were regularly burned down as part of military stratagems (Hughes & Thirgood, 1982).

As additional information is made available through new dating technologies that can more precisely quantify the presence of different forest and farm plants, a complicated cycle of increases and decreases of tree cover, related to both changes in climate and human manipulation of ecosystems, will continue to emerge with potential additional examples, such as Ethiopia, that indicate concurrent forest and agriculture expansion. Although local evidence of deforestation coinciding with the introduction of new agriculture approaches or technology, typically through foreign invasion by a different cultural group, begins to be documented around the world in the last few millennia, agriculture as a social phenomenon grew along with trees and

treelike perennials out into nonforested post-LGM lands for a much longer time period and over much larger areas.

Evidence of nonmilitary mass deforestation as part of grand scale land degradation is more clearly associated with 19th-century and now globalized expansion of the European plantation farming models propagated by commoditization of food, fiber, drug, and more recent international biofuel trade (Crosby, 2004). Agricultural expansion into forests seen in the recent past is driven by commodity prices and weak institutions (Lambin et al., 2001). Although agricultural expansion is the primary threat to tropical forests resulting in awful consequences to biodiversity loss (Lambin & Meyfroidt, 2011), current monoculture-dominated globalized food systems are the overall leading cause of worldwide negative impacts on climate and human health (Willett et al., 2019). The trend toward ecosystem oversimplification of monoculture farming, accompanied by an increasing complexity of the global supply chain, are two sides of the same industrialized coin that may be a global existential threat over time but certainly is particularly destructive to vulnerable people and the marginalized places where they live now.

Sustainable intensification of farming both spares land (Lamb et al., 2016) and is central to strategies such as the UN's Sustainable Development Goal 2 of Zero Hunger with related targets for improved food security and nutrition (Pretty et al., 2018). Induced intensification of Boserup (1965/2017) would predict current challenges will be met by reaching back into traditional systems to innovate, as has happened over millennia when population pressure increased. This provides hope for a potentially necessary transformation away from zero-sum antipodean and artificial

delineation of treeless agriculture from wooded lands and forests. The troubling trends now seen (Gibbs et al., 2010) realistically represent, at most, 500 years or less than 5% of the history of agriculture.

The antisymbiotic false dichotomies of agriculture vs. forests and society vs. nature, represented by Marsh (1864/2013) and the institutional disciplinary divisions of the time, is a product of the same theoretical and ontological foundations that produced the logic of plantations and concentration of capital that led Haraway (2016) to question the appropriateness of the term Anthropocene. Use of the term Anthropocene would indicate the changes observed on the planet are due to humans but Haraway contends that the terms Plantationocene and Capitalocene are more accurate descriptions of the industrial and commodifying forces driving potentially apocalyptic changes in the systems that sustain humans and the planet.

Misreading the African landscape broadly by outside experts as undergoing degradation and deforestation, due primarily to population pressure, too often has been used as evidence for policy and programs to alienate farmers and communities from managing their own land in ways that optimize their livelihood outcomes of food security and well-being (Fairhead & Leach, 1996). In the 19th century, colonial administrative contemporaries of Marsh mistook the trees growing around villages across savanna and semiarid grasslands as evidence of ancient great forests, stretching across never-forested biomes where none has existed for at least a geological epoch.

Fairhead and Leach (1996) contended this misconception about the extent and causes of deforestation was then used as a pretext for imposing European-style farm systems, regulation of common areas, and criminalization of previously important

livelihood activities. Assumptions, stemming from historical and environmental misconceptions, about rural people across tropical areas of Africa and the Americas abusing the environment began a pattern of policy and research that now continues in much of the developing world with research that insufficiently interrogates these assumptions or considers alternative understanding of place history and localized livelihood systems.

Blake and Brookfield's (1987) final analysis on the primary cause of land degradation, particularly in the rich diversity of locally adapted food systems of Africa, was this imposition of external regulatory structures destroying local institutions and food systems along with the diversion of production from food security to commodities. Exaggerated concerns about eucalyptus trees on farms, featured prominently in Chapters 3 and 5, are an example demonstrating how local knowledge typically is more contextually relevant than contested external research claims untried in local contexts, as Jagger and Pender (2003) found the allopathic traits of the trees had in fact little impact on crop yields as feared from controlled experiments, but rather produced a fine profit for households in real world conditions, particularly when grown on marginal land. Local rather than external control of land management decisions is increasingly recognized as supporting simultaneous increases in well-being and decreases in degradation.

Broadening empirical evidence, less encumbered by unexamined assumptions behind theories, research practices, and institutions rooted in outdated singular perspectives from temporally and geographically distant sources are likely to produce problem framing and policy solutions more relevant to African smallholder

livelihoods and have led to calls for agroforestry research to do more representative research in real-world community and food systems contexts on existing rather than model farms (Coe et al., 2014). Leach et al. (2010) advocated for the pathways approach to focusing the “dynamic sustainabilities” present in a specific geography reflecting the place and livelihoods of the people who live there.

Consideration of successful alternative livelihood pathways that value a broader range of well-being outcomes, in addition to income or production, and that are supported by indigenous or marginalized knowledge systems and institutions, may provide more immediate, context-sensitive, and less disruptive options to inform transformational programs and policy. Innovative and resilient pathways rooted in a diversity of traditions and a plurality of perspectives may not only be germane to reversing the troubling food security trends, but these time-tested systems also likely offer the most apposite, accessible, and sustainable solutions to food system transformation. Furthermore, Rockström et al. (2017) called for a shift of research and policy paradigms away from the focus on production and income to indicators of sustainability and resilience that will be required if we as humanity want to both sustain ourselves and the systems that sustain our planet.

Unique among theories of production, Boserup’s (1965/2017) comparative work on indigenous agricultural systems has a somewhat more limited focus but similar spirit to pathways approaches and is a formative methodological and theoretical foundation for current sustainable intensification research that often does not always draw the link to the theory of “induced intensification” except among the most thoughtful authors. Theories of value and production functions, when exposed

to rural geographies and livelihoods, suffer from the same major gap identified but never addressed by Blaikie and Brookfield (1987): “In none of its forms does the theory of value take adequate account of the ‘value’ contained in the natural source of all energy in the ecosystem, the sun’s energy and of the stored products of that energy” (p. 5).

The work in this dissertation makes the case that one indicator of a portion of this missing “value” can be measured by TonF and the biomass stores and management they represent. This living biomass store is an indicator of the natural value of land, the transformed and stored energy of the sun, that Blaikie and Brookfield (1987) considered inadequately captured as a no-cost contribution to the use value concept in development economics, economic geography, and other analyses focusing on production and income-focused research, while only hinted at in the labor-focused value constructs they highlight, such as Marx (1887/2013) who described how workers are helped by the transformative “natural forces” at work on the land. Like Bernoulli’s (1738/2005) take on Leibniz’s *vis viva*, stored potential “living force” animating systems, natural energy of the sun for a time captured in increasing TonF, can reflect the medium-term capacity for improved biomass management that promotes improved livelihood outcomes. Sustainable intensification may require this extra value from TonF, and TonF may at the same time be an indicator of induced intensification.

Some recent studies from Ethiopia that have found “more people, more trees” (Duriaux-Chavarría et al., 2020, p. 10) corroborate similar patterns investigated in this dissertation where trends towards smaller farms with higher population density

would in turn promote intensification strategies that in Ethiopia appear to include more TonF. Research considering TonF as an intensification strategy, an innovation on traditional knowledge, may contribute to understanding the faults of previous production models and the unfortunate policy implications separating research on forests from research on farms, ignoring how, together, humans and trees/treelike perennials function in both. The research pursued in this dissertation proposes that modelling pathways and measuring food security outcomes related to biomass exchange between TonF, other plant, human, and non-human animal elements of the farm system can contribute to better understanding how value inherent in regenerative systems is captured, stored and used to improve well-being of farm households.

More research on TonF, and more original research on small farms in general, are necessary to address global hunger through sustainable intensification that spares land from further extensive agriculture expansion (Chambers & Longhurst, 1986; “Ending Hunger,” 2020). Trees represent an alternative biomass-based strategy for savings and security, according to Chambers and Leach (1989), for poor households on small plots, and are an indispensable element underpinning rural livelihoods. Small farm-oriented food systems proven to support relatively high population densities exist.

There are more than 500 million small farms around the world (Lowder et al., 2019; Lowder et al., 2016). By sheer force of numbers, innovative solutions for sustainable intensification are likely to be found among these locally adapted food systems formed around small farms and may in practice prove synergistic by providing much needed and appropriate food system context to complement solutions

originating in a laboratory or on a research station. Once abundant in precolonial times across Africa, Ethiopia boasts a copious diversity of smallholder, locally adapted farming systems (Harlan, 1969).

As a source of novel research to support more secure and sustainable food system policy solutions and programmatic approaches, Leach et al. (2020) suggested investigation of diverse food socionatures where place-specific human and nonhuman relations coevolved to produce alternative and potentially more equal distributions of both desirable and undesirable well-being outcomes of farming. As Vavilov (2009) wrote in 1932 of the need to identify places that were the centers of origin for agriculture, “Many historical problems can be understood only because of the interaction between man, animals and plants” (p. xxi). It is in this spirit that the following chapters investigate how small farmers may have reasserted or maintained traditional functions of TonF to support livelihood outcomes of food security and well-being in different places across Ethiopia and to identify how they may differ from treeless farms.

More data-driven, tree-related journal articles are promoting dubious policies on contested models, such as massive campaigns of tree planting, in place of, rather than an appropriately small part of, a comprehensive climate change mitigation strategy that more carefully considers who and how people live in places on their map, indicating two thirds of the Earth’s surface as either currently forested or a candidate for afforestation (Bastin et al., 2019). Once again, millennia of tree agriculture coevolution are at risk of being disregarded and are a source of knowledge that is likely to be essential information to form reasonable policy. Care must be

taken that benefits from massive tree planting campaigns do not only concentrate benefits for the elites, as royal hunting forests of past. Leach et al. (2013) worried draconian regulation violating social justice may be imposed in defence of planetary boundaries to protect the environment.

Similar danger exists in narrowly focused policies intending to protect the trees from the poor, in common areas or on their farms, that insufficiently consider the essential role of trees to rural livelihoods and ultimately to achieving sustainability. As an alternative resilience-focused example of a more broadly pro-poor policy framing taken up in Chapter 3 of this dissertation, tree-based agriculture is much less sensitive to variable timing of rain compared to annual crops that may prove an important climate change resilience strategy. Farmer-led inclusion of TonF may produce social and environmental benefits likely outweigh other mitigation strategies such as monoculture tree plantation or hybrid cereal varieties, and the benefits are likely to be more equally distributed. Marsh (1864/2013) was wrong about trees being cut down because they do not produce food, and it is much more likely, considering global agricultural history, that we cannot produce enough food as a planet without them.

The original research in the following chapters of this dissertation using population representative longitudinal observations data is intended, in some small part, to add more empirical information to these important if not existential research questions about how trees and agriculture related in the past, present, and should relate in the future. Chapter 3, the first paper, addresses the persistence of seasonal hunger associated with biomass poverty on small farms that many farmers have decided to counter by strategies that include maintaining small private forests.

Chapter 4, the second paper, explores an unusual autochthonous food system based on the enset, a type of false banana, and how small farmers treat these treelike perennials as an asset to insure against worst-case scenarios. Chapter 5, the final paper, works with one of the only 20-year panels in the world that incorporates asset, socioeconomic, food security, well-being, and tree data. Trees are modelled as instrumental in building a resilient foundation of livelihood assets to promote food security and well-being.

Subnational areas of Ethiopia, most intensely farmed and at higher elevations, are investigated in the analytical Chapters 3, 4, and 5. Lowland areas tend to be arid pasture lands in the eastern parts of Ethiopia bordering Somalia, and forested areas in the western parts of Ethiopia bordering South Sudan are therefore not geographically included in this research. Chapter 3 makes use of a statistically representative panel, the Ethiopian Socio-Economic Survey (ESS), from the rural areas of the Amhara Region where cereals are cultivated in a farming system characterized by animal drawn plows (Central Statistics Agency of Ethiopia & The World Bank, 2017). Chapter 4 focuses on the enset growing farming system and makes use of panel data representative of the Southern Nations Nationalities and Peoples Region (SNNPR), also available from the ESS. Chapter 5 uses the Ethiopian Rural Household Surveys (ERHS) that are intended to be representative of the three primary farming systems of Ethiopia, “the grain-plough areas of the Northern and Central highlands, the enset-growing areas and the sorghum-hoe areas” (Dercon & Hoddinott, 2004, p. 2). The sampling of the ERHS covers a relatively smaller number of only 14 locations but interviews many more households at each location and for nine survey rounds over a

20-year period. More details about the study sites and data are given in each chapter.

To have the most parsimonious models and clearest results, this dissertation narrowed its geographic and farming system focus. Future research could extend into other important regions such as Tigray Region and Oromia Region, or a more comprehensive model including multiple farming systems featuring trees and treelike perennials potentially could be constructed.

Chapter 2: Background

Of particular relevance [to the evolving definition of resilience] is that the ecology literature focused on the natural environment; the psychology literature focused on the people; the engineering literature focused on human constructions; and the geographic literature integrated the natural environment, built environment, and society. (Weichselgartner & Kelman, 2015, p. 251)

Because each chapter is constructed as a working paper submitted for publication on its own, more specific background sections appear in each subsequent chapter (Chapters 3, 4, and 5). This background overview briefly presents the knowledge gaps that are contextual, theoretical, conceptual, or practical—cutting across and motivating the research in each of the three papers. The three background subsections are tied together by the theme of TonF and their connection to resilience and sustainability in Ethiopia. The subsection briefly identifies the key strands of literature relevant to the thesis, measures, and methods of the investigations. These present existing gaps are often well known to a variety of review and perspective articles but rarely benefit from original research using spatially and temporally explicit observation to support more sophisticated modeling.

The overall takeaway from a literature review is there exists a clear disconnect between what engaged sustainability and resilience scholars know needs to be investigated at multiple scales with multiple feedbacks and the typical reductionist

research tools available for analysis of often insufficiently comprehensive field-based observations lacking necessary temporal and spatial resolution. Firstly, dependent outcome indicators for analytical models must shift from a sole focus on production and income to more inclusive well-being measures such as food security to provide the necessary evidence base for Rockström et al.'s (2017) paradigm shift from a narrow focus on agricultural yields to more inclusive goals of resilience and sustainability. Secondly, alternative critical framings of problems and innovative multiclausal modeling and measuring techniques, such as Leach et al.'s (2010) pathways approach and Cartwright's (1989) multicausal "capacity bootstrapping," could become more widely accepted and applied to make progress on these global sustainability and resilience challenges.

2.1 Resilience implications of a recent rapid re-afforestation of the Abyssinian center of origin for agriculture

Any rural land user shall be obliged to plant tree species that can't cause any damage on agricultural land and production and those having economical and environmental advantages.

Proclamation to amend the Proclamation No. 56/2002, 70/2003, 103/2005 of Oromia Rural Land Use and Administration Proclamation (No. 130 /2007)

Trees on farms have never been quantified for Ethiopia in terms of extent or value (United Nations Food and Agricultural Organization, 2002), but Teketay et al.

(2010) reported the rural highlands were increasingly covered with farm forestry in the years around the turn of the 21st century. Even in the 1980s, Poschen (1986) found farmers had well-developed preferences for different trees in different sampled water catchments that each had site specific pollarding regimes to protect crops with desired density between 1 to 20 trees per field. Planted forest area, defined as continuous tree cover of more than 0.5 hectares without agricultural or other use, quadrupled in Ethiopia between 1990 and 2020, while naturally regenerating forests area reduced by approximately 15% (United Nations Food and Agricultural Organization, 2020b). It is unclear how much of Ethiopia was ever covered with forests. It was estimated less than 3% of Ethiopia was covered in forest in the early 1990s, and most were concentrated in the southwest of the country (Kebede, 2002).

The trend toward increasing the number of managed trees on private land and public common area landscapes continues a historically heavy interaction, including waves of afforestation and deforestation over millennia and of population fuel and timber demand on trees across different land uses and landcovers in Ethiopia. In this most recent cycle of afforestation over the last 30 years, recent research reports a highly localized selection of a huge variety of indigenous and introduced nonnative species by rural households and communities. Iiyama et al. (2017) concluded hyperlocalization and diversity are the elements of tree-related livelihood success to be supported by extension over more generic agroforestry models.

Ethiopia in some ways provides an ideal research site for understanding the role of trees in agriculture. Due to its political history, rural Ethiopia is an unusually egalitarian space and one in which the constitution forbids private ownership or sale

of land. Following a national decree in 1974, land is equally divided to all over 18 years of age who wish to farm and is allocated largely based on family size.

Subsequent policy reform has increasingly placed communal resources such as forested areas or plantations under local control (Crewet, 2006; Gebreselassie, 2008).

Unfortunately for trees in common areas of Ethiopia and the communities that depended on them, the implementation of policies, particularly simple ones, often produce behaviors that are directly counter to the intended and desirable outcomes. As Cartwright (1989) rightly observed in their work on improving the science of measuring natural capacities, “Simplicity is an artifact of too narrow a focus” (p. 73). Ethiopia’s revolutionary Derg regime’s 1975 *Proclamation to Provide for the Public Ownership of Rural Lands* placed all community wood lots and forests under local public control “to conserve any public property in the area especially soil, water and forests” (FAOLEX, 2016, p. x) and nationalized tree crops as part of the larger effort to reduce inequality and promote economic development. With uncertain land tenure and heavy restrictions on any tree harvesting, there was no incentive on the part of the public to plant or care for trees (Kassa et al., 2011).

Although the causes were complex, massive droughts in 1984 and 1989 resulted in widespread famine conditions that underscored the lack of resilience of annual crop and livestock–dependent livelihoods. The government later partnered with international organizations on massive reforestation campaigns, but, subsequently, the majority of these common woodlots and forests were completely cut down during the political transition of 1990-1991. The end result of the series of unfortunate events following a well-intentioned, but poorly considered, policy was

that very few trees were planted on farms or survived in common areas in an environment that was already terribly lacking in standing stores of biomass.

When the prohibition on tree cutting was rescinded in 1991, there was a boom in on-farm tree planting to meet fuel wood and construction demands (Ethiopian Ministry of Water and Energy, 2013; Kebede, 2002). In 2010, the government of Ethiopia estimated more than 90% of the country's rural energy needs were met with biomass. Making biomass a more efficient source of energy is a central policy objective in Ethiopia's long-term "green" sustainable development strategy that intends to raise GDP while limiting carbon emissions (Government of Ethiopia, 2011). Eucalyptus trees are the largest source of fuel and construction materials in rural Ethiopia (Turnbull & Booth, 2002). In recent years, farmers in Ethiopia without access to common area wood lots have begun increasingly to grow eucalyptus trees on their own plots to use branches and leaves as cooking fuel. They harvest trees for construction poles and posts or as a form of insurance when annual crops fail. According to Turnbull and Booth (2002), "Many people in Ethiopia are absolutely dependent on eucalyptus as a source of fuel and house building material" (p. 55).

What was witnessed in the last 30 years was not the first wave of afforestation. There is an early account from the 16th century of "reforesting mountain-sides with *tidh* trees (*Juniperus procera*)" at the emperor's order (Pankhurst, 1995). The recent afforestation is not the first wave of afforestation that included eucalyptus trees. Three hundred years after the juniper planting, another emperor was searching for a solution to a fuel wood shortage that threatened the sustainability of the capital at Addis Abba; Emperor Menelik II imported a variety of eucalyptus

seedlings to be tested in a trial plantation in 1894-95 (Horvath, 1968; Pukkala & Pohjonen, 1990; Von Breitenbach, 1961). Several seedlings thrived in the environmental conditions and local landowners quickly recognized the value of the trees' capacity for rapid growth and resistance to disease (Pukkala & Pohjonen, 1990).

Although policy has varied over the years and from place-to-place, rapid adoption of eucalyptus was supported by tax incentives from the start, with reduced taxes for land with trees and public support for distribution of seedlings beginning at the turn of the 20th century. These incentives mostly favored the elites, and the peasant class and later poor farmers had to receive permission to access forest resources or harvest out-of-forest trees or face punitive fines or punishment (Kebede, 2002). Before the revolution, protected forests and plantations were symbols of the aristocrats in the feudal system and either became targets for redistribution or were cut down during political instability during transitions of the revolutionary DERG regime.

International development actors have also favored large-scale tree plant schemes that have had varied success and raised the same issues of exploitation during times of instability. Regional or local policy, often citing academic studies or experiments, in some cases continued in this populist line of targeting plantations, particularly eucalyptus, on grounds of competing with the more urgent food security needs of the population.

Authors like Mekonnen (2010) and Ango et al. (2014) have reviewed the mixed results of eucalyptus ecological “services and disservices” and their impact on

food security and livelihood activities. Literature is available on the negative effects of eucalyptus and mostly comes from more controlled experiments limiting real world moderating effects (El-Khawas & Sheheta, 2005; Verma, 1990). Literature on the livelihood and economic benefits are more common for study sites on real world farms in communities with demand for eucalyptus products (e.g., Eshetu et al., 2018; Mekonnen et al., 2007; Turnbull & Booth, 2002). There are mixed results of the outcomes of eucalyptus' direct impact on food crops through changes in soil quality, and, overall, authors find it is similar to other trees in real world conditions (Bai, 1996; Baumer, 1990; Zerfu, 2002). Great uncertainty exists because traditional reductionist science and agricultural experiments often provide seemingly contradictory results. For example, eucalyptus seems to be deadly to nearby corn crops but has little or no effect on millet and sorghum (Baumer, 1990; Chanie et al., 2013). Interpretation of these divergent results over the years has led to inconsistent policy across Ethiopia and between administrative areas.

More than 30 locally named and more common international varieties of trees were recorded in the ERHS survey that produced the data set used in this dissertation's Chapter 5 analysis. Wanza (*Cordia Africana*) is preferred among maize-growing farmers and has been shown to improve soil traits (Yadessa et al., 2001) and helpful in treating diarrhea (Asrie et al., 2016). Gesho (*Rhamnus prinoids*) is common and particularly known to contribute a hops-like flavoring to a national fermented beverage similar to beer called *tella* that can be an important source of income in rural areas, particularly for women (Lee et al., 2015). Birbira (*Milletia ferruginea*) has a variety of uses, most notably as a poison used to intoxicate and then

catch fish. Woriya are also found on farms in Ethiopia; these wild olive trees were likely first used for their excellent fuel characteristics before being domesticated for oil production in the Medeteranean area around 6500 BP (Galili et al., 1997; Kostelenos & Kiritsakis, 2017).

The “red list” for Ethiopia includes more than 400 endemic trees and shrubs (Vivero et al., 2005). Unfortunately, the Ethiopia Socio-Economic Survey (ESS) data set used for analysis in Chapters 3 and 4 of this dissertation has a much smaller list of surveyed trees and perennial plants—generally limited to international varieties and commodity crops like coffee (Carletto et al., 2015). Other trees are not generally identified, but, if they are grown together in a plot, they are categorized as “forest” and assumed to be often dominated by eucalyptus. Thankfully, Miller et al. (2019) have recently released improved guidelines to better include trees and perennial plant on farms in agricultural and other surveys. Similar integrated surveys on agriculture, jointly supported in a limited number of countries by the World Bank and Bill and Melinda Gates Foundation, have produced and made available representative panel data sets including agricultural production, rural livelihoods assets, several species of TonF, and socioeconomic well-being outcomes.

The Abyssinia center of origin for agriculture, identified by Vavilov (2009) in 1927 in Ethiopia and surrounding areas, is also an ideal study site to observe if the central tenet of Boserup’s (1965/2017) induced intensification concerning the central role of indigenous innovation could be observed in the 21st century at an unprecedented scale. Vavilov (2009) said of Abyssinia:

An exceptional diversity of a number of cultivated plants is concentrated in that area . . . also typical number of endemic forms of plants not known anywhere else in the world . . . unquestionable presence there of an autonomous main centre of cultivated plants. (p. 154)

The rapid re-afforestation of Ethiopia aligns with Boserup's (1965/2017) predictions that a deep well of cultural knowledge exists that can be tapped into with excess labor to meet demands as population density increases. Unfortunately, neither Vavilov nor Boserup considered trees as part of the productive system. Vavilov separated out classes of grains, oils, spices, stimulants, vegetables, and plants for various purposes that sometimes included woody perennials. Boserup discussed tree clearing only in passing as part of certain tropical and temperate farming practices.

Clearly, as seen in Chapter 4 of this dissertation, treelike perennials such as enset can even be the central staple of autochthonous regional food systems. The myriad trees reported on farms with a wide variety of uses and the hyper-localization of farmer selected combination of trees identified by Iiyama et al. (2017) suggest trees are central and not peripheral to traditional, indigenous, autochthonous systems of knowledge that can be called upon to innovate in the face of new challenges. This dissertation aspires to contribute new analysis about how trees related to agriculture during the observed period of afforestation had any affect on farmer livelihood outcomes such as food security and well-being.

2.2 Indicators and information on well-being, food security, and trees on farms for developing systems of evidence for resilience and sustainability in Ethiopia

The improvement of data at the policy and planning levels needs to be matched by the information that improves the role of trees and tree products in the household economy at the local level.

J. E. Michael Arnold (Arnold & Dewees, 2014, p. 286)

A systematic review of articles from 1950 to 2015 identified only 74 papers that have examined the relationships among trees, livelihoods, and food production and only nine studies that have investigated longer term data sets covering more than 7 years (Reed et al., 2017). Furthermore, the authors focusing on production and income did not investigate the effects of trees on desirable livelihood and food security outcomes more broadly. As a result, the policy relevance for identifying alternative pathways that could promote the use of trees in sustainable development policies and programs with higher-level human development outcomes is limited. Modeling and investigating relationships among trees or permanent crops with other critical indicators of medium and longer term asset development indicated by a variety of asset indexes, livestock holdings, or inexplicably overlooked stores of values (such as dwelling value), have rarely been investigated beyond case descriptions. Parenthetically demonstrating the lack of attention to medium and longer term indicators, the research presented in Chapter 5 is the only peer-reviewed and published study ever to investigate the value of rural dwellings—the most valuable household asset in the survey—and the dwelling value dynamics over a period of decades in rural Africa.

More generally, environmental assets represented most visibly by trees, but also foundational system elements such as soil, have not been included in typical demographic, health, and poverty surveys, neglecting a very significant source of income, assets, and resilience for poor farmers (Bakkegaard et al., 2016; Jagger & Rana, 2017; Rasmussen et al., 2017; Sorrenti, 2017). Sustainable intensification and development policy requires that context-specific, human-environment conditions directly related to biophysical drivers of environmental change, including deforestation, should be studied in tandem with impact pathways for socioeconomic outcomes (Jagger & Rana, 2017; Lambin et al., 2001; Rockström et al., 2017). For example, in Africa, climate-smart sustainable development and resilience strategies must consider agriculture as the leading driver of deforestation and the pressures of fuelwood demand as the second leading cause of deforestation (Geist & Lambin 2002; Lambin & Meyfroidt, 2011). Unfortunately, few research data sets have included both trees and socioeconomic measurements to provide a broad, coherent, and inclusive evidence base at adequate scales for trade-off and policy discussions. This may thankfully change with recent efforts from the World Bank and others to issue guidance for more environmental asset and tree-inclusive surveys (Miller et al., 2019).

More than 40 journal articles, 10 book chapters, and numerous working papers and conference presentations have analyzed the ERHS panel data. Stefan Dercon, an author of at least half of these documents, has written papers investigating the effect of shocks, seasonality, and infrastructure on consumption, livelihoods, and vulnerability—among other themes (e.g., Dercon et al., 2009; Dercon &

Christiaensen, 2011; Dercon et al., 2005; Dercon & Krishnan, 2000). Other authors have written about the relationships among gender, education, assets, access to credit and food aid, and other poverty-related variables (Carroll, 2006; Demeke & Rashin, 2012; Sepahvand, 2009; Weir & Knight, 2007). The vast majority of these papers relied on econometric measures and only focused on consumption as the poverty indicator.

There is a demand for quantitative, empirical, sustainable, development pathway research, with policy-relevant and underinvestigated measures related to human-centered and social resilience such as food security, in anthroposized agricultural contexts over the longer term—thus the need to measure not only the resilience capacities of intact forest but also farms with trees. However, an analysis of the literature on development pathways leading to resilience demonstrated a lack of empirical evidence (beyond case studies) and an acute lack of quantitative studies because of the substantial methodological challenges inherent in resilience measurement (Cutter et al., 2008). Natural scientists have relied heavily on modelling and simulation, whereas social science has been largely descriptive or speculative (Janssen et al., 2006). Experimental constraints have made many researchers resort to case studies when investigating the links between resilience and a catastrophic loss of socioecological systems' ability to support well-being (Scheffer & Carpenter, 2003). Case studies and descriptive observations from the agroforestry literature have noted on-farm and out-of-forest trees as sources of resilience for rural households (HHs), primarily through diversification (Leakey, 2010; Mbow et al., 2014). Increasingly, there have been calls to address the lack of quantitative and time series evidence by a

more systematic inclusion of resilience and environmental assets in agricultural adaptation monitoring systems (Dinesh, 2016).

Rather than proposing new indicators or embarking on new data collection programs, Rasmussen et al. (2017) argued more can be done to leverage existing data sets with innovative approaches that link environmental, economic, and sociocultural factors when researching sustainable agriculture. Empirical quantitative studies of alternative resilient development pathways require methodological innovations beyond simply adding new indicators to models constructed on a production-only focused theoretical paradigm. Model creation for alternative resilient development plans, that bridge existing discipline and sector silos, must precede the application of econometric or other quantitative approaches to the measurement of the effect on outcomes over time. If we seek a model that truly bridges economic, sociocultural, and environmental aspects of resilient rural development for understudied aspects of rural livelihoods, it is imperative not simply to apply traditional measures production and income tied to economic paradigms of welfare but to identify and use measures of well-being like food security relating to conceptual frames of resilience and sustainability. Rockström et al. (2017) were more explicit in their perspective piece that said agricultural policy and activities should intentionally move from a focus on production to goals associated with resilience and sustainable well-being. Shifts in goals and policies require the development and validation of indicators that reflect resilience and sustainable well-being.

Food security measures, particularly the element of stability, have been closely associated with resilience, particularly in rural areas where so many

households are engaged in work with food. Upton et al. (2016) made a good case for food security being accepted as a good general proxy for a resilience outcome. Food security is a multidimensional concept that has evolved since it was initially put forward as a political statement in the 1950s linking protection from hunger to wider political stability (Committee on World Food Security, 2012). The most widely cited definition from the United Nations Food and Agricultural Organization outlines the key elements of availability, accessibility, and utilization of food, as well as the stability of those elements over time, as essential to the enjoyment of food security (United Nations Food and Agricultural Organization, 1996). The broad nature of food security spans a range of disciplines including agriculture, economics, health sciences, nutrition, and resilience. No single indicator or unidimensional measure for food security has been universally accepted—perhaps because of these diverse disciplinary perspectives and the range of experiences of food insecurity that span micronutrient deficiencies from a low-quality diet in an urban food desert to weather related production shortfalls in a subsistence agricultural community (Webb et al., 2006). More recently, when simple identification of hazards and risk response has not provided enough evidence for effective program or policy interventions to address the stability concerns, there is a demand for more focus on measuring a capacity for resilience in understanding food security status (Frankenberger, 2013).

Well-being measures are used as dependent measures in research on resilience across a number of disciplines, such as uninterrupted school attendance for education sector resilience, and can be seen more generally as acceptable for resilience studies that are “human-centered” as opposed to resilience at a higher societal level or in a

completely different context like infrastructure resilience (Armitage et al., 2012; Manyena, 2006). Resilience is a broad term and there are many caveats to ensure it is clear that, when the term resilience is used to describe social interactions with other parts of nature, differences in social groups are recognized and the audience knows resilience “of what” and resilience “for whom” (Cote & Nightingale, 2009, p. 479).

In quantitative studies, the research usually selects a subset of indicators based on an adapted definition of resilience for the context—typically as an index (Levine, 2014). Directly related to the study in Chapter 2 of this dissertation, one of the main insights from Devereux et al. (2013) is that agriculture projects, as well as development projects more generally, should not only measure increases in production to judge success but also aim to build resilience by designing activities and measuring outcomes that stabilize that production.

Resilience and well-being have not figured into research on trees on farms in Ethiopia to a great extent thus far. Specific studies on household behaviors related to on-farm trees in Ethiopia have been limited to the rural demand for biomass or the links between agricultural investment and land tenure with permanent crops and trees (Dercon & Ayalew, 2007; Newcombe, 1987). Another paper focused on tree materials from forests and farms as a source of income-generating activities for small enterprise but did not consider how this income further contributed to livelihoods and well-being (Gebremariam et al., 2009). In new research from southern Ethiopia proposing a contextually nuanced pathway from trees to desirable food security outcomes, Baudron et al. (2017) found complex biomass flows to the household—rather than direct harvest from the forest—was likely a primary contributor to

increased diet diversity. In other words, taking into account fuel requirements, exchange of different biomass products, and the range of rural household capacities and assets is essential to the accurate characterization of development capacity pathways. In Ethiopia and at research sites around the world, the impact of TonF could potentially contribute to better articulation of these potentially alternative resilient pathways to sustainable development by including the contributions of environmental assets—such as fuel, food, income, and water provision—to broader range of well-being and livelihood outcomes including food security.

2.3 Accounting for value relevant to resilience and sustainability; the synergic pathways approach of Leach et al.’s dynamic sustainabilities and Cartwright’s measuring capacities

Sustainability refers to explicit qualities of human wellbeing, social equity, and environmental integrity, and the particular system qualities that can sustain these.

(Leach et al., 2010, p. 5)

When approaching relatively understudied topics and seeking to identify pathways to contested outcomes without universally accepted definitions such as resilience and sustainability, a “problem framing” step precedes, complements, or replaces more typical hypothesis testing of a well-established theory with accepted common indicators of key constructs. Instead, the authors of studies presented in this dissertation engaged in approaches to pathway modeling and capacity measurement rooted in empiricism of the natural processes and socioecological systems at the foundation of rural livelihoods that are aligned with the pathways approach of Leach

et al.'s (2010) dynamic sustainabilities and Cartwright's (1989) measuring capacities. In fact, based on the issues discussed previously, it was not possible to simply adapt an existing theory and previously used model from agriculture or forestry literature; a process of structured exploratory data analysis was required to identify appropriate measures of on-farm trees and related variables of interest.

The pathways approach is not so much a method as it is a focus on framing and reframing issues from multiple perspectives when results can have decision-making consequences and are taken in complex contexts under various level of uncertainty—such as facing both climate change and economic volatility in a marginalized region (Leach et al., 2010). In this dissertation, the pathways approach is used first to reduce to high levels of uncertainty about the unexpected increase in TonF by situating observations in the local context and reframing contested evidence as functional dependency where they exist. This situated understanding can then facilitate construction of a model and variable selection to better measure the unexpected phenomenon of mass afforestation on private land in newly market-oriented Ethiopia. Therefore, the investigation must be “located and context specific,” “building upon farmers own adaptations,” and, considering the desired outcomes, that may not be the same for all stakeholders in the study area; most importantly, the investigation should describe pathways of “alternative possible trajectories of knowledge, intervention and change that value different goals, values and functions” (Leach et al., 2010, p. 5).

Capacity identification and measuring, following Cartwright (1989), can be considered somewhat as a quantitative complement to Blaikie and Brookfield's

(1987) description of “regional” (in the regional political ecology approach) because the studies in this dissertation also formally incorporate context and “take(s) account of environmental variability and the spatial variations in resilience” (p. 17).

Multicausal frames of Cartwright for selecting variables and ordering models are used in a similar way in practice as Blaikie and Brookfield’s (1987) “chains of explanation” to describe the “social process” behind degradation that can be conceptually similar to modeling resilience and measuring its outcomes. The quantitative work is usually not quite as expansive in scale and may only include two or three levels—such as household and community. Quantitative work is also often more limited in the variety of indicators considered because there are not always good indicators (e.g., institutional functions or policy impacts that might be part of a more narrative chain of explanation).

When a capacity framing is not necessary, quantitative work would begin with existing theory that typically provides preconceived causal relations followed by a typical quantitative analysis that focuses solely on measuring the strength of those preidentified relationships while controlling for, rather than highlighting, the potential policy-relevant contextual details. Thus, a broader range of indicators and alternative functional relationships are studied less frequently, if they are ever studied at all, when staying strictly within disciplinary boundaries. By contrast, capacity measurement identifies the contextual configuration of preconditions favorable to a development pathway based on consideration of the observed or recounted perspectives that can make use of steps suggested in the pathways approach (Leach et al., 2010).

The papers reviewed in this dissertation, through exploratory data analysis focused on identifying capacities, pulled from the data itself—including boundary conditions, instrumental variables, and, ultimately, the causal relations that may have been overlooked in agriculture studies and forestry’s productivity-focused research. Instead of proceeding directly to a regularity or statistical framework for testing a generic preconceived hypothesis, a measurement model acknowledging context-specific elements informs a multicausal configurational framing of the capacity pathway analysis (see Bennet & Checkel, 2012; Cartwright, 1989; Liberman, 2005; Stern et al., 2012). Observational studies of this type can meet or exceed all the same assumptions as experimental randomized control trials and, according to the description of the Campbell Collaboration, are as equally rigorous and perhaps more useful to inform policy and decision making (Konnerup & Kongsted, 2009).

The dependent indicators in the research presented in Chapter 5 are unique in that they are assets identified in bootstrapping that were most explanatory but that are found in other studies using the ERHS panel. The authors of more than 40 journal articles, 10 book chapters, and numerous working papers and conference presentations have analyzed the ERHS panel data that cover many subjects but have almost no differences in terms of their dependent variable. The vast majority of these researchers have relied on econometric measures and focused only on consumption as a proxy of income as the poverty-related outcome indicator.

Particularly relevant for research intended to form an evidence base for policy, Cartwright (1989, 2012), a renowned philosophy of science scholar, specifically proposed “capacity pathway bootstrapping” as an approach to quantify policy-

relevant evidence from context-specific investigations with existing data sources. Bootstrapping is intended in both (a) the general sense of working with what you have and (b) the more technical sense of pulling bounding conditions, instrumental variables, and meaning from the data for use in econometric approaches to measurement. For in-depth information on the terminology and theoretical underpinning of capacity pathway bootstrapping from the multicausality literature and empirical inductive approaches, see Cartwright (1989, 2007) and Cartwright and Hardie (2012).

These inductive methods for context-aware multicausal analysis of observational data without experimental controls, and the application of econometric techniques without a preconceived theory, have a wide potential application for reanalysis of existing secondary data sets and research in complex real-world contexts (Cartwright, 1989; Cartwright & Hardie, 2012). These methods are particularly useful for complex problems involving socioecological systems and studies of subjects like resilience and well-being, where application of experimental controls is complicated or can be unethical.

The capacity measurement modelling approach relies on a set of assumptions and on sufficient information about the relationships of essential factors, functional dependencies, and their preconditions and sequencing vis-à-vis the outcome of observation. These are the kinds of information that can be gathered through qualitative instruments in a mixed-method approach (Eriksen & Silva, 2009). The boundary of the capacity pathway investigation is formalized in the concept of multicausal sets traced back to the point where error terms are uncorrelated. This

scenario is not always possible with any given set of data or outcome of interest because one of the pathways must also have a factor identifiable as an instrumental variable (Angrist et al., 1996; Cartwright, 1989; Riess, 2005).

A limited number of certain sets of causes—those meeting these criteria that ensure the independence of predictive factors—can define a capacity pathway that can then be presented in a diagram and then represented in econometric equations (Cartwright, 2007; Fennel, 2007). Agriculture and socioecological systems at the household and landscape scale have many of the key characteristics required for capacity pathway bootstrapping, because their foundations are often linked with clearly exogenous variables at the edge of the energy—carbon and nutrient—water Earth system cycles. Sunlight entering the atmosphere, mineral deposits, or the dormant potential of a seed presents an appropriate opportunity to initiate a capacity pathway.

For the research in this dissertation, a 3-step heuristic is used for model development to guide the choices that limit the scope, identify the key variables, and ground the investigation in contextual preconditions that create the required boundary conditions for the measurement model and the capacities to be identified and measured. Not every functional dependency identified, or even those that make intuitive sense, can be a capacity pathway measured with a linear model. Assumptions associated with capacity measurement require functional dependencies that can be traced back to a point where the factors do not have the possibility of redoubling on themselves but, in fact, have separate exogenous origins. Capacities are found working to produce patterns of events, and the possibility of observing the

patterns are greater or lesser in specific contexts under certain circumstances—largely due to preconditions and sets of constraints (Cartwright, 1989). For example, in Chapter 5, the relationship between on-farm trees and dwelling value (DV) in Ethiopia is demonstrated where private investment in houses largely made of wood exhibit these necessary characteristics for capacity measurement and resilience capacity pathway identification. In another context, where cement apartments are provided by the state, the same functional dependencies with privately owned trees would be much more difficult to observe or measure.

Following a generalized heuristic for an inductive approach to multicausal set model development, three steps for bootstrapping capacity pathways from secondary panel data are as follows:

- (a) The first step is developing a graphic summary of the qualitative relations and factors that relate to on-farm trees and influence well-being in a functional dependency overview (FDO).
- (b) The second step is to formalize the FDO into a capacity pathway diagram (CPD); then, the boundaries of the inquiry can be set and variables for modelling can be identified. Informed expert judgment is essential to this step, as the top-level variables must be genuinely independent for capacities to be bootstrapped from observations and provide a causal explanation for why errors are uncorrelated with the primary variables of interest. The most important part of this step is identification of the instrumental variable, α' , which initiates a capacity pathway with specific characteristics that make this variable unique in its ability to bring about

the outcome of interest. Cartwright (1989) gave the example of “the property of being an aspirin carries with it the capacity to cure a headache” (p. 141), but that does not guarantee that a specific aspirin doseage will be fully effective for every specific headache. What is important is the clear direction of the functional dependence and the elimination of the possible spurious correlation in a possible backpath that both the aspirin and cause of the headache have the same cause.

- (c) The third step is to apply an econometric model to estimate the strength of the relationships and capacities at work. Using panel data to parameterize the model can reduce the additional problems of controlling for individual heterogeneity or other fixed effects associated with omitted variable bias.

An FDO development begins with defining the key relationships and then sequencing them in a logical order. Correlation is an indication of association and not causality (e.g., Aldrich, 1995; Hume, 1793). A spurious correlation—a correlation that implies a causal relationship that does not exist—is typically the result of the omitted variable bias. The sequencing of factors in an FDO is a practical way to guard against omitted variable bias by identifying pathways that limit the impact of unobserved and mediating variables acting on observed correlations. Iterative refinement of the research question for a specific study area with exploratory analysis of the observations and broader sociohistorical context should guide the development of the FDO.

A CPD abstracts and formalizes the FDO by naming variables and establishing analysis time periods that, in this case, represent the different panel

rounds. In developing a capacity pathway, the change, or factor of interest (dependent variable or effect), must be traced back to at least one nonredundant intervention at a specific point in time. In the model presented in Chapter 5, α' is the eucalyptus seedling and the nonredundant cause event that anchors the analysis of the resilience capacity pathway. This anchoring of the pathway can be likened to the experimentalists' mantra "no causation without manipulation" (Holland, 1986, p. 959).

When working primarily with observational—rather than experimental data—in studying natural capacities, the intervention requirement need not be a manipulation—in the sense of an intentional human action—to start a pathway but can be any identifiable critical event or instrumental variable that produces an INUS (Insufficient but Necessary, Unnecessary but Sufficient) path (Mackie, 1965). This intervention is not necessarily, in and of itself, enough to produce the change of interest (effect) but must be independent of any other possible paths to the effect. Most importantly, an instrumental variable cannot possibly be related to any other path, and all other unobserved variables are relegated to the unknown error terms. For example, again in Chapter 5, the outcome effect of an increased DV from planting on-farm trees can then be identified apart from all potential confounding variables included in the model as unknown error—such as variable market access or microclimate variability.

An econometric model based on the capacity pathway is then estimated using real observational panel data from a source like the ERHS to measure the contribution of planting trees to an increase in DV. From a purely methodological point of view,

panel analysis methods are particularly useful for measuring the relationships between indicators of interest while isolating the effects of individual heterogeneity that can cause unobserved indicator bias in empirical interpretation and data analysis (Baltagi, 2013; Hsiao, 2014; Wooldridge, 2011). Location-based fixed effects can be easily included in a panel analysis model, when appropriate, to account for systematic environmental or context-specific differences. Time interval fixed effects, such as changing the terms of exchange or a new policy, can also be controlled in a panel analysis. In this way, the true relationship of the variables of interest can be measured over the period of the panel, and the individual, location-based and time-specific effects can be controlled.

Although many authors use stepwise regression or reduce dimensionality with factor analysis, bootstrapping is more appropriate in research contexts of high uncertainty and where there is a need to apply policy solutions or other interventions in the same area of the study site making context paramount. Cartwright's (1989) capacity pathway bootstrapping approach has the potential to exploit observations from existing secondary data sets by using formalized measurement heuristics that use time series data to quantitatively measure the outcome of alternative pathways (Cartwright, 1989, 2007; Cartwright & Hardie, 2012). The approach does not assume a predetermined theoretical framing of causal relations but seeks to apply a systemic approach to identifying functional dependencies, boundary conditions, and instrumental variables from the data. An iterative, exploratory, and inductive approach, such as that proposed by Cartwright (2012), favors contextually relevant dependencies and variables that may cross traditional sectors of environment,

economic, social, or cultural factors. Therefore, approaches that can bridge sectors may be highly relevant to research investigating complex relationships, rooted in a rural livelihood context, that look beyond measuring production to on-farm trees' capacity to protect assets, improve well-being, and build resilience.

Currently successful alternative livelihood pathways, that value a broader range of well-being outcomes in addition to income and are supported by indigenous or marginalized knowledge systems and institutions, may provide more immediate, context-sensitive, and less disruptive options to inform transformational programs and policy (Leach et al., 2010). Innovative and resilient pathways rooted in a diversity of traditions and a plurality of perspectives may not only be germane reversing the troubling food security trends, but these time-tested systems also likely offer the most apposite, accessible, and sustainable solutions to food system transformation. This approach requires a departure from sole reliance on typical cross-sectional surveys with largely descriptive statistics to a focus on alternative exploratory pathways through engaging with communities and households, better historical-geographic framings of problems and solutions in context, and more rigorous and systematic spatially and temporally aware analysis focused on alternative perspectives, indicators, and causal models.

Chapter 3: Biomass Poverty—Small Farm Forests Syncopate Persistent Seasonal Food Insecurity in Panel Data Evidence From Ethiopia

3.1 Introduction

Seven hundred and fifty million severely food-insecure people, who reported running out of food or going a day or more without eating in the last year, live largely in low and middle income countries that are notably located in tropical latitudes (*The State of Food Security*, 2020). Persistent seasonal hunger, repeating in the same temporal pattern year after year, remains the dominant experience of food insecurity for the large majority of this primarily rural population who most often make their living on small dryland farms (Devereux et al., 2008, 2013; Vaitla et al., 2009). However, recent research from Ethiopia shows continuing strong and predictable seasonal variability in calorie consumption for both rural and urban populations (Dorosh & Minten, 2020).

Despite favorable mild temperatures conducive to year-round agricultural production in sub-Saharan Africa, water constraints on agriculture during the prolonged dry season in semi-arid regions limit many annual staple crops—as well as grassy green forage—to a single season on nonirrigated farms. In the large semi-arid African region of the Sahel, 70-90% of rainfall generally occurs in only 1 to 3 months, linked to atmospheric patterns related to the seasonal travel of the sun during the Northern Hemisphere summer. Recent observations indicate a trend toward more intense rainfall events with longer dry periods portended by rising global temperatures associated with climate change (Biasutti, 2019). While single season

cereal crops growing in temperate climates, primarily on former grasslands of the global North, capitalize on peak water and solar energy availability conjoined in the favorable temperatures of summer, Bayliss-Smith (1981) pointed out that trees, perennials, or long vegetative period crops like bananas or sugar cane have an advantage in year-round growing season in both the humid as well as drier areas of the tropics. Precious land area on small tropical farms is appreciably wasted, in terms of natural capacity, on single season crops. Perhaps an even more devastating loss in communities with limited off-farm employment opportunities, a “slack season” of low labor demand, with accompanying low wages during the large part of the year when nothing is growing in the fields dedicated to single season crops, severely limits potential household income for many and thereby deepens risk of hunger and malnutrition (Feuerbacher et al., 2020; Lipton, 1983; Sen, 1966).

Chronic vulnerability is concentrated in semi-arid lands with more pronounced dry seasons (Barrett, 2014), but climate itself is clearly not the sole or perhaps even the primary cause of seasonal patterns of deprivation. In fact, chronic food insecurity is defined as repeated and systematic experience of hunger even in nonexceptional conditions and the result of structural deprivations, but the definition does acknowledge that the structural causes are most often expressed as a predictable seasonal period of food insecurity (Food and Agriculture Organization of the United Nations, 2020). Perhaps the most telling incongruity illustrating that food insecurity is primarily determined by socioeconomic structural factors and feedbacks in context, rather than purely related to climate, is that the seasonal peak of hunger during the “lean season” in dry places of the tropics, in fact, occurs during the rainiest time of

the year (Chambers et al., 1981). Of all the burdens during the period before the harvest, seasonally higher prices for food and other basic necessities are perhaps the most insidious feature of volatile markets that are so damaging to individual and community well-being. A recent survey of markets across Africa found a mean 28.3% seasonal gap in food prices between seasons (Gilbert et al., 2017). This gap would effectively reduce purchasing power by one third for the period of greatest need with the gap larger in the most vulnerable isolated and marginal markets.

The lean season “is the time of year when poor people are at their poorest and most vulnerable to becoming poorer” (Chambers, 1981, p. xv). Chambers (1981) later noted, in the preface to *Seasons of Hunger* (Devereux et al., 2008), that seasonality, as an analytical concept, highlights the interlocking nature of diverse vulnerabilities across health, education, employment, food-energy-water security, and well-being while still being the most neglected dimension of rural deprivation in policy and research.

The structural stress of the labor and food markets make single season farmers more susceptible to the worst outcomes from exposure to risks that also often increase in the rainy season. Infectious disease and recurrent epidemic outbreaks are largely driven by seasonal factors (Stone et al., 2007), including hygiene issues associated with seasonal vector for water born disease in the rainy season. Floods, landslides and other storm-related disasters may also occur during the coincidence of the lean and rainy seasons. Yet, the largest problem of any of the associated risks is that the shocks also strike at a time when households and communities are least able to cope because of exhausted reserves of energy, food, and money. Exposure to these risks may act as

ratchets pulling households into serious and extended deprivation because negative coping may undermine the ability to recover when, for example, productive assets are sold (Chambers, 1984; Krishna, 2011). The “myth” that markets have lessened the impact of seasonal deprivations has been deemed “false” from World Bank led meta-analysis across Africa (Christiaensen, 2017). Additional research from Ethiopia confirms that seasonal declines in child nutrition status persist irrespective of individual or community access to markets (Abay & Hirvonen, 2017).

Technology-centric approaches to increasing counter-seasonal functionality proposed today are often inspired by solutions used in farm systems common to the global North that have been subsequently adjusted for small tropical farms. For illustration, these may be more conceptually accessible for those who are unfamiliar with rural areas or more natural approaches most small farmers use to achieve similar integrated solutions. An excellent systems analysis and integrated solution from Burney and Naylor (2012) applies systems thinking to propose an integrated green system of solar energy-powered drip irrigation coupled with improved storage of both water and crops. Green intensification is intended both to improve the well-being of farmers but also spare agricultural land through more efficient use—thereby reducing contributions to greenhouse gasses (Burney et al., 2013; Lamb et al., 2016). These same functions, if considered from a slightly abstracted perspective, are performed naturally by trees. Trees ensure year-round production and storage of biomass—without the added complication, expense, training requirements, transportation, and maintenance of mechanized systems—as well as minimize industrial extraction processing of silicon, metal, and rare earth minerals.

The function of the technological solution and the strategy for sparing land through intensification is essentially intended to provide more biomass, selected to meet household needs, in a more stable fashion throughout the year. Trees off farms in common areas, farmed trees, and small forests found on farms all provide these exact functions for individuals and communities when access or ownership rights are assured (Agrawal, 2001; Dercon & Ayalew, 2007; Ostrom, 2009). Through a mechanism that is so ubiquitous that it may seem obvious, trees produce biomass in the counter season by boring down with their roots to access year-round water foregoing drilling expenses that are prohibitively expensive in many rural areas and often exceed in costs an amount equivalent to several years of mean local wages (Holm et al., 2016). Maintenance and running costs of boreholes are even more unaffordable resulting in an estimated 1 of 3 wells in Africa currently not in working order (Banerjee & Morella, 2011). Even when thoughtfully designed solutions using the latest technology are perfectly suited to solve some of the structural issues associated with seasonality, a lack of political will and associated government budget allocation or private resources may hinder implementation (Vaitla et al., 2009).

The hypothesis builds from Chambers and Longhurst's (1986) policy suggestion stemming from their work with the Food and Agricultural Organization of the United Nations (FAO) that multiuse, multivariety trees on privately owned land could reduce seasonal deprivation linked to single growing seasons by accessing subterranean water to produce biomass in a variety of forms to meet household needs throughout the year.

Ethiopia has experienced, in the last decades, policy shifts that have promoted more private tree planting and preserving (Government of Ethiopia, 2011). This research narrows its focus to plot areas on farms in the Amhara Region that are classified as “forest” in the Ethiopian Socio-Economic Survey (ESS) that do not include farmed trees of diverse international fruit varieties or commercial crops from woody shrubs—like coffee—that are intercropped or planted as a small orchard and measured separately. The ESS data included a short text description of the forest plots only in the second wave of the survey but was unfortunately limited to only differentiating those plots that contained eucalyptus—neglecting to characterize any other trees. We therefore use farm forests, in all three survey waves, to characterize the area on small farms dedicated to unidentified trees in the survey that include eucalyptus and presumably other unspecified native and introduced species. This does not include TonF around the household, grown at the edges of fields, or intercropped with other specified cultivated species. This research develops hierarchical linear mixed models that can control for differences in socioeconomic status, wealth, and location to measure the marginal capacity of farm forests to shorten the reported food insecure period. This research focuses on an easy-to-collect and self-explanatory measure of duration of seasonal deprivation as the dependent variable: months of food insecurity (MINS).

This research is intended to contribute to growing knowledge of natural and accessible low-cost approaches that mitigate the predictable seasonal suffering of food insecure households through sustainable intensification. Seasonality as a subject has been largely ignored in development economics or rural land management

research in the first two decades of the 21st century. This issue is exacerbated, at the same time it is overlooked, all the more completely by what Haraway (2016) characterized as logics of the Capitalocene and Plantationocene represented by globalization of food systems and further marginalization of rural communities.

Although recent case studies have recounted benefits of various agroforestry systems, a lack of tree-inclusive appropriate population representative panel data has forestalled quantitative research on poverty-related hunger that could model the relationship of farm forests to duration of seasonal food insecurity until now. The knowledge gap on interventions and policies to address seasonality, although objectively ignored too long considering the level of persistent deprivation, has never been more important than at the current moment. With considerable uncertainty about changes in seasons under climate change, the need for research on ready, flexible, and palatable pro-poor natural approaches to ensuring resources, particularly biomass resources necessary to support livelihoods of small farmers all year long, have never been more necessitous or consequential (Devereux et al., 2013; “Ending Hunger,” 2020).

3.2 Background

Biomass availability and effective management is the foundation of regenerative approaches underpinning sustainable agricultural practices and intensification. Whether organic by choice or by inability to afford chemical fertilizer inputs, biomass as fodder for farm animals is the principal resource for producing

necessary manure to nourish annual crops and promote horticulture and perennial plant productivity. Crop residue is a primary source of fodder on many small farms but is typically insufficient to support enough livestock to produce all necessary manure to meet requirements for optimal production in sub-Saharan Africa (Powell et al., 2004). Residue management is the primary technique used in conservation agriculture (CA), and suitable biomass production and cycling, adjusted to cropping strategy, is a key indicator of sustainable intensification (Jat et al., 2020; Musumba et al., 2017). Depending on circumstances and amount of biomass production, applications of residue directly to the fields, or transformed and applied as manure, would be more-or-less appropriate in different ratios depending on specific farm characteristics or farm system logic.

Biomass poverty, the lack of sufficient biomass to support rural livelihoods to achieve desirable well-being outcomes, is the major constraining factor for many hungry and poor farmers to sustainably intensifying their farms. Insufficient biomass, particularly on small farms with single season crops, restricts the options small farmers have to sustainably intensify by realizing optimal nutrient cycling with *in situ* resources. Low adoption of CA in Africa points to the need for greater research on the conditions in which it is appropriate and preferred (Giller et al., 2009). Competing uses, including as cooking fuel and overall insufficiency of biomass, is a key factor (Lal, 2007).

At the most abstract, models of farm-related cycles with inputs and outputs point back to the law of conservation of energy and an early example of systems thinking put forward in Daniel Bernoulli's (1738/2005) *Hydrodynamica*. Bernoulli

mphasized flows as *vis viva*, the life of the system, describing the motion or kinetic energy—entering and often transformed but conserved—as it moves through the system. Early studies on seasonal hunger, deprivation, and cycles of poverty framed the issue as a temporal mismatch; the overall insufficiency of energy supply stored in the form of grain to meet the household demand were quantified as required calories. Solar energy that entered the system—captured in annual crops in the field and stored as grain after harvest—was compared to energy requirements that peaked for farm workers during labor intensive cultivation in the rainy season as the structural causal explanation of the annual the lean period (Bayliss-Smith, 1981).

General systems theory and its focus on constraints (von Bertalanffy, 1950) can further contribute to articulation of the analysis by considering the obstacles to optimal balances, uses, and transformations of energy and biomass at the farm or landscape scale. Specifically informed by the scale and importance of teleconnections to external drivers, the “chain of explanation” approach of political regional economic geography, associated with Blaikie and Brookfield (1987), focused on land degradation and is specifically relevant to identifying and measuring the processes reducing biomass and further exposing vulnerable farmers to seasonal deprivations.

Subsequent research, increasingly informed by the feedbacks, interscale integrations, and complexity of systems thinking, refined the conceptualization of seasonal deprivation with consideration of more diverse biophysical constraints and socioeconomic dimensions. Price feedbacks, investigated by development and agricultural economists, contribute significantly to the large gaps in access to food between postharvest and lean season for those relegated to single season crops on

small plots (Sahn, 1989). These researchers first transform production and household consumption into monetary equivalent in prevailing market prices while ignoring noncommodified biomass or considering it waste to be eliminated. In fact, many crop genetic breeding programs for so-called high yield varieties, often associated with a green revolution, build on this premise of eliminating noncommodified waste biomass, thereby increasing the ratio of commodity cereal produced on a plot (Conway, 1998).

The advantage of single dimensional studies—using a monetary quantitative unit—is that earnings from labor, sales of other goods gathered or produced in the household, taxes, credit, and savings could be more readily considered. Gil et al. (1991) built a mean-variance equilibrium model to illustrate how these main factors interact with seasonal gaps in food access and concluded, like many other authors, that lack of access to formalized credit, savings, insurance, and fair wages work against the possibility of the majority poor households smoothing their consumption over the year. As minimum access to these essential market services is not available to low-wage seasonal workers whose diets are primarily staple cereals, there is actually a negatively reinforcing cycle—a ratcheting down toward destitution—of the poorest and least able to manage seasonality through savings and stored wealth and who are, therefore, more exposed to the negative impact on assets of seasonal variability for the poor (Gill & Gerard, 1991). Sadly, after 30 years of market-focused structural adjustment, World Bank-financed research finds rural people in the most vulnerable geographies still face these same challenges despite policies and powerful

voices propagating the myth that economic growth and expansion of markets has improved the situation in these marginalized places (Christiaensen, 2017).

Biomass stocks such as tubers, livestock and their fodder, and trees represent an accessible form of savings intended to smooth out consumption during seasonal disruption of access to cereal based staples (Sahn, 1989). In Ethiopian livestock research, Lybbert et al. (2004) found desirable-equilibrium herd size represented the stocks necessary to recover from adverse events. In the neighboring Southern Nations Nationalities and Peoples (SNNP) region of Ethiopia, research reported in Chapter 4 of this dissertation shows households maintained an equivalent of an 18-month stock of their staple food enset, an autochthonous treelike perennial that would ensure basic food security through an entire year of disaster food loss. It remains unclear what might determine a desired stock of biomass in a farm forest, but it would likely be related to the capacity to produce enough biomass to meet household needs without negatively impacting other cropping or livelihood activities.

According to Chambers and Leach (1989), trees represent an alternative biomass-based strategy for savings and security for poor households on small plots and are an indispensable element underpinning rural livelihoods. With the proposition that trees may be able to increase livelihood security by offsetting contingency expenses, Chambers and Leach reviewed literature investigating rural livelihoods to find that trees serve as a stock of value that is less likely to suffer high overhead costs or losses due to theft or calamity—with better returns on investment for most poor households than jewelry, livestock, available informal financial services, or land.

Trees grow faster in the tropics—with ready markets for timber and fuel wood. There have been documented cases where planting and caring for seedlings was a successful strategy for paying off debts—even as they accrued interest or were used for extravagant social expenses like a dowry (Chambers et al., 1989; Conroy, 1992). More recent research is sparse, with a limited number of studies finding a short-term direct link between a risk exposure followed by immediate tree cutting to meet expenses (Ravindran & Thomas, 2000; Winchester, 2000). Trees appear to hold value similar to other major productive assets for rural livelihoods. Therefore, households make grave sacrifices, even in times of famine conditions, to maintain their trees over shorter-term consumption smoothing (Chambers, 1997; deWaal, 1989).

Where the strategy of planting trees becomes common, the market for tree products can become saturated as it did for eucalyptus in parts of South Asia—diminishing potential returns on tree investments (Conroy, 1993). Noting that trees tend only to be considered in livelihood studies when they are too abundant to have the same savings function (such as in remote forest communities), Chambers et al. (1993) reflected on the lack of research on trees in rural livelihoods more broadly in a professional bias subsection: “Whatever is important to the poor tends to be neglected because of foresters’ concerns with industrial and conservation forestry, agronomists’ concern with field crops, and the absence of a profession with energy and fuel as its central concern ” (p. 2).ⁱⁱ This bias toward reductionism during the past 30 years of structural adjustment, commoditization, and globalization of food systems has only reinforced the narrowly myopic focus away from understanding naturally integrated

foundations of small farm systems that rest on contributions of a variety of plants, nonhuman animals, and, perhaps most of all, the woody and nonwoody contributions of TonF.

While the contributions to production or income by farmed trees has been largely confined to studies on research stations and test farms, the influential work of Ostrom (2009) and others on common areas has inspired broader thinking of how trees contribute to resilience, sustainability, well-being, and food security of farmers and farm communities. Working often with multiple case comparisons, flows from commonly held resources of natural capital and the social institutions that govern their management became the dominant discourse on the relationship of trees and forest-related products to well-being measured by income or food security outcomes (Agrawal, 2001; Babulo et al., 2009; Reardon & Vosti, 1995).

Perhaps the most investigated relationship of off-farm trees and food security is the observed direct link between child nutrition, measured by dietary diversity, and access to communal forests (Powell et al., 2011). Both tree cover and deforestation have also been associated with dietary outcomes of children living near common areas with trees (Galway et al., 2018; Ickowitz et al., 2014; Johnson et al., 2013). Even the shape of forests, where longer edges are increase, the interface of treed and nontreed areas have a positive impact on diet diversity (Rasmussen et al., 2020).

Although studies on forest contribution to food security often focus on fruit, wild foods, or nontimber income (Rowland et al., 2017; C. Shackleton & Shackleton, 2004), newer research from Ethiopia found evidence that a primary pathway to positive food security outcomes from forests is the transfer of biomass via animal

fodder to the farm that supports production of nutrient rich animal protein, horticulture products, manure (Baudron et al., 2017), and general nutrient cycling for improved soil quality (Reed et al., 2017; Wood et al., 2018). This additional biomass from forests sets in motion virtuous cycles to improved food security through additional milk production at the height of the lean season (Wilson et al., 1980), additional fuel for cooking nutrient rich legumes (Galway et al., 2018), or (as previously discussed) the most important input to organic sustainable farming. Biomass is so basic to these functions that additional sources from treed areas off the farm may have always factored into the necessary functional foundations of small farms.

Fruits, nuts, and other commodity production, although the major focus of most tree-related research, is not the only source of social and economic value derived from TonF. Farmed trees providing diverse benefits as part of farm systems, beyond commercial orchards and plantations, feature most prominently in agroforestry literature rather than agro-economic development literature. Agroforestry land management promotes intentional intercropping of trees with other crops for specific benefits such as improved nutrient cycling or water and soil conservation. In case studies across Africa and around the world, such intercropping has been shown to increase production of agricultural products and has been successful in boosting production while conveying other benefits (Garrity, 2004; Garrity et al., 2010).

Unfortunately, agroforestry research is often also presented as a collection of case studies or small-N agriculture and soil surveys that narrowly focus on incremental improvements such as the marginal benefit of nitrogen fixation of one

subspecies of tree to another. There has been little focus on population level impacts on livelihoods, well-being, or food security aggregates. Nor does the literature give attention to a diversity of trees that exist on farms but are not (a) necessarily intentional, (b) commercially viable, or (c) of the same species of farmed trees in agroforestry systems.

Longer-term benefits of agroforestry approaches and farm adjacency to forests may more likely be attributed to additional biomass flows to protect and enhance soil quality and may, in the case of silvo-pastoral and integrated crop livestock farm systems, include provision of green fodder. This may explain in part the ubiquity of trees on farms. Acknowledging that TonF are widely ignored by both agriculture and forestry services, Miller et al. (2018) found trees are nonetheless widespread and provide significant income primarily by producing cash crops like coffee or cashew nuts to sub-Saharan households.

Recently updated estimates from satellite earth observation reported more than 43% of agricultural land globally has more than 10% tree cover; this disciplinary blind spot between agriculture and forestry has real world policy implications such as undercounting the biomass of these trees in accounting for carbon sequestration globally (Zomer et al., 2009, 2014, 2016). However, as these studies have focused on improving the quantification of carbon in on-farm trees, they did not measure other potential benefits or well-being focused outcomes at population scales (Schnell et al., 2015; Zomer et al., 2014).

In recent work funded by the World Bank, Place et al. (2016) summarized the many benefits of trees for agriculture in arid lands of Africa in a resilience-based

conceptual framework—illustrated with five case studies—emphasizing the ability of trees to reduce shock exposure, minimize the effect, and improve the ability to cope with negative effects of shocks. Although the study primarily focused on productivity of the agroforestry systems with an income-centric framing of resilience, the authors employed the same basic explanatory mechanism of tree capabilities to access water year-round that lessens the effects of variable rainfall to produce biomass for the generally protective functions related to soil quality. The authors only briefly mentioned fruit or leaves eaten like a vegetable in stew preparation as direct coping with seasonal food insecurity.

Chambers and Longhurst's (1986) study remains one of the only policy-oriented research reviews to begin their analysis with the problem of seasonality for rural livelihoods before focusing on widely applicable policy recommendations relevant across specific circumstances, tree species, or local farming systems. The balance of access to trees on common areas, where these areas are scarce, can be enhanced by protecting rights or facilitating private planting and care for trees on farmsteads.

For many years, agricultural policy actively promoted disincentives to tree ownership because it was seen as competition for nutrients and water with primary crops. These disincentives further fueled concerns about allopathic properties of certain trees, but research from Ethiopia confirmed the low risk of reduced production and high returns of investment in trees particularly on less productive land (Jagger & Pender, 2003). Some authors have also looked at the benefits of private tree plantings as an economic case for afforestation based on the demand for biomass or

investigated the relation of agricultural investment in permanent crops and trees with policies for securing land tenure (Dercon & Ayalew, 2007; Newcombe, 1987). With markets failing to smooth consumption and the continued lack of off-farm income opportunities reaching marginalized communities, the evidence suggests that policy promotion of sustainable intensification through TonF-related increases in biomass production and more evenly spaced timing of that production with improved biomass management may be germane to reducing or eliminating seasonal food insecurity.

When considering appropriateness and feasibility of solutions to seasonal deprivation, it may be important to reflect that both the reduction of biomass availability on farms and even the occurrence of a hungry season is intimately related with the imposition of policies and technology originating from outside the impacted food systems. In fact, many crop genetic breeding programs for so-called high yield varieties, often associated with the green revolution, build on the premise of eliminating noncommodified waste biomass, thereby increasing the ratio of commodity cereal produced on a plot (Conway, 1998).

The term *hungry season* was first observed by Richards and Land (1939), writing from colonized Northern Rhodesia that is now Zambia, who chronicled diets of formerly swidden agriculturalists transitioning to peasant farming with the associated issues of maintaining fertility of the soil and periods of deprivation related to a lack of on farm food source diversity. A peasant agriculture that, by design and throughout history, produces easily taxable and tradable commodities while leaving a large seasonally under-employed workforce available to exploit in industry or ready to be engaged for militarized conflicts. There is a great demand for research that

focuses on practices readily accepted by farmers if given an encouraging policy environment or based in coevolution of traditional sustainable practices. A shift of research and policy away from the focus on production and income to indicators of sustainability and resilience is required if we as humanity want to both sustain ourselves and the systems that sustain our planet (Rockström et al., 2017).

3.3 Data, Study Site and Descriptive Statistics

3.3.1 Data

Large-N panel data sets that include on-farm trees, perennial crops, and other food system elements—along with socioeconomic and well-being information—were exceedingly rare until the recent Living Standards Measurement Survey–Integrated Survey on Agriculture (LSMS-ISA) program cosupported by the World Bank Group and the Bill and Melinda Gates’ Foundation (Carletto et al., 2015). The Ethiopian Rural Socio-Economic Survey in 2011/12 was the first of three LSMS-ISA compatible data collection activities undertaken by the Central Statistical Agency of Ethiopia (Central Statistics Agency of Ethiopia World Bank Group, 2017). It was later renamed the Ethiopian Socio-Economic Survey (ESS) for the second and third wave. Additional enumeration areas in small, medium (population of 10,000-100,000), and big towns (population over 100,000) were included in the second (2013/14) and third (2015/16) waves of the survey prompting a name change to simply the Ethiopian Socio-Economic Survey. The ESS sampling design is intended to be representative for each of the four larger regions of Amhara, Oromia, Tigray,

and SNNP and for a multiregion agglomeration of the five smaller regions of Afar, Benshangul Gumuz, Dire Dawa, Gambella, Harari, and Somalie.

The ESS administered five questionnaires over 6-8 months in each wave of the survey requiring enumerators to spend a large amount of time, or even temporarily relocating, near to the enumeration areas. A postplanting questionnaire at the household level was administered between September and October. This instrument measured individual fields with GPS and recorded relevant planting information about type of crops along with inputs. Further information was collected at the plot and household level. A livestock questionnaire and crop cutting samples for cereal yields in Waves 2 and 3 were also given to the same selected households—sometimes as late as November or December. Post-harvest, household, and community questionnaires were then administered between January and April. The work was completed in March for Wave 1 but was typically somewhat later, ending in April, for Waves 2 and 3.

Specific limitations of the ESS data set are documented for each wave of the survey in the Basic Information Document (Central Statistics Agency of Ethiopia World Bank Group, 2017). Yield data were collected inconsistently in the first ESS wave and then correlated with crop cutting measurements for cereals only in the second and third. Enset and other non-cereal yield estimations are particularly challenging because of the wide diversity of genetically diverse local varieties, growth rates, maturity at harvest, and water content. This is further complicated by inconsistent local measures and yield questions over the three ESS waves, so there is

little confidence in the consistency of any reported yields for enset and most other crops of ESS.

Detailed field-level analysis was conducted with global positioning system (GPS) area measurements for nearly all households in each wave. These fields are very consistent in terms of size, number, and crop composition between the postplanting and postharvest questionnaires in the same wave. The measurements and number of fields per household are unfortunately not consistent between waves and indicate fields were completely reidentified and measured with each new wave of the survey. This may be completely appropriate as new planting arrangements of annual crops intercropped with perennial and multiyear enset fields might have regularly changed between waves.

The ESS household survey module was administered in a relatively abundant time of year between December and January after the harvest of annual crops. The food security indicators with shorter recall times of 1 week, such as the Household Dietary Diversity Score (HDDS) and the Food Insecurity Experience Scale (FIES), would, therefore, potentially not capture the worst food insecurity over the 12 months that likely occur around July or August when stored food may be exhausted and staple prices are often at their maximum (Central Statistics Agency of Ethiopia World Bank Group, 2017). Anthropometry for young children is notoriously difficult to measure under difficult field conditions and, although it is not mentioned specifically in the ESS documentation, should be considered in the association with other indicators.

Area of farm forest (FFarea) is measured in m² and was selected as the variable of interest in part because GPS measurements in ESS were some of the easiest measures to collect with highest levels of consistency, completeness, and relative objectivity of all the survey data. There are few non-GPS measured fields in Amhara because the most common reason for nonmeasurement was that the fields were extremely far away from the household; that is not typical of the region (Central Statistics Agency of Ethiopia World Bank Group, 2017). There are no measurements of yields, numbers of trees, and numbers of harvest trees available from the “forest” areas in the survey, but the area measurements do not suffer some of the potential errors and biases that can be introduced during data conversion. The regional sampling structure of the ESS survey from Ethiopia makes available for the first time a statistically representative panel of the rather ubiquitous presence of farm plots designated as forest in the Asmara.

Economic access to food is often related to overall measures of consumption and assets. Consumption aggregates were included in the data set by the World Bank. This research used the common measure of economic food access as percentage of food expenditure to total expenditure. Dummy variables for consumption quintiles were also included as explanatory indicators in the model. Cattle were included in the model as the valuable asset most closely associated with demand for fodder and manure-related nutrient cycling. All variables confirmed somewhat weak, but nonetheless significant, relationships with the food security indicator MINS in simple pooled correlation. Data were downloaded from the World Bank micro data site

(<https://microdata.worldbank.org/index.php/catalog/2053>) and analyzed using STATA version 15.1 (StataCorp, 2017).

3.3.2 Study site – Ethiopia Deforestation and Afforestation of Small farms

The Amhara region has very little forest cover according to the most recent estimates, with woodlands covering 4.2%, highland forests covering 0.48%, and plantation forests including bamboo at 1.23% of the land area (Wassie, 2017). Ethiopia, at the country level, may have been covered by as much as 40% forest. Only 7% of the land area is estimated to have remained with forest cover after extensive deforestation in the 20th century but before the famine inducing droughts of the mid-1980s (United Nations Food and Agricultural Organization, 1986). For much of Ethiopia's history, royal and imperial elites have exploited forests and trees in service of their military actions related to ongoing conflicts (Bekele, 1992; Kassa et al., 2011) and later under the post WW-II imperial restoration to a policy of agricultural expansion (Ayana et al., 2013). Ethiopia's revolutionary DERGs decreed in 1975 that cutting of trees was forbidden, presumably to stop deforestation and perhaps in response to previous impunity of elites with respect to forest exploitation (Kassa et al., 2011). The result of the decree was that very few trees were planted in an environment that was already terribly deforested. By the time the regime transitioned in the early 90s, it was estimated that 97% of Ethiopia was deforested, with almost all remaining trees in the South West of the country (Kebede, 2002). Across much of Ethiopia, particularly in the highlands of Amhara Region, it is now likely that most trees are now found on farms rather than in areas meeting a definition of forest.

When the prohibition on tree cutting was rescinded in 1991, there was a boom in on-farm tree planting to meet fuel wood and construction demands (Ethiopian Ministry of Water and Energy, 2013; Kebede, 2002). In 2010, the government of Ethiopia estimated that more than 90% of the country's rural energy needs were met with biomass. Making biomass a more efficient source of energy is a central policy objective in Ethiopia's long-term "green" sustainable development strategy that intends to raise GDP while limiting carbon emissions (Government of Ethiopia, 2011).

Eucalyptus trees are far and away the largest source of fuel and construction materials in rural Ethiopia (e.g., Turnbull & Booth, 2002). In recent years, farmers in Ethiopia without access to common area wood lots have begun increasingly to grow eucalyptus trees on their own plots to use branches and leaves as cooking fuel. They harvest trees for construction poles and posts or as a form of insurance when annual crops fail. According to Turnbull and Booth (2002), "Many people in Ethiopia are absolutely dependent on eucalyptus as a source of fuel and house building material" (p. 55).

Natural resource management issues, in conjunction with food security issues like land degradation and access to communal resources, dominate policy discussions and resource allocation decisions at lower administrative levels of Ethiopia (Snyder, 2014). Decentralization of legislative and executive power began at the regional level in 1992, and further decentralization to Woreda level began in 2001. Distinct policy differences emerged particularly at the regional level, where eucalyptus planting was essentially banned on farms in the Tigray and Oromia regions but soared in areas of

the Amhara Region. The “mixed economic policy” of the last year of Mengistu’s regime in 1990 stopped redistribution of land. This helped increase the security of tenure encouraging farmers to invest. The impact, particularly in terms of planting eucalyptus trees, was immediate and highly visible (Dercon & Ayalew, 2007). The overall result of the establishment and increase in size of small farm forests across the Amhara region are presented in the descriptive statistics below.

3.3.3 Descriptive Statistics

Here are presented basic descriptive statistics and focus on FFarea as the independent variable of primary interest and the dependent variable MINS. In the 6-7 years from the first ESS survey visit to the end of the third wave of measurements, mean FFarea for the Amhara Region more than doubled from 143 m² to 343 m². This was driven in equal measure by an approximately even increase in both number of households reporting FFarea growing from 110 to 177 and the increasing area devoted for FFarea from 830 m² to 1261 m² for those with farm forests. The largest farm forests were equivalent to just over one hectare of land where presumably the majority of the household compound would be wooded.

Table 3.1

Descriptive Statistics for FFarea (N = 640)

<i>(square meters)</i>	Mean all households	Standard Deviation	HH reporting Farm Forest	Mean for HH >1 m2 of Farm Forest	Min	Max
FFarea Wave 1	142.56	714.17	110	829.45	0	12647.95
FFarea Wave 2	239.77	909.69	155	1010.00	0	11461.3
FFarea Wave 3	342.94	1303.56	177	1261.38	0	12800.0

Unfortunately, the ESS only recorded a text field identifying plots that included eucalyptus in the second wave of the survey. It does not describe any other tree or perennial species and is not available in waves one or three. However, we can assess for the second wave that 94 small farm panel households' farm forests included eucalyptus, 59 households' farm forests contained only other species, and two households had separate plots of both eucalyptus and other tree species. This would mean that eucalyptus farm forests outnumbered other forest species by 60% to 40% for households in the panel and were also about 25% larger at a median size of 427 m² compared to 323 m² for other types of trees on forest plots.

MINS saw a peak in wave 2 of the ESS with a mean of 1.2 months or 37 days of reported food insecurity. Wave 2 also saw the highest number of households, constituting more than one third of all households surveyed, reporting one or more months of food insecurity.

Table 3.2

Descriptive Statistics for MINS (N = 640)

(measured in months)	Mean	Standard Deviation	HH reporting# MINS	Min	Max
MINS Wave 1	0.79 (23 days)	1.53	167	0	12
MINS Wave 2	1.2 (37 days)	1.88	241	0	12
MINS Wave 3	0.6 (18 days)	1.5	126	0	12

Later in the modeling, two dummy variables were included. Female-headed households were correlated with MINS by a spearman coefficient of 0.17 at

significance of $p < .001$. There were 170 female-headed households and 470 male-headed households. Between Wave 1 and Wave 2 of the panel, there was an increase of 20 households, or 3% of the sample, becoming female-headed. Households that reported burning crop residues as their primary source of cooking fuel was selected through a stepwise procedure when considering potentially significant controls among household and sociodemographic variables. As a dummy variable, crop residue burning contributed the most explanation of many variables considered. There were 51 households that regularly burnt crop residue as their primary fuel source in all three waves of the ESS survey.

3.4 Methodology and Modeling

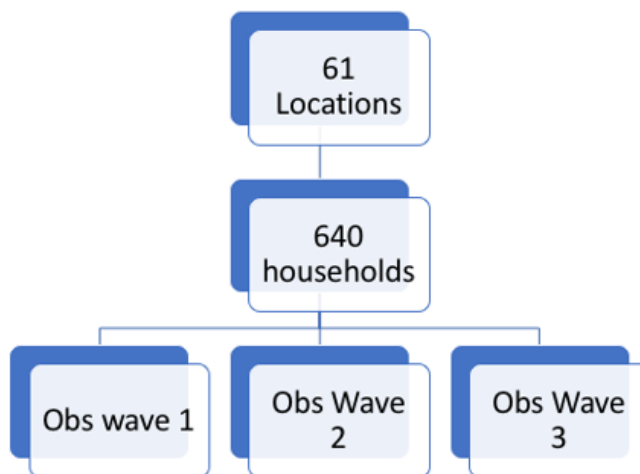
To estimate the marginal impact of FFarea on the dependent food insecurity measure, a three-level linear mixed modelⁱⁱⁱ of the data included repeated measurement across three waves of the Ethiopian LSMS-ISA survey for households(i) within enumeration areas(j). Exploratory data analysis confirmed high levels of spatial variability in variables of interest related to the context that included a mosaic of geographic features, local weather, marginalization, and combinations of infrastructure but few that were coherently and significantly correlated with any of the dependent variables or asset measures. The place-based context of communities were represented by the 61 enumeration areas in the hierarchical model by first nesting observations into the 640 households and then households nested into locations (see Figure 3.1).

MINS is a typical food security-related microeconomic measure used in areas with seasonal hunger. It is a slight adaptation of an early food security indicator

required for several years for USAID (i.e., months of adequate household food provision) that agricultural surveys would collect to assess the postharvest food stores (Bilinsky & Swindale, 2010). This remains the goal level indicator for the government of Ethiopia's operational plan for the Alliance for a Green Revolution in Africa (Government of Ethiopia Agricultural Transformation Authority, n.d.). The MINS is a somewhat more inclusive indicator that includes food purchased on the market or that is acquired in other ways such as gathering or working for in-kind food.

Figure 3.1

Tiered Hierarchical Model



As food security is closely related to poverty status, this research included flow measures of poverty with the World Bank-provided consumption quintiles (CQuint) to create unique asset indexes to control for differences in stores of wealth. Information on assets is regularly collected in socioeconomic surveys, but these data

must be transformed into a unidimensional measure if they are to be easily compared over time in a longitudinal analysis (Barrett et al., 2016; Naschold, 2012).

Data reduction through factor analysis is the most common way of reducing dimensionality and appropriate for the ESS data that collected information on 34 household items and agricultural implements. Sixteen items were selected of the possible 34 assets recorded in the ESS module that were owned by at least 1% of the population. Several of the items, such as private cars and satellite television receivers, were only owned by one or two of the 640 households and, therefore, dropped from consideration in the indexes.

Factor analysis identified two orthogonal factors that accounted for 95% of the variability in the asset data. The first, HHobjs, related to household and personal objects such as blankets and mobile phones. The second, AgImp, related to agricultural implements such as an axe, yoke, or plow. The two asset indexes were orthogonally rotated to capture the highest level of information in the fewest factors. Therefore, the HHobjs and AgImp Spearman correlation of -0.23 showed that, in this region, those with plows and yokes typical of the AgImp were somewhat less likely to have mobile telephones or the other items of the HHobjs index. Livestock and land holdings are fundamental to rural Ethiopian livelihoods. Tropical livestock units (TLUs) were calculated following the standard transformation and implemented in the Stata do files provided on GitHubb (Alia et al., n.d.).

Female-headed households were included as the sole sociodemographic indicator. A dummy variable for burning crop residue as a primary fuel source was included because it was the only other descriptive variable that was found to be

highly significant with a relatively strong correlation to FFarea. Although there was a good deal of variability in outcomes between locations, this was not true of the households as a population overall. Descriptive measures such as household size, education status, and age of household head had relatively low variation across the survey population and, therefore, insignificant levels of correlation to the outcomes or even the independent variables.

It is important to note that a variety of geo-contextual variables such as altitude, mean rainfall, and distance to market were available as part of the ESS data set. These were also not significantly and consistently correlated across panel waves or when the waves were pooled. The large contextual variability observed in both the cultural and more environmental context only became significantly correlated with different levels of food security or assets as specifically manifested in a specific place for a wave.

The complexity of the interactions and context led to specific and not easily correlated outcomes for any one place in any one wave. For example, a community might have relatively poor rainfall but locally available irrigation. The combinations in the study site were so numerous that significant differences were only realized when the unique combination of factors came together in a single place. Inclusion of random and fixed effects for location accounted for much of this variability and the observed correlations. In the end, no other variables were included to preserve the parsimony of the model because the monetary flow indicator, assets, and location variables captured most of the variability in the outcomes of interest.

For MINS as the dependent variable of interest, the three-level variance components model was defined using FFArea and the control variables for the panel survey wave (t), household (i), and enumeration area (j) following Baltagi (2013) and Rabe-Hesketh and Skrondal (2008). The hierarchical mixture model approach allowed for between and within subject variance to be modeled separately as random intercepts and random slope coefficients. In the model, household variance, as well as variability by location and location-over-wave, was modeled with separate random effects that, in turn, captured the high levels of local contextual and temporal variability. Random effects for intercepts at household level captured different starting places in the case of expected food security status. This research included both a random intercept for locations—to capture the more static infrastructure—and context-related difference between locations. Then, random effects for slope by survey wave were added to compensate for primarily negative, but also occasionally positive, idiosyncratic shocks determined by geography or location.

The models follow a structure where the dependent variable of interest (Y), values for MINS, are regressed on independent variables and the random components as:

$$(y_{ijt}|x_{ijt...}) = \exp \{ \beta_1 + \beta_2 x_{1ijt} + \beta_3 x_{2jt} + \beta_4 x_{3ijt} + \beta_5 x_{4ijt} + \beta_6 x_{5ijt} + \beta_7 x_{(6-9)ijt} + \zeta_{1jt}^{(2)} + \zeta_{1t}^{(3)} + \zeta_{2t}^{(3)} t_{it} + (.../2) \}$$

where:

y_{ijt} is the dependant variable MINS

$\beta_2 x_{1ijt}$ is FFarea

$\beta_3 x_{2jt}$ is dummy variable for female headed household

$\beta_4 x_{3ijt}$ is HHObjs index

$\beta_5 x_{4ijt}$ is AgImp index

$\beta_6 x_{5ijt}$ is a dummy variable for crop residue burning

$\beta_7 x_{(6-9)ijt}$ are dummy variables for consumption quintiles 1 – 5

$\zeta_{1jt}^{(2)}$ is a random intercept coefficient at household level

$\zeta_{1t}^{(3)}$ is a random intercept coefficient at location level

$\zeta_{2t}^{(3)} t_{it}$ is a random slope for location by wave

The model is adjusted to a Poisson gamma distribution for dependent variable MINS because of its limited range of count variables from 0-12. The analysis was conducted with the option to report exponentiated regression coefficients for easy comparison across all variables. A linear fixed slope is assumed for households within locations. Allowing slope to vary at household level did not provide additional significant explanation variance beyond location heterogeneity for three of the four dependent variables, which is discussed in the following section. ζ_1 random intercepts have a mean of zero and variance $\psi^{(3)}$ given covariates x . Random slope $\zeta_{2k}^{(3)} t_{it}$ also has a mean of zero and covariance matrix $\Psi^{(3)}$ given covariates x . The ϵ_{ijt} error term has a mean of zero and variance θ .

3.5 Results

Small forests on farms significantly reduced reported length of food insecurity as measured by MINS. The marginal effect is greatest for the poorest households and for those households with signs of energy insecurity measured as burning crop residue as the main source of fuel. The strength and significance of the covariates presented in Table 1 are considerable. All significant at a minimum of $p < 0.05$ level, FFarea, livestock ownership, and all the wealth measures reduced MINS in the

model. Female-headed households and those that burn crop residue significantly increased their estimated MINS, according to the model. For random effects parameters varying with random effect for location, the intercept mean was 2.13 MINS and hh 0.34.

Extrapolating based on the pooled coefficients, an FFarea near the mean of 1000 m² would reduce MINS overall by 0.23 months, or the equivalent of a week. Depending on wealth, gender of head of household, or primary cooking fuel source, this effect can be larger or smaller. From a starting point without FFarea, a female-headed household would experience 11 more days of food insecurity compared to male-headed households. Moreover, those who burn crop residue are estimated to be food insecure for 24 more days in a year than those that use other sources of fuel.

Wealth measured by assets appears to have a stronger effect on reducing MINS than flow measures of consumption. Household objects reduce expected MINS by more than agricultural assets and have a lower standard error. The wealthiest households as measured by consumption would experience at least half the MINS as the relatively poorer households. Overall, the standard errors are very low compared to the magnitude and significance of the coefficients, indicating a strong explanatory set of independent variables (see Table 3.3).

High values of log likelihood, further strengthened by the large sample size, suggest a strong congruence of observations and model. The Wald statistic is highly significant indicating support for inclusion of all selected covariates (see Table 3.4). The likelihood ratio test is highly significant and rejects the null hypothesis in favor of inclusion of the random coefficients for both location and household.

Table 3.3*Coefficients and Their Level of Significance for the Longitudinal Mixed Model*

	Months of insufficient food provision+ (MINS)/Std. Error
Forest on Farm (1000 m2)	-0.23**/0.752
Burn Crop Residue As Fuel (0/1)	0.77***/0.2
Female-headed household	0.35***/0.06
Household Objects Index (HHObjs)	-1.23***/0.02
Agricultural Implements Index (AgImp)	-0.3***/0.07
Tropical Livestock Unit (TLU)	-0.13***/0.02
Consumption (q2)	-0.31***/0.07
Consumption (q3)	-0.39***/0.08
Consumption (q4)	-0.34***/0.08
Consumption (q5)	-0.62***/0.12
Constant (alpha)	-0.41**/0.17

p value < .10 = *
p value < .05 = **
p value < .001 = ***

Table 3.4*Goodness of Fit Statistics*

	Log Likelihood	Wald statistic	Likelihood ratio-test	Between location standard deviation / Standard error (random component)	Between household standard deviation/ Standard error (random component)
Months of Insufficient Provisioning (MINS)+	-2106.39	368.71***	1234.48***	2.13/0.4	0.37/0.27

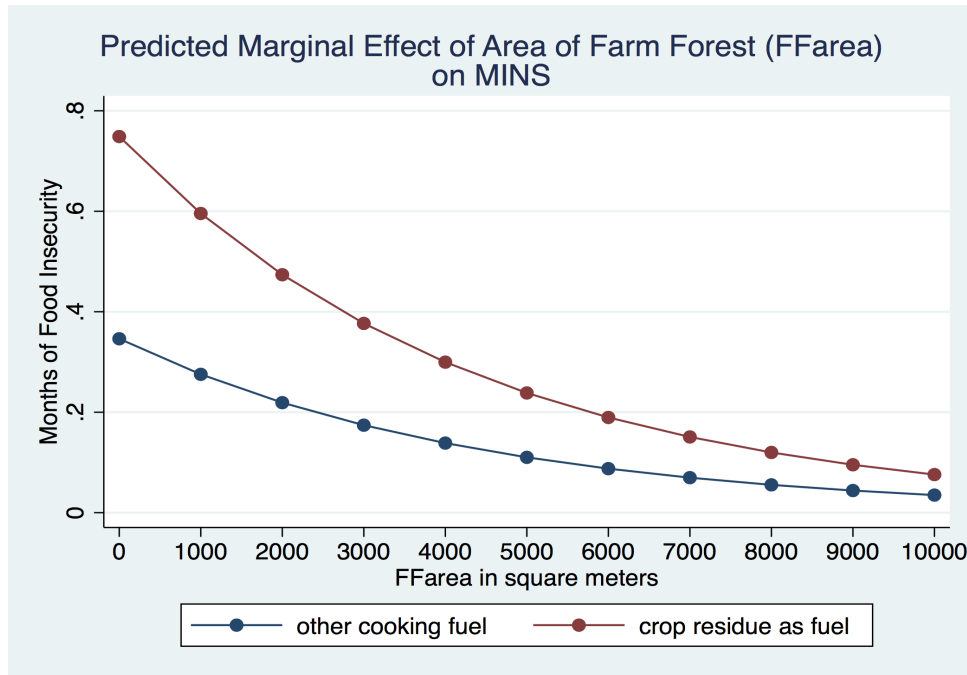
p value < .10 = *
p value < .05 = **
p value < .001 = ***

Margins plots are useful visualizations of the marginal effect of categorical variables on the relationship of FFarea to MINS. It is important to keep in mind that they only represent the fixed portion of the hierarchical mixed model that can be thought of as the mean effect before considering the random effects. Please note that the fixed portion of a multilevel mixed model is not the same as a fixed effect in the econometric although they sound similar (Little et al., 2000). Random effects, particularly for location in this data set, can have a significant multiplier effect for an individual household or location above and beyond the rather conservative estimates displayed in the marginal effects plots.

Observing the marginal effect of burning crop residue as a primary fuel source (see Figure 3.2), residue burning households were estimated to report twice the level of MINS compared to those that burned other fuels. As marginal effect FFarea increased, controlling for the influence of other variables in the model and random effects, the reduction in MINS for the crop residue burning households dropped off precipitously. The rate of reduction was almost double for residue-burning households as it approached the mean FFarea of 1000 m². With an estimated quarter hectare dedicated to FFarea, crop residue-burning households cut their expected MINS in half, and projected confidence intervals overlapped with non-residue-burning households. At FFarea above half a hectare, the expected MINS, considering the confidence interval, approaches zero.

Figure 3.2

Marginal Effect of FFarea on MINS by Crop Residue Use as Fuel

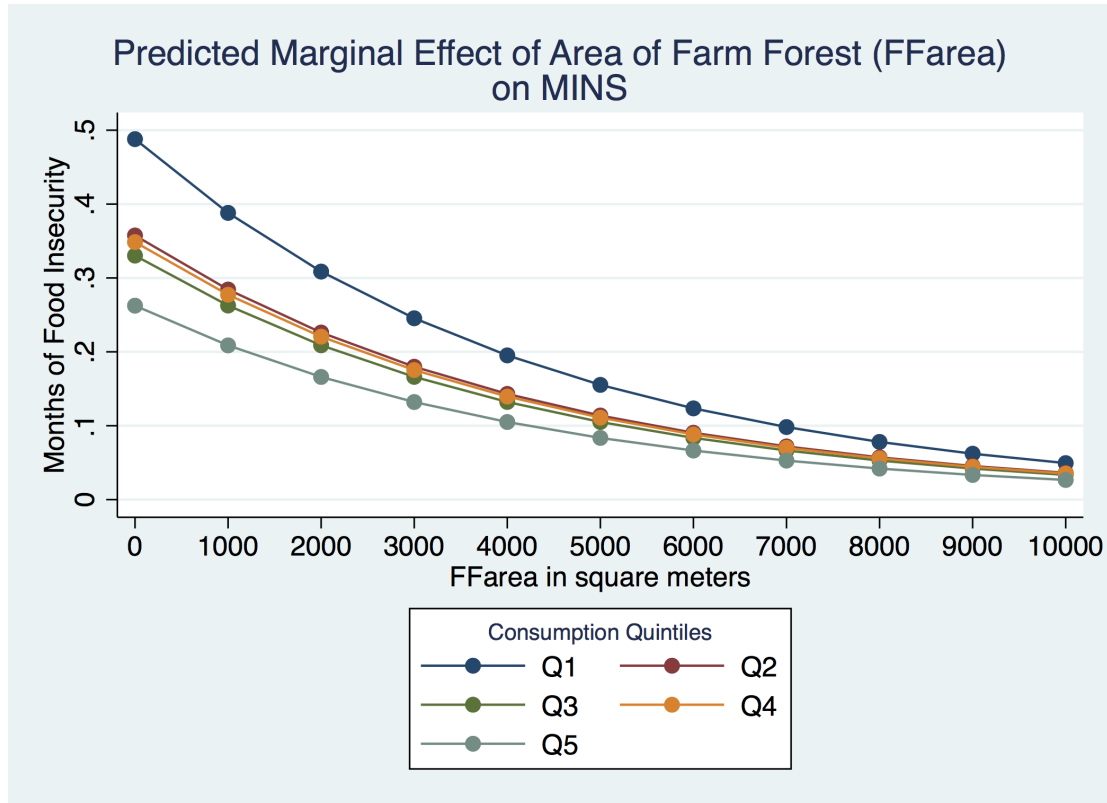


The poorest households without FFarea are expected to experience more than 1 week of additional food insecurity, nearly twice the men, than households in the wealthiest consumption quintile (see Figure 3.3). Convergence is more gradual for different wealth groups compared to the rapid drop for crop residue burning households with increased FFarea. Nonetheless, major disparities in MINS for different wealth groups are significantly reduced with one-third HA or more of FFarea. The marginal differences between consumption Quintiles 2, 3 and 4 appear small on the graph, and a chi-square test revealed they are not significantly different from each other. On the other hand, Quintile 1 is significantly different from Quintile 2 at $p < .001$, and Quintile 5 is significantly different from Quintile 4 at a slightly

lower level of $p < 0.05$. This again confirms that FFarea has the greatest impact for the poorest households in terms of MINS reduction.

Figure 3.3

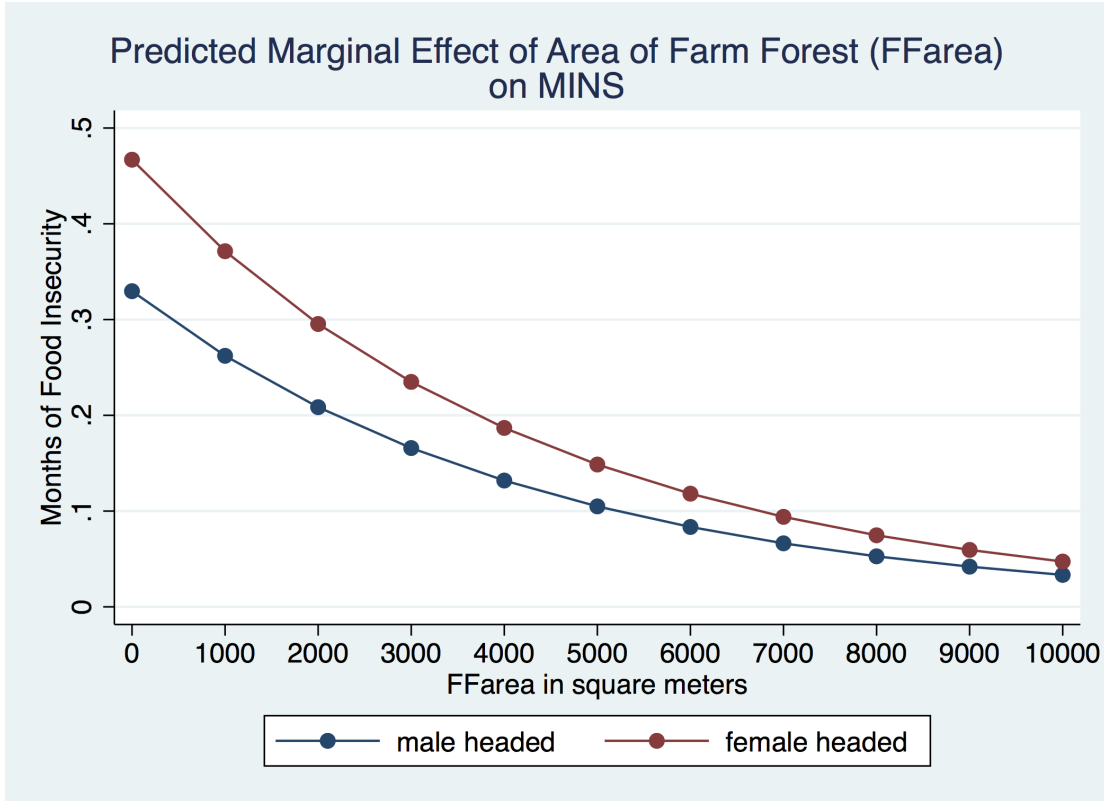
Marginal Effect of FFarea on MINS by Consumption Quintile



Female-headed households experienced higher levels of MINS compared to male-headed households (see Figure 3.4). The difference was greatest, about 1 week of additional expected food insecurity for the fixed part of the model, when neither female- nor male-headed households have FFarea. A chi-square test confirmed the marginal differences in female and male headed households is significant at $p < .001$.

Figure 3.4

Difference for Female Vs. Male-Headed Households in the Marginal Effect of FFarea on MINS



3.6 Discussion

Biomass, either indicated by a relative abundance in a farm forest or relative scarcity indicated by burning crop residue as a primary fuel, has a strong, significant relationship with the duration of food insecurity even after controlling for differences in wealth and gender of head of household. This points to the important role of biomass availability and management in the mitigation of seasonal food insecurity on small farms in rural areas of the Amhara Region. Having no FFarea exaggerated the

differences in MINS between richest and poorest as well as between female and male-headed households. Female-headed and poorest households also saw the most relief in terms of food insecurity duration from increasing areas dedicated to farm forests. The negative reinforcing cycles of food insecurity and poverty are well known (Dasgupta, 1997), and biomass poverty reinforcing food insecurity for the most vulnerable and economically deprived households appears to follow a similar pattern.

There is no clearer indicator of chronic vulnerability related to unsustainable agricultural practices and policy that threaten resilience than persistent seasonal hunger. Sustainable intensification indicators will play a large role in crafting policy and designing programs balancing social and environmental boundaries that address the two most pressing goals in the coming decades of (a) ensuring food security for more than 9 billion people and (b) facing potentially existential threats associated with environmental change (Leach et al., 2013).

Biomass production and management as an indicator of sustainable intensification, as represented in farm forests investigated in this paper, are an excellent example of potential intensification—in terms of production following the norms in agroforestry research—but also more directly to a food security well-being outcome. Rockström et al. (2017) were more explicit in their perspective piece that says agricultural policy and activities should intentionally move from a focus on production to goals associated with resilience and sustainable well-being. Shifts in goals and shifts in policies require the development and validation of indicators that reflect resilience and sustainable well-being. Biomass poverty (indicated by lack of

FFarea and residue burning), with a strong association with reducing duration of hungry periods and, thereby, markedly improving well-being, is prototypical of the types of indicators necessary to realize this shift to resilience and sustainability.

Trees are a universal sign of prosperity, well-being, and good policy. The hypothesis, building on recommendations from Chambers and Longhurst (1986), is largely confirmed by the findings and can be summarized this way: if the policy environment is favorable, farmers will grow trees to address issues related to seasonality in the tropics, which will improve their food security and well-being. Policy that can build on local resources and rely widely on freeing individuals and communities to act in their own best interest will have the highest opportunity for success and lower level of resistance to implementation.

Relatively small areas of forest made a consistently large reduction in predicted MINS—particularly for the poorest households. Dedicating 1200 m², approximately 10% of the mean farm area, would cut estimates of mean MINS by 15 days, reducing the expected period of food security deprivation by more than half. The potential for FFarea to reduce disparities in seasonal food insecurity measured by MINS across socioeconomic groups has powerful implications for adopting policies that encourage more trees and forested areas on farms higher on the policy and program intervention priority list.

Results are even more dramatic where FFarea contributes to cessation of crop residue burning. Even the smallest area dedicated to FFarea indicated a wide difference with a more than 75% lower MINS for non-crop-residue-burning households. As biomass fuel remains essentially the universal fuel source for cooking

in the survey, those households that do not burn crop residue and do not have FFarea are most likely able to collect fuel through access to common areas, which is likely to become increasingly less available in Ehtiopia. Farm forests are likely to become increasingly in demand in more places.

Farms forests are a sign of future adaptation. Deforestation and environmental damage are not the inevitable outcomes of increased population and agricultural activity responding to increased demand for food. Environmental degradation is most strongly linked to policy failures rather than the fault of poor people, as recent randomized control trials from Benin find secure land tenure is the key factor in reducing deforestation (Wren-Lewis et al., 2020). It is the same protection by the law and security of tenure that was also associated with increased tree planting on farms in Ethiopia (Dercon & Ayalew, 2007). Sustainable intensification will be key to both meeting the needs of the growing population and stopping further environmental damage with recent research identifying food systems with higher density of humans and livestock have more biomass production (Valbuena et al., 2012).

This approach to land sparing through intensification has perhaps the greatest potential to arrest further destruction of forested and common areas (Lamb et al., 2016). In fact, recent research from Southern Ethiopia confirms that “more people, more trees” (Duriaux- Chavarría et al., 2020, p. 10). This transformed perspective to seeing opportunities in improving both environmental and human health through sustainable intensification requires researchers and policymakers to fundamentally rethink their assumptions and take advantage of what Fairhead and Leach (1996) concluded in their book *Misreading the African Landscape* as “where history reveals

policy to be driven by misreading of environmental change, it may also reveal ways of revising policy” (p. 294). Rethinking assumptions makes it possible to see the farmer-initiated natural resilience solutions that ensure and insure food security while maintaining balance—including biomass cycling—with the environment.

Seasonality, both changes and increased intensity, will be a defining feature of climate change (Shukla et al., 2019). Seasonal dimension of human suffering, deprivation, and poverty—represented by recurrent periods of food insecurity—have persisted at least since they were first documented nearly 100 years ago (Richards & Land, 1939). Addressing biomass poverty through farm forests and other methods will play a central role in the global sustainable future.

The most important limitation of this study is the lack of greater involvement of small farmers in framing the hypothesis and interpreting the results from a contemporary Amhara region-aware perspective. Although updated nearly every decade by a group of authors interested in seasonality and actively engaged in participatory and policy-oriented research in rural communities, the hypothesis for this paper is likely even older than the cited work by Chambers and Longhurst (1986). Much more could also be done to investigate discussions of biomass poverty in critiques of the green revolution. A deeper dive into agroforestry, agroecology, and permaculture literature may identify additional research employing more quantitative and statistically representative data to model and measure links to food security, livelihood, and well-being outcomes. Review, case studies, and perspective pieces abound on natural approaches to reducing vulnerabilities with trees as a subset, but

there is very little research with original data and essentially none with population representative sample data.

Another limitation in this study is found in the ESS data itself and the design of the questionnaire. The survey does not specify the types of trees that are in the “forest” plots of the ESS definitively. Most trees are left out of this survey instrument that is clearly focused on commodified international varieties and investigating commercial aspects of agriculture. Luckily, Miller et al. (2019) have been not only writing about trees on farms but also engaging the World Bank and others to do a better job of including these important green assets in agricultural and multisector surveys. This work on better inclusion of trees could extend to a better approach to characterizing biomass production and management on small farm surveys and studies more broadly. When crop residues are considered by scientists, academics, and experts as waste—while poor farmers value them as fuel, fodder, and fiber that underpin their farming and livelihood strategy—there is the indication of a serious disconnect between the biases of the powerful and the wisdom and ingenuity of the poor who work the land every day.

These initial findings indicate a large gap in knowledge and ripe opportunities for multiple streams of future work. More research is needed to understand the size and dynamics of a broader range of observed farm forests. Comparative analysis could inform the optimal balances of trees to achieve desired biomass production in farm forests and other farmer priority-driven livelihood and food systems. This kind of analysis can inform and promote a biomass-centric perspective to ongoing programs mapping indigenous and other agroforestry systems.

Beginning in other regions of Ethiopia and then extending into other parts of Africa and the world, the role of trees should be thoroughly investigated, creating new data sets that include a wider range of green livelihood assets in the form of perennial, indigenous, and woody plants. Advocacy for greater inclusion of natural and environmental status, management, and access in survey data—and the promotion of panel data more generally—will serve to better illuminate the underlying processes and indicators of resilience and sustainability. There is a great deal of work to be done to compare observed trends in policy and policy change that encourage greater autonomy in livelihood choices and natural affinity to well-being and food security-focused strategies that favor increasing trees and other natural green assets. Finally, some technology, such as improved synoptic observation with remote sensing, may help expand awareness and understanding of the extent, variability, and magnitude of both biomass poverty and local solutions to biomass constraints emerging in the face of current challenges.

Perhaps most encouraging, there seems to be a growing awareness—brought about by existential threats to the planet related to facing environmental change—that the need to ensure the basic dignity of food security to an unprecedented number of humans will require shifting the focus from agriculture on commodity production at any cost to the sustainability and resilience of agriculture and food as part of natural systems (Rockström et al., 2017). This work investigated an old solution of dedicating a relatively small portion of the farm to promote a foresty treed area. This practice can supplement the inadequate production of biomass to ensure the natural function growing things and nonhuman animals and support livelihood in a

sustainable way. These are observations, not of an interventionist project or specific policy, but of the natural outgrowth of farmers enjoying more sovereignty over their decisions, resources, and food security.

Food security as a first concern, ensured by local resources and in harmony with natural systems, is a priority for rural people that explains widespread resistance to technocentric solutions with market-focused—rather than well-being focused—objectives (Morris, 1989). There is a promising future, as more data sets become available, to grow the evidence base of natural autochthonous approaches that harmonize with geography, climates, and context where farmers pursue fruitful and sustainable futures.

3.7 Conclusion

Employing a longitudinal hierarchal linear mixed model that controlled for key determinants of food security such as wealth, gender of head of household, and location, this research was used to quantify the marginal contribution of farm forests—defined as small multipurpose stands of trees—to reducing food insecurity duration on small farms of the Amhara Region of Ethiopia. Results of this research show a mean-sized farm forest of 1000 m² reduced the mean reported duration of food insecurity by nearly half—or approximately 7-15 days—with the greatest benefits for female-headed and poorest households. The greatest reductions in food insecurity duration were for female-headed and poorest households that burn crop residue as a primary fuel. Focusing on trees—including multispecies farm forests as sources and stores of biomass with multiple uses rather than overly narrowly accounting for a commodified fruit or nut—reveals the critical biomass-related

counter seasonal functionality and contribution to household well-being through improved food security.

Biomass poverty occurs when households lack enough biomass production or effective management to meet requirements for optimal function of their farming or livelihood strategy. This research found households that keep farm forests as a ready source of biomass throughout the year are less likely to burn crop residue as a primary fuel and risk comparably shorter durations of food insecurity. Sustainable intensification is an important policy goal to reduce hunger and spare land while building resilience to potential increased seasonality under climate change. Farm forests represent a potentially powerful solution—as well as possible indicator—of these sustainable livelihoods.

Chapter 4: Green Assets: Modeling and Measuring Food and Nutrition Security Outcomes From the Autochthonous Treelike Perennial *Ensete ventricosum* (Welw.) Cheesman as a Resilient Pathway for Small Farms in Ethiopia

“[enset] q’ils cultivant en grand pour leur consommation – ‘culture d’une importance encore plus capitale que ne l’est celle du Froment chez nous’”

“[enset] grown in great part for auto-consumption is – ‘a greater cultural asset of traditional cultivation of than that of our own wheat’”

D Bois in the Bulletin of the Museum Nationale d’Histoire Naturelle 1930
quoting correspondence from Scey-Montebeliard

4.1 Introduction

A lack of original research is partly responsible for the inability to resolve the global food system’s cardinal incongruity of small farms producing the lion’s share of food in most countries while these same small farmers are themselves disproportionately food and nutrition insecure (“Ending Hunger,” 2020). Achieving poverty and hunger-related Sustainable Development Goal targets hinge on reducing deeply rooted disparities in those marginalized places, communities and groups that economic growth and mainstream development have left behind (Stuart & Samman, 2017; United Nations General Assembly, 2015). Persistent ultra-poverty associated with chronic hunger is concentrated among African farmers living on small plots of land that are nutrient and/or water constrained (Ahmed et al., 2007; Barrett, 2014; Tittonnell & Giller, 2013). Adding those displaced from small farming livelihoods that

failed in the face of conflict or climate change, the estimated total number of undernourished people in drought-sensitive rural sub-Saharan Africa steadily increased from 2014 to 2019 to more than 250 million (*The State of Food Security, 2020*).

African economic growth, thus far in the 21st century, outpaced all other regions except for developing countries in Asia, but well-being gains are unequal and continue the decades-old pattern of neglecting to adequately protect marginalized groups (Organisation for Economic Cooperation and Development & African Union Commission, 2018). This undesirable trend in food security highlights both the unlikelihood of success in meeting hunger and well-being related Sustainable Development Goals by 2030 through economic growth (U.N. Task Force on Financing for Development, 2020) and the implausibility of sustainably intensifying production on the smallest farms with current agricultural development approaches. Such approaches largely depend on nutrient mining (Vanlauwe et al., 2014), technology better suited to large farms (Harris & Orr, 2014), and commodity cereal crops with limited potential upside value. The result forces household members off the farm to seek supplemental income to make ends meet (Frelat et al., 2016).

Relying on technology-centric solutions of a market-focused food regime requires increasing flows of expensive annual inputs to produce irregular profits. As a result, rainfed agricultural areas have only become drier and poorer while using nonregenerative practices rather than investing in fundamental assets like soil quality. The small farms of Africa, on average, have also become smaller (Hazell, 2020). Smaller farms that successfully reduce hunger need refreshingly unconventional,

more sustainable, intensification strategies that are locally adapted to the risk environment with low adoption costs and oriented toward food security outcomes that ensure basic consumption stability.

Small farm-oriented food systems proven to support relatively high population densities exist. There are more than 500 million small farms around the world (Lowder et al., 2019; Lowder et al., 2016). By sheer force of numbers, innovative solutions for sustainable intensification are likely to be found among these locally adapted food systems formed around small farms and may, in practice, prove synergistic by providing much needed and appropriate food system context to complement solutions originating in a laboratory or on a research station. Leach et al. (2020) suggest investigation of diverse food socionatures, where place-specific human and nonhuman relations coevolved to produce alternative and potentially more equal distributions of both desirable and undesirable well-being outcomes. Such an approach would be a source of novel research to support more secure and sustainable food system policy solutions and programmatic approaches.

A food system perspective, rather than commodity specific or technology focus, is also particularly policy relevant for understanding well-being issues facing the hungry poor because their livelihood strategies are typically deeply connected, not only with production, but more broadly with earning money for purchasing, procuring, and processing a variety of foods (Barrett, 2008b). Currently successful alternative livelihood pathways—that value a broader range of well-being outcomes in addition to income and are supported by indigenous or marginalized knowledge systems and institutions—may provide more immediate, context-sensitive, and less

disruptive options to inform transformational programs and policy (Leach et al., 2010). Innovative and resilient pathways rooted in a diversity of traditions and a plurality of perspectives may be germane to reversing the troubling food security trends. These time-tested systems also likely offer the most apposite, accessible, and sustainable solutions to food system transformation.

Until recently, household surveys rarely considered income derived from forests or other common areas (Angelsen et al., 2014; Babulo et al., 2009). Trees on farms (TonF) that did not produce commercial international varieties of fruit along with indigenous trees, shrubs, or perennial crops were almost never included (Miller et al., 2019). Only with the recent Ethiopia Socio-Economic Survey (ESS)—and similar Integrated Surveys on Agriculture jointly supported in a limited number of countries by The World Bank and Bill and Melinda Gates Foundation—have representative panel data sets including agricultural production, rural livelihoods assets, several species of TonF, and socioeconomic well-being outcomes become available (Carletto et al., 2015). The regional sampling structure of the ESS makes available for the first time a statistically representative panel for a unique regional autochthonous food system based on the enset (*Ensete ventricosum* (Welw.) Cheesman).

Enset is a treelike perennial staple crop in an Ethiopian food system—predating the introduction of cereals in the area (Stanley, 1966)—that has supported some of the highest population densities on the continent for millennia (Smeds, 1955; Westphal et al., 1975). Germane to the challenging future of African small farms more generally, enset cultivation increased in reaction to farms becoming smaller,

according to research undertaken with Wolayta households of Southern Ethiopia (Dessalegn, 1995). Cultivation of a few enset directly adjacent to the dwelling has been reported as contributing to food security for households with such small holdings as to be effectively landless (S. A. Brandt et al., 1997). The persistence and the intensity of enset cultivation was a motivating factor in the site selection for this study. The uniqueness of a food system based on an autochthonous perennial treelike staple raised expectations for illuminating previously understudied elements and time-tested pathways to resilient and sustainable food security from a unique alternative point of view.

The moniker “tree against hunger,” or a close variation, is common across different cultural groups cultivating enset and was first recorded in a European language by the traveling Portuguese priest Jeronimo Lobo in a 1640 description that additionally noted “anyone that has one of these trees is not in fear of hunger” (S. A. Brandt et al., 1997, p. 8; Lobo et al., 1640/1984, p. 245). The enset, or “false banana,” has been characterized as the most understudied crop in Africa, even as it is the second most widely grown in Ethiopia and a staple for over 20 million people (Borrell et al., 2019).

Endemic to the highlands perennial agro-ecological zone of East Africa, Garrity et al. (2012) described the region as a “natural experiment” for intensifying resource-constrained small farms faced with increasing population pressure. Although several small-scale studies and anecdotal information find enset systems to be drought tolerant and essential to ensuring well-being and food security (Abebe & Bongers, 2012; Negash & Niehof, 2004; Quinlan et al., 2015), there is a lack of

systematic quantitative investigations that model the system elements or livelihood assets and approaches that achieve these reported desirable outcomes (Borrell et al., 2020).

In this paper, longitudinal asset-based and spatially informed hierarchical quantitative modeling were applied to investigate food security outcomes utilizing a statistically representative regional subset of the ESS for the enset-growing region. The hypothesis is essentially equivalent to the 17th century observation of Jeranimo Lobo. The research seeks to quantify the ability of relatively small areas planted with enset to ensure household level food security. The research begins from the basic proposition of Chambers and Leach (1989) that trees, behaving like an asset, are the savings and security of the poor.

Enset, as a treelike perennial whose primary purpose is to be eaten but can also be transformed to meet other farm household needs or sold to raise funds, prompted the reconceptualization of tree-related savings concept toward a broader framing as a multipurpose green asset. Recognizing money and food security are often correlated but not perfectly substitutable, this research included a measure of enset quantity in the analysis in a similar way to other more conventional asset measures rather than attempting to first transform stands of enset into their monetary value. As discussed in a later section, the particular difficulties in estimating yields and income from enset are significant if not atypical for nonconventional crops and may have contributed to aforementioned meager agricultural research attention. This research then was used to model how much enset-based savings, in the form of a

green asset measure, contributes to provision of food security and strengthening resilience in two steps.

Small numbers of enset trees were expected to make a relatively large positive difference to household food security for the poorest. Like other assets conforming to the assumption of diminishing marginal returns (Carter & Barrett, 2006), the benefit plateauing at one or more dynamic equilibria was expected as the amount of mature enset increased toward a threshold. In a second modeling step, this research was used to investigate if the threshold amount of mature enset had any independent “marginal” impact on household food security and nutrition with a multilevel modeling approach that controls for other income and asset poverty variables as well as context specific fixed effects like “starting points” and random effects of local weather.

4.2 Background

4.2.1 Green Assets—applying asset-based approaches to understand food security dynamics in agricultural systems with autochthonous perennial crops and trees on farms (TonF)

Assets are a store of value to be differentiated from monetary flow measures of income or consumption (Hoddinott & Quisumbing, 2010). Both store and flow indicators can be causally related to well-being status. While income-related benefits are more likely to be mediated through the market, assets affect levels of income as a means of production and can be a more direct source of enjoyment—like tasting the difference between a store-bought and homegrown tomato. Direct benefits of taste and safety made homegrown maize worth significantly more to small farm

households than grain available in the market, according to research from Kenya that weighed preferences against premiums willing to be paid (Hoffmann & Gatobu, 2014). Resilience-building aspects of TonF, seen as a multiyear reserve of value, may go beyond the risk management aspects of other traditional crops in smallholder preferences. Dessalegn (1995) reported households in the enset growing zone of Ethiopia maintained an enset garden of sufficient size as a strategic crop intended to maintain food security of the household through any potential future crisis. It is the strategic allocation of land and labor to manage future shocks—rather than only meet initial needs—that illustrate the greater role of assets in productively contributing to household welfare and sustaining well-being during trouble.

Assets, along with agency and institutions, are at the foundation of rural livelihoods and critical to understanding household-level resilience and capacity to sustain minimum well-being while absorbing or adapting to shocks and stresses (Chambers & Conway, 1992; Moser & Dani, 2008). As stores of value that can be drawn upon when confronting large or unexpected expenses, assets have a broader role in sustainable livelihoods beyond increasing production. Maintaining a minimum asset level to re-establish livelihoods—even at the expense of current consumption—is a priority for households in risk-prone environments such as rural Ethiopia (Carter et al., 2007). In a wide literature on smallholder autarky with respect to traditional staple foods, one could broadly generalize key motivating factors for maintaining a degree of sovereignty in livelihood choices around provisioning—in particular with traditionally cultivated plants and other traditional assets—from greater to lesser importance: (a) asset preservation, (b) cultural preference and taste, (c) security of

minimum food access, and (d) additional income once basic needs have been assured (Barrett, 2008b; Fafchamps, 1992; Zimmerman & Carter, 2003).

Assets, or rather, lack of a sufficient minimum level of assets, investigated with longitudinal methods significantly advanced the understanding of poverty dynamics that differentiate between those that are temporarily suffering low levels of consumption or monetary flows from those who are chronically hungry and poor (Baulch & Hoddinott, 2000; Carter & May, 2001; Filmer & Pritchett, 2001; Grootaert & Kanbur, 1995). When applied to increasingly available panel data, asset-based approaches prove policy relevant in their ability to identify processes and quantify asset deficiencies that contribute to some households or geographies becoming trapped in poverty and hunger (Carter & Barrett, 2006; Jalan & Ravallion, 2002). The systematic colocation and coincidence of hunger and extreme poverty is illustrative of a negative gravitational pull on the most vulnerable households and communities toward persistent and extreme undesirable well-being outcomes. Dasgupta (1997) used asset-based longitudinal methods to articulate these negative reinforcing feedback processes where human capital is undermined by cyclical or persistent food insecurity—that in turn leads to low productivity that traps households across generations in hunger-driven extreme poverty, vulnerability, and persistent food insecurity.

Asset-based approaches to poverty assessment, most closely associated with the thread of development economics literature related to poverty traps, can be potent instruments for identifying clear disparities and distinguishing levels of inequality as an evidence base for designing policy or program interventions (Barrett et al., 2016;

Barrett, 2008a). Premised on the law of diminishing marginal returns, the hypothesis behind identification of concentrations of asset-related disparities supposes further asset accumulation for the least wealthy, the relatively poor, and is more profitable and, therefore, more likely to grow up to a point where the dynamic switches (Carter & Barrett, 2006; Lybbert et al., 2004; Naschold, 2012). After a dynamic equilibrium point is reached, adding additional assets of the same type becomes less profitable with increasing diminishing marginal returns; relatively rich households will divest of excess assets of that type in favor of another asset option with better returns.

Proven robust in identifying two distinct types of typical asset dynamics, the basic approach is to compare panel measurements of single items or asset indexes at two or more points in time (Barrett et al., 2016; Carter & Barrett, 2006). In a population without a poverty trap, there should be an observed convex curve in plotting current assets measures_(t) against asset measures at a time lag_(t-1) that will cross a simple expected static asset line $f(y_t=x_{t-1})$ at a dynamic equilibrium point A^* (see Figure 4.1).

This process driving the convex curve is called convergent asset dynamics. Below the dynamic equilibrium point households are expected to continue accumulating assets, and those above this point in the research population are expected to lose assets, accumulate them more slowly, and eventually switch efforts on accumulation to another store of value that has higher marginal returns. If the asset equilibrium point A^* is above the desired well-being level, such as the poverty line, then households are expected to converge toward this point of improved well-being

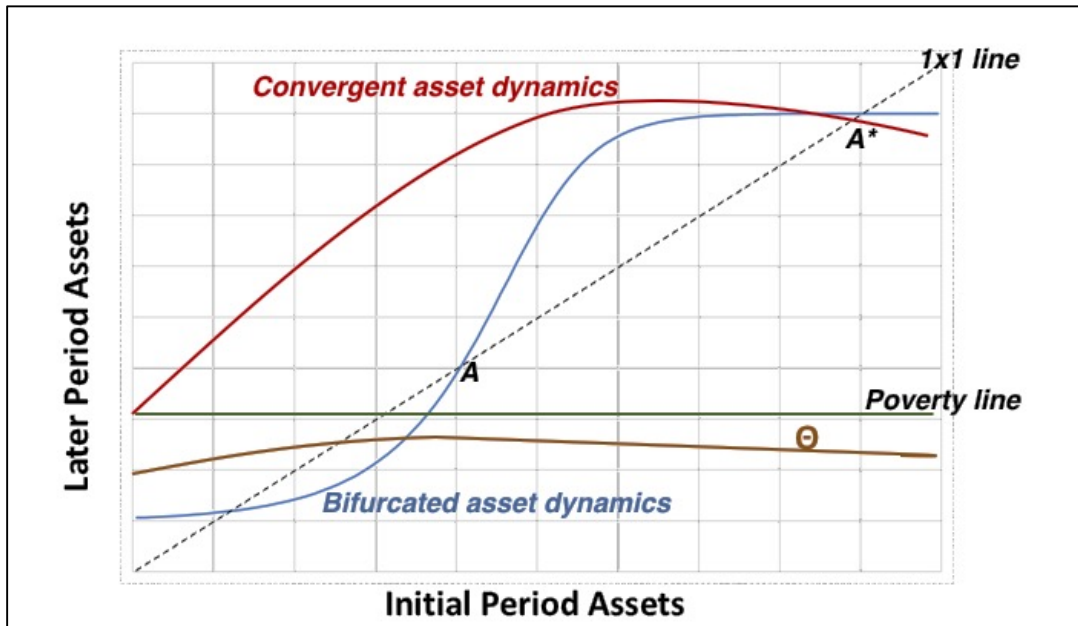
over time. This is the possibility that drives optimistic expectations of households growing out of poverty over time (Kuznets, 1955; Sachs, 2006).

In a second possible situation, there should be an *s*-shaped curve in the plot of asset measures against lagged-asset measures indicating two distinct equilibria that diverge at point A. In this situation, there are constraints, structural factors or otherwise, preventing the convergent asset dynamics. This indicates a poverty trap when the lower equilibrium point is below a poverty line and, therefore, exerts downward pressure on asset accumulation for some households that prevents them from arriving at a higher level asset and welfare equilibrium. This is called bifurcated asset dynamics and can be readily applied as an evidence base for policy or program interventions intended to help the poor when identified (Barrett et al., 2016).

In an exemplar case where there is a clear difference in access to specific resources, services, or technologies between households nearer each of the bifurcated equilibrium points (e.g., poor people lacking jobs live predominantly in an area with no transport to employment hubs), a relatively strong and simple policy solution may be evident such as subsidising public transportation to jobless households. Obviously, program and policy design becomes more complicated when sustainable solutions also require addressing the underlying causes of bifurcated access, in the broader sense of lived access with protections from marginalization and alienation, that may be mired in more complex feedbacks and messy historical evolution of inequality.

Figure 4.1

Idealized Asset Dynamics



Apropos to the observed megatrend of ultra-poverty concentration on African small farms that are clearly on a pathway to destitution, bifurcating from other small farming communities that continue to by-and-large live relatively well, a third type of possible asset dynamics has been identified by a limited number of authors as stagnation in a low productivity trap. This is represented on Figure 4.1 as the flattened curve at the bottom labeled by Θ Oomicron. Prima facie, this dynamic is troubling in that it would imply nearly all households are living below what that society has already determined to be an unacceptable level of consumption required for dignity indicated by the poverty line. Stagnation does not seem to conform to the principles

of convergence and is rarely observed in practice at either macro levels of nations or at individual levels over any significant length of time (Kraay & McKenzie, 2014).

Only at a mesoscale for a subpopulation or a geographic region could these wider concentrations of disparity coalesce as a temporal-spatial geographic poverty trap. Jalan and Ravallion (2002) found contextual factors of marginalization, infrastructure, and other geographic constraints led to a spatial or regional pattern of lower productivity. The onset growing region was, in fact, identified as a stagnant growth area in low productivity poverty trap as measured by their livelihood asset index by Kwak and Smith (2013). Nutrient and water cycle degradation, reinforcing the apparent socioeconomic marginalization as primary drivers of geographic poverty trap dynamics, has been postulated by some authors concerned with links between natural resources, environmental services, and sustainability (Barbier & Hochard, 2018; Barrett et al., 2016).

Barrett et al. (2016), in a stocktaking survey of asset-based poverty analysis literature, noted the overarching importance of the class of assets associated with natural capital and the associated biophysical mechanisms to rural livelihoods and concluded that natural asset-based studies have been “strikingly thin.” Mixed and limited evidence for the persistence or underlying causes of these low productivity poverty traps do not advance easy policy solutions, but identifying the dynamics of asset equilibrium(s) have proven a useful tool to exploring current constraints to more equal development and well-being (Kraay & McKenzie, 2014). Investigating asset dynamics—associated with overexploitation of natural and regenerative capital that may undermine resilience—appears increasingly relevant to assess the persistence

and possible permanence of concentrated low productivity, chronic vulnerability and food insecurity.

Green assets are defined in this study as a store of living green biomass that accumulates value over time and more narrowly defined in this study focused on enset as autochthonous, in the sense of being broadly indigenous and involved in coevolution over the medium and longer term of identifiable food socionatures, TonF, and other perennial plants on small farms.^{iv} Autochthonous TonF as green assets are to be distinguished from farmed trees—both in plantations as well as agroforestry—that primarily promote intentional intercropping of trees to boost production of commodity crops in a more sustainable way.

Agroforestry with a vibrant research community has been successful in boosting production while conveying other benefits such as improved nutrient cycling or water and soil conservation in case studies across Africa and around the world (Garrity, 2004; Garrity et al., 2010). However, agroforestry does not necessarily focus on the cultural, poverty alleviation-related, and other characteristics of the green asset-type plants that coevolved in any specific place as stores of value that lend themselves to quantification in similar ways to other assets.

Green assets are rather strategic and valued for their flexible or asynchronous timing vis a vis annual crops. They can be fully harvested to realize a lump sum payout of multiple years of value accumulation. Green assets are also privately held in contrast to more general notions of natural capital that are often commonly held. These distinctions merit consideration of non-cropped and not necessarily annually

fruit or nut producing TonF being classified as a distinct class of livelihood assets—green assets.

It is reasonable to assume that if green assets were a significant direct source of income, they would have been more widely included in agricultural, forestry, and socioeconomic surveys and research.^v The assumption is, therefore, their contribution to livelihoods or well-being would be better measured and discussed with indicators and outcomes that are not limited to monetary flows but, rather, with resilience, sustainability, and livelihood well-being outcomes. In fact, Quisumbing and Baulch's (2013) work on chronic food insecurity in Bangladesh was the only study found that included value of "trees and land" as an asset in their index; however, the authors did not report any tree-related results or include TonF further in the analysis.

Chambers and Leach (1989) proposed secure tree tenure was a prerequisite to robust investment in TonF that serve not primarily to provide a flow of income but as savings that can be used directly as needed (e.g., rebuilding a roof or sold to pay for an irregularly large expense or contingency). Although several case studies in Asia confirmed trees were sometimes used to raise funds or secure credit (Chambers et al., 1989; Conroy, 1992), large numbers of farmers investing in eucalyptus as a cash crop eventually saturated local markets, producing rapidly diminishing returns in Asia (Conroy, 1993). By contrast, research from Ethiopia on a 20-year panel demonstrated that savings over time in enset as a green asset, playing an instrumental role in supporting other types of asset creation, resulted in significant increased investments in the households' second most valuable asset—livestock. At the same time, investment in eucalyptus as a TonF led to significant increases in the households' first

investment choice measured by dwelling value (Morrow et al., 2018). As green assets increased, they were not necessarily turned immediately into monetary flows of income but, rather, into better well-being outcomes like improved food security and increased investment in other assets.

In risk prone and marginalized areas, green assets may play a role similar to other renewable assets, such as livestock, in arid-land pastoral communities. As a source of resilience—because of their natural ability to grow back or regenerate as long as a minimum viable asset level or, in this case, reproductive herd size is maintained—livestock can aid households in recovery from shock (Cissé & Barrett, 2018; Lybbert et al., 2004; Meadows, 2008). The stock of animals, according to Lybbert et al. (2004), is determined predominantly by ensuring a herd size large enough to survive the most severe shocks. In other words, the dynamic equilibrium of animals is not determined solely by subsistence needs or to maximize income but, rather, in a sort of mental accounting of what is necessary in remain resilient under a worst-case scenario.

4.2.2 Enset cultivation and potential indicators of savings, security and resilience

For subsistence farmers, enset provides a savings and security function. Both the growth pattern and the processing of enset facilitate storing and increasing value that can be saved until required. As a monocarpic perennial, enset can be harvested at any point prior to flowering, which occurs at approximately 7-12 years old depending on the local climate and landrace, though starch accumulation in the corm and pseudostem increases with maturity (Borrell et al., 2019). The resulting food products comprising the pulverised corm and pseudostem are traditionally fermented for

several months to improve palatability (Tamrat, 2020). The fermented product can be stored in pits for long periods, and if needed, quantities of pulp can be removed for consumption.

Flexibility is at the core of enset's contribution to household security. Households require ~60 mature plants on average to meet annual staple food requirements (Demeke, 1986). Sale of surplus enset products is possible on local markets, though enset is primarily consumed within the household (S. A. Brandt et al., 1997). As needed, larger enset plants can be sold as a standing plant before being processed or a portion of fermented starch may also be taken from the storage pit for sale at any time (Borrell et al., 2020). If other crops are doing well or money is available for alternative foods, households can generally save the current stand of enset for another year. Security from green assets such as enset would include both the consumption stability implied in food security and the more resilience-focused sense using enset as an auxiliary resource for contingency expenditures. Taking together the resilience and food security aspects, the moniker "The Tree Against Hunger" resonates both with the communities that farm enset and those who research it (S. A. Brandt et al., 1997).

Resilience and sustainability through land sparing is evident in the economical use of space and is an important strategic characteristic of enset cultivation (Tsegaye & Struik, 2002). Enset is clonally propagated, enabling a 2- to 3-year-old plant to generate up to 200 suckers within a few months. Each of these is genetically identical to the parent and will share any desirable traits for which the plant was selected (Borrell et al., 2019). Farmers employ a strategy of repeated transplantation which

makes efficient use of space for different age-classes, maximizes use of manure, and likely delays maturation, encouraging allocation of resources to edible starch tissues. This efficient use of space makes enset the crop with highest biomass and food yield per hectare in Ethiopia (Kanshie, 2002; Tsegaye & Struik, 2001) and able to support a larger population per unit area than regions relying on growing cereals (Yirgu, 2016).

Specific enset traits relate to improving individual and household resilience. Diversity in uses and coproducts include (a) as medicine (certain landraces); (b) the use of leaf midribs and petioles as cattle fodder, particularly in the dry season; (c) fiber as a coproduct of processing; and (d) the use of leaves and leaf sheaths as thatching/fencing or mulch. Enset is indigenous to and was domesticated in the current enset growing region. The plant is ostensibly well adapted to the variance of local climate conditions with various authors tentatively citing drought and frost tolerance (Quinlan et al., 2015; Zewdie et al., 2008).

Well-managed enset home gardens are a hallmark of well-being for the household as “well dressed kids give prestige to their parents, well managed enset homegardens give prestige to household and hamlet” (Olango et al., 2014, p. 11). In contrast, a lack of sufficient mature enset plants is indicative of premature consumption to meet critical emergent or chronic ongoing needs (Habtewold et al., 1994). Having a large number of mature enset is recognized as a status symbol (S. A. Brandt et al., 1997). As an exemplar of its cultural importance, typical housing of an enset growing household is displayed on the SNNPR’s regional flag and used as the official regional seal reflecting the importance of enset to common identity.

While enset signifies the presence of a source of staple food, it also indicates additional food diversity, as enset farmers tend to produce, on average, more than 10 different crop and livestock species (Sibhatu et al., 2015). Working with women in focus groups and describing the multifold uses of enset to meet household needs, MacEntee et al. (2013) reported the common conclusion of discussions with the women who process and use the plant is “enset is a good thing” (p. 105). Novel, and perhaps very useful, indicators of food security and resilience measured at farm household level but reflecting more broadly the status of the traditional food system could be developed and tested through an improved understanding of the role of key traditional foods. An indicator reflecting the status of enset, based in understanding of its cultivation practices and role in the traditional provision of food, as well as reflecting the health of the larger role of the farm system, may prove to be an innovative example of a context-appropriate resilience and food security indicator required for greater understanding of sustainable pathways to intensification on small farms.

Enset’s particular traits and cultivation practices has meant that it is difficult to apply typical survey methodology, resulting in enset being both overlooked in regional agricultural surveys as well as inclusion in carbon accounting (Negash et al., 2013); there has been significant variation in yield values when it has been included (Borrell, 2020). Similarly, the time lag between planting and harvesting (4–10 years, depending on the local conditions and management efficiency) may result in data artefacts. For example, overharvesting (harvesting enset at a faster rate than enset

plants are replenished) could give the temporary impression of increased production while the overall hectareage declines—unless rigorous survey methods are employed.

Trends in the market price of enset products are poorly known (Lefebvre et al., 2016). Many of these issues were encountered in the three-waves of the ESS where harvest quantities seemed inconsistent, and methodologies and indicators for measuring production for estimating yields changed between survey rounds.

Considering these issues and aiming to select the most reliable estimates available in the panel data, the enset-related independent variable for modelling was constructed from area measured by GPS along with an estimated percent coverage of the plot when intercropped with other plants and the age of plants estimated by the farmer. Menset is defined as area of enset more than four years old in square meters.

4.2.3 Food Security Indicators and the Ethiopian Socio-Economic Survey

Food security is a multidimensional concept that has evolved since it was initially put forward as a political statement in the 1950s linking protection from hunger to wider political stability (CFS, 2012). The most widely cited definition from the United Nations Food and Agricultural Organization outlines the key elements of availability, accessibility, and utilization of food, as well as the stability of those elements over time, as essential to the enjoyment of food security (United Nations Food and Agricultural Organization, 1996). The broad nature of food security spans a range of disciplines including agriculture, economics, health sciences, nutrition and resilience. No single indicator or unidimensional measure for food security has been universally accepted, perhaps because of these diverse disciplinary perspectives and the range of experiences of food insecurity that span micronutrient deficiencies from

a low-quality diet in an urban food desert to weather-related production shortfalls in a subsistence agricultural community (Webb et al., 2006).

Food security measurement that began with simple macro level production figures at a national level began to add different disciplinary and technical perspectives when confronted with other indicators of hunger. The realities of inequality of local food availability, when measured with market of household surveys, were again confronted with the complexity of volatile household access to food or more individual level differences where poor nutrition outcomes associated with food utilization were concentrated among subgroups of people. Drèze and Sen's (1989) work on famines, in the face of sufficiently available but inaccessible food, gave rise to the entitlement theory, basis of access measures of economic-focused food security, becoming common in the 1990s. Because of climate-related events, conflict, and market price volatility—in addition to seasonal deprivations commonly increasing food insecurity—more emphasis has been given to the element of stability.

More recently, when simple identification of hazards and risk response has not provided enough evidence for effective program or policy interventions to address the stability concerns, there has been a demand for more focus on measuring a capacity for resilience in understanding food security status (Frankenberger, 2013). Food security analysis, therefore, usually relies on presenting several food security-related indicators following the logic established by their historical development and then triangulating the results by household, community, or region to assess overall food security status. The somewhat surprising, but common, situation where different well-accepted food security indicators do not correlate—and may in fact diverge—is, in

fact, a reflection of the nature of food insecurity specific to a particular context or food system (Barrett, 2010). In the case of divergent food security indicators, contextual information and more sophisticated systems analysis can be employed to more accurately assess who and under what circumstances food insecurity occurs.

The ESS collected four widely employed food security indicators used as dependent variables in the analysis. The indicators and a brief explanation of how they relate to the different elements of food security are included in Table 4.1. Months of food insecurity (MINS) is a typical microeconomic measure used in areas with seasonal hunger. It is a slight adaptation of an early food security indicator required for several years for USAID (i.e., months of adequate household food provision) that agricultural surveys would collect to assess the post-harvest food stores. MINS is more inclusive of food purchased at the market or that is acquired in other ways such as gathering or working for in-kind food.

The Food Insecurity Experience Score (FIES) was developed to measure food insecurity in primarily urban contexts of middle and upper income countries for their food assistance programs where participants almost exclusively access food through markets. The FIES has been successfully applied at scales ranging from an add-on to a local survey to international global comparisons reported in the U.N. Food and Agriculture Organization's flagship annual food security publication (Cafiero et al., 2018). FIES ranks severity of food security from worrying about accessing enough food to more severe experiences such as going without eating for a day. FIES is highly sensitive to short-term changes in the financial situation of poorer households and used as SDG target indicator 2.1.2 (Morrow, 2018).

Table 4.1*Food Security Elements and Indicators*

	Utilization	Access	Availability	Stability
MINS (months of food insecurity)		May indicate temporary food purchasing issues from loss of income or market failure	Typical measure of availability of food from own stores or markets	A measure of intra-annual variability in food security; particularly for measuring 'lean season'
FIES (Food Insecurity Experience Score)		Food insecurity perception indicator are considered typical measure of access to desired level of food		Skipping meals and going one or more days without food are included as more extreme examples of food insecurity in this scale
STUNT (Household has at least one stunted child)	Anthropometry is a typical outcome measure of utilization as nutritional status			
HDD (Household Diet Diversity Score)	Associated with more nutritious diet	Associated with access to a variety of food in the market	Associated with availability to a variety of food in the market or on farm from gardens and livestock production	

Children's nutritional status is a well-being outcome from the combined effects of health care and childcare practices, clean water, and several other factors in addition to adequate and well-balanced food consumption (UNICEF, 1990).

Comparison of linear growth to an age adjusted reference group can identify children

under 5 years old who are more than two standard deviations below the norm and, therefore, identified as stunted. To make this indicator—measured at the individual child level—comparable to the other variables measured at household level, the variable STUNT was defined as a household with one or more children stunted. Most directly related to the consumption patterns of the household, and broadly applicable to the elements of food security, the Household Diet Diversity Score (HDD), following the method proposed by Hoddinott and Yohannes (2002), groups foods by using a 12-category scale of household diet diversity that includes categories, such as staple cereal and protein-rich foods or vegetables, and then makes a simple count of how many food groups were included in the household's diet in the last week. Data were downloaded from the World Bank micro data site (<https://microdata.worldbank.org/index.php/catalog/2053>) and analyzed using STATA version 15.1 (StataCorp, 2017).

4.3 Methodology: Two-step modeling approach to estimate the dynamic equilibrium asset level for mature onset and then measure related marginal effect on household food and nutrition security status

A two-step approach was employed to model how Menset (a) behaves like a green asset that (b) contributes to household food security over and above flow measures like consumption. First, a measure of the dynamic equilibrium threshold for Menset was taken and indications of a green poverty trap related to potential multiple equilibria were identified. Other common asset indexes were calculated for comparison. In the second step, this research modeled the four previously discussed ESS food and nutrition security indicators as dependent variables; each of the assets

served as potential significant independent variables while controlling for relative wealth measured by the flow variable of consumption per adult equivalent.

Differences in consumption were grouped into quintiles for ease of interpretation and for estimating potential differences in the effect of Menset for different wealth groups. Marginal contributions of Menset to different food and nutrition security elements were then discussed with respect to the green asset dynamic equilibrium identified in the first step.

4.3.1 Methodology: Lagged-asset comparison

Information on assets is regularly collected in socioeconomic surveys, but these data must be transformed into a unidimensional measure if they are to be easily compared over time in a longitudinal analysis (Barrett et al., 2016; Naschold, 2012). Data reduction through factor analysis is the most common way of reducing dimensionality and appropriate for the ESS data that collected information on 34 household items and agricultural implements. Sixteen items were selected of the possible 34 assets recorded in the ESS module that were owned by at least 1% of the population. Several of the items such as private cars and satellite television receivers were only owned by one or two households and, therefore, dropped from consideration in the indexes.

Factor analysis identified two orthogonal factors that accounted for 95% of the variability in the asset data. The first, HHobjs, related to household and personal objects such as blankets and mobile phones. The second, AgImp, related to agricultural implements such as an axe, yoke, or plow. Livestock and land holdings are fundamental to rural Ethiopian livelihoods. Tropical livestock units (TLUs)

followed the standard transformation and were implemented in the Stata do files provided on GitHubb (Alia et al., n.d.). A measure of farm size (AgLand) was also calculated by adding together all cultivated, fallow, and pasture plots reported by ESS households. The dependent variable was already unidimensional and required only a minimum calculation of adding together the fields of a small number of households that had multiple plots of Menset.

The dynamics of the four asset measures—HHobjs, AgImps, TLU, and AgLand—were compared to the newly suggested green asset of MEnset following the lagged-asset analysis local spline procedure described in increasing detail by Carter and May (2001), Carter and Barrett (2006), Adato (2006), and Naschold (2013). In this nonparametric approach, that employs locally weighted regions to fit a line to variation present in the data, asset dynamics were investigated with a simple temporal comparison of asset measures at two time periods to visually identify the dynamic equilibrium point for each of the assets investigated. A simple locally weighted regression was applied at this point in the analysis to LOWESS Stata command based on Royston and Lambert’s (2011) method and using *Stata Statistical Software: Release 15* (StataCorp, 2017). The approach applied weighted least squares regression to produce a spline that can be overlaid on a scatter plot of two one-dimensional variables. For this investigation, the y variable is the asset at time period 2015/16 (t) and the x variable is the asset at (t-2) 2011/2012. Following Cleveland (1979) and described in an abbreviated form here, y_i is modeled as a weighted function of x_i with weight g and error ϵ_i :

$$y_i = g(x_i) + \epsilon_i$$

The local weighting function proceeded so values closer to x_i were weighted exponentially higher so that the r th x is at the point where the weight w is equal to zero. For each i , the distance from x_i to the r th nearest neighbor is h_i . w_k is the dependent variable of the polynomial regression of nearest neighbors so

$$w_k(x_i) = W(h_i^{(-1)}(x_k - x_i))$$

The “bandwidth” option allowed the percentage of data considered in the local regression to be adjusted and was set at 50% for this analysis. That was, therefore, estimated for each value of x to create the LOWESS spline where Y hat =

$$\sum_{k=1}^n w_k(x_i)(y_k - \beta_0 - \beta_1 x_k - \dots - \beta_d x_k^{(d)})^{(2)}$$

The dynamic asset equilibrium was then estimated where the LOWESS spline crosses the 45-degree line of $asset(t) = f(asset(t-2))$. This can be rounded to the nearest whole number for interpretation.

Authors such as Jalan and Ravallion (2002) and Naschold (2013) suggested hierarchical or mixture modeling approaches to understanding asset dynamics to overcome the one-dimensionality constraints of the lagged-asset approach. Instead, breaking the method into two steps preserved the elegant simplicity of LOWESS in identifying dynamic equilibria in the first step. Then going on to a fully parameterized spatially informed hierarchical model, differences in location and consumption flows, while identifying the specific marginal effect of Menset apart from other assets, could be controlled.

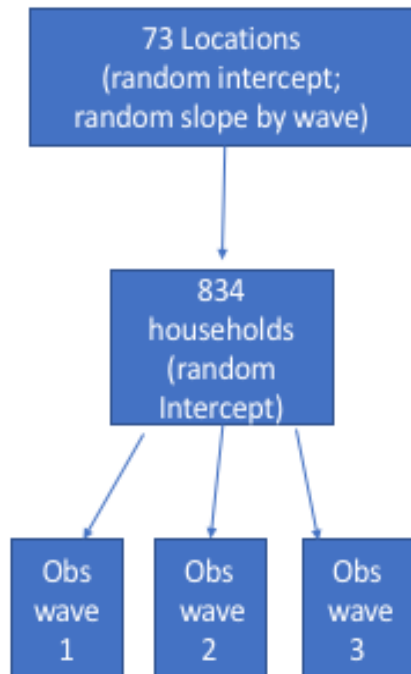
4.3.2 Methodology: Mixture Model Design

To estimate the marginal impact of Maset over the other assets while controlling for flow measures of consumption/income, a three-level mixture model of the data was constructed, including repeated measurement across three waves of the Ethiopian LSMS-ISA survey for households(i) within enumeration areas(j).

Exploratory data analysis confirmed high levels of spatial variability in variables of interest related to the context that included a mosaic of geographic features, local weather, marginalization, and combinations of infrastructure but few that were coherently and significantly correlated with any of the dependent variables or asset measures. This is consistent with other authors' observations that local conditions in Southwestern Ethiopia play a strong role in the spatial variability through a place-based combination of infrastructure such as (a) market dynamics and access, (b) cultural practices related to localized food systems, (c) geophysical aspects primarily related to elevation, and (d) climate conditions, including shock events such as drought or flood (Quinlan et al., 2015). Therefore, this place-based context of communities represented by the 73 enumeration areas is included in the hierarchical model by first nesting observations in households and then households nested into locations (see Figure 4.2).

Figure 4.2

Tiered Hierarchical Model



For each food security measure of interest, the three-level variance components model were defined for the panel survey wave (t), household (i), and enumeration area (j) following Baltagi (2013) and Rabe-Hesketh and Skrondal (2008). Effectively, four separate models were fit for each of the four dependent variables. The hierarchical mixture model approach allowed for between-location variability and within-household-over-wave variability to be modeled with the separate random and fixed coefficients that, in turn, captured the high levels of local contextual and temporal variability. Fixed effects for intercepts at household level captured different starting places, while random effects for slope were included at household level to compensate for primarily negative, but also occasionally positive,

idiosyncratic shocks. Similarly, fixed effects for the intercept at location were included to account for geographic, infrastructure, and other contextual differences present at the start of the panel. A further random effect on slope coefficient for location by wave was included to capture primarily negative covariate shocks such as poor weather between waves—except for the model with STUNT because of the lack of significant variation at location level.

The independent variables were Menset and the four other asset variables described above—HHObjs, AgImp, TLU and FarmSize. Female-headed households were included as the sole socio-demographic indicator. The flow poverty indicator of income and consumption was included as an ordinal variable representing different levels of wealth measured by consumption quintiles (CQuint). This facilitated quantification and graphical display of the marginal impact of assets on the dependent variable by different household poverty status. Although there was a good deal of variability in outcomes between locations, descriptive measures—such as household size, education status, and age of household head—had relatively low variation across the survey population and, therefore, insignificant levels of correlation to the outcomes or even the independent variables.

It is important to note that a variety of geo-contextual variables such as altitude, average rainfall, and distance to market were available as part of the ESS data set. These were also not significantly and consistently correlated across panel waves or when the waves were pooled. The large contextual variability observed in both the cultural and more environmental context only became significantly correlated with different levels of food security or assets as specifically manifested in

a specific place for a specific wave. The complexity of the interactions and context led to specific, and not easily correlated, outcomes for any one place in any one wave. For example, a community might have relatively poor rainfall but locally available irrigation. The combinations in the study site were so numerous that significant differences were realized only when the unique combination of factors came together in a single place. Inclusion of random and fixed effects for location accounted for much of this variability. In the end, no other variables were included to preserve the parsimony of the model and because the monetary flow indicator, assets, and location variables captured most of the variability in the outcomes of interest.

The models followed a structure where the food security or nutrition dependent variable of interest (Y) for continuous scaled values of HDD was regressed on independent variables and the random components as:

$$y_{ijt} = \beta_1 + \beta_2 x_{1ijt} + \beta_3 x_{2jt} + \beta_4 x_{3ijt} + \beta_5 x_{4ijt} + \beta_6 x_{5ijt} + \beta_7 x_{(6-9)ijt} + \zeta_{1jt}^{(2)} + \zeta_{1t}^{(3)} + \zeta_{2t}^{(3)} t_{it} + \epsilon_{ijt}$$

where:

y_{ijt} is the dependent food security measure such as HDD

$\beta_2 x_{1ijt}$ is area of mature enset

$\beta_3 x_{2jt}$ is dummy variable for female headed household

$\beta_4 x_{3ijt}$ is HHObjs index

$\beta_5 x_{4ijt}$ is an interaction term of Menset and HHObjs

$\beta_6 x_{5ijt}$ is AgImp index

$\beta_7 x_{(6-9)ijt}$ are dummy variables for consumption quintiles 1 – 5

$\zeta_{1jt}^{(2)}$ is a random intercept coefficient at household level

$\zeta_{1t}^{(3)}$ is a random intercept coefficient at location level

$\zeta_{2t}^{(3)} t_{it}$ is a random slope for location by wave
 ϵ_{ijt} is the observation level error component

A linear fixed slope was assumed for households within locations. Allowing slope to vary at household level did not provide additional significant explanation variance beyond location heterogeneity for 3 of the 4 dependent variables, which is discussed further in the following section. ζ_1 random intercepts had a mean of 0 and variance $\psi^{(3)}$ given covariates x . Random slope $\zeta_{2k}^{(3)} t_{it}$ also had a mean of 0 and covariance matrix $\Psi^{(3)}$ given covariates x . The ϵ_{ijt} error term had a mean of 0 and variance θ .

The model was adjusted to a poisson gamma distribution for dependent variable MINS and FIES because of its limited range of count variables from 0-12 and 0-56, respectively. Households with at least one stunted child, STUNT, was coded as a binary dependent variable and regressed on independent variables using a logit model. An example of the modification of the modelling equation necessary to incorporate the poisson distribution for MINS and FIES or the binary distribution for STUNT can be found in section 3.4 of this dissertation. A random slope coefficient at the location level was not significant for STUNT and, therefore, dropped. The analysis was conducted with the option to report exponentiated regression coefficients for easy comparison across all four variables.

4.4 Results

The results are presented in two parts. In the first section, a comparison of conventional asset indexes is presented that contains items such as mobile phones and plows to livestock, land holding, and the Menset as a green asset measure. In the second part, the marginal effect of Menset on four common food security measures is quantified. This allows the results to differentiate effects of Menset for poorer and richer households by Cquint. Because of the 2-step process, the specific inflection point was able to be identified where diminishing marginal returns for enset as a green asset occurred, and then any difference that amount of enset makes for household food security was measured.

Descriptive statistics tables for enset cultivation across the 3-waves of the survey are presented in Table 4.2. Average farm size increased to just over one hectare in Wave 2 of the survey, but the median reflects the reality that most of the farms are closer to half of one hectare; a few relatively larger farms skew the average area higher. This is also seen in a slight increase in area under enset cultivation that was driven by several new large and presumably commercial enset plantations in the third wave of more than 10 hectares. These are not small farms, under a 5-hectare threshold for this study, so they were dropped from consideration in the hierarchical mixed model. The area of mature enset drops between Waves 1 and 2.

Table 4.2*Farm and Enset Garden Area by Wave*

	Number of households growing enset	Mean and (Median) Farm size in mtsq	Mean area under enset	Standard deviation of area under enset	Mean Area of Mature (Menset) enset	Standard deviation of Menset
Wave 1	618/834	8779.03 (5172.08)	590.94	1210.04	203.59	948.67
Wave 2	671/834	10,859.89 (6397.58)	583.8	854.75	184.11	543.24
Wave 3	672/834	10,602.1 (5754.47)	757.29	4993.01	149.79	423.37

Although found significant at a $p < .01$ level because of the large data set, weak correlation factors between asset measures, monetary flow indicators, and food security outcomes were generally around 0.1 for pooled data (see Table 4.3). Because the dynamic assets approach only compared two points in time, here are presented only Wave 1 and Wave 3 Spearman correlations. Multicollinearity is, therefore, unlikely because the majority of measures were so weakly correlated. Where a relatively strong correlation factor of 0.54 was found, such as for AgLand and TLU, the least significant variable was dropped from the modelling to further reduce any possibility of multicollinearity issues. A set of t tests indicated a significant discrimination ability for HHobjs, with respect to the poverty line, and AgImp for MINS and FIES. Menset was the only indicator with a relatively strong and significant discrimination of STUNT, while also indicating significant differences in MINS and HDD. The significance of the modeling results relies on the strength of the

relationships between assets and outcomes specifically dependent on the wave, place, and household rather than on high correlations between all the indicators across the board.

Table 4.3

Correlation of Assets, Poverty and Food Security Indicators in Waves 1 and 3 of ESS

Wave 1	Menset	AgImp	HHOb	TLU	Farm size	Pov Line	MINS	FIES	STUNT
AgImp	.12*								
HHObs	.15*	.25*							
TLU	.31*	.38*	.11*	.00					
Farmsize	.33*	.54*	.20*	.51*					
PovLine	.10*	-.09	.22*	.07	.05				
MINS	-.11*	-.11*	-.24*	-.06	-.15*	-.16*			
FIES	-.08	-.13*	-.10*	-.12*	-.19*	-.15*	.32*		
STUNT	-.09*	.07	-.06	-.01	-.02	-.15*	.00	.02	
HDD	.10*	.14*	.30*	.15*	.20*	.50*	-.17*	-.18*	-.05
Wave 3									
AgImp	.01								
HHObs	.15*	.25*							
TLU	.14*	.51*	.26*						
farmsize	.13*	.42*	.27*	.59*					
PovLine	.05	-.01	.19*	.01	.04				
MINS	-.09*	-.10*	-.19*	-.17*	-.21*	-.2*			
FIES	-.07	-.08	-.13*	-.19*	-.26*	-.18*	.5*		
STUNT	-.01	.02	-.06	-.06	-.01	-.13*	.06	.08	
HDD	.09*	.11*	.30*	.12*	.20*	.4*	-.26*	-.24*	-.04

* $p < .05$

Menset had a weak but consistently significant correlation with all indicators except FIES in Wave 1. In Wave 2, Menset had weaker, but still significant, correlations with the other assets of livestock, farm size, and HHobjs as well as with the food insecurity indicators of MINS and HDD. The generally weak correlation

between the poverty gap and asset measures may reflect overall poverty and low level of assets in the region where 60% of households were below the Wave 1 poverty line and 88% of households were below the Wave 3 poverty line. It is particularly striking that measures of agricultural assets, including livestock or farm size, were not correlated with the flow-based consumption poverty measure.

4.4.1 Evidence of hunger poverty traps in the enset growing areas and temporal dynamics of enset as a green asset

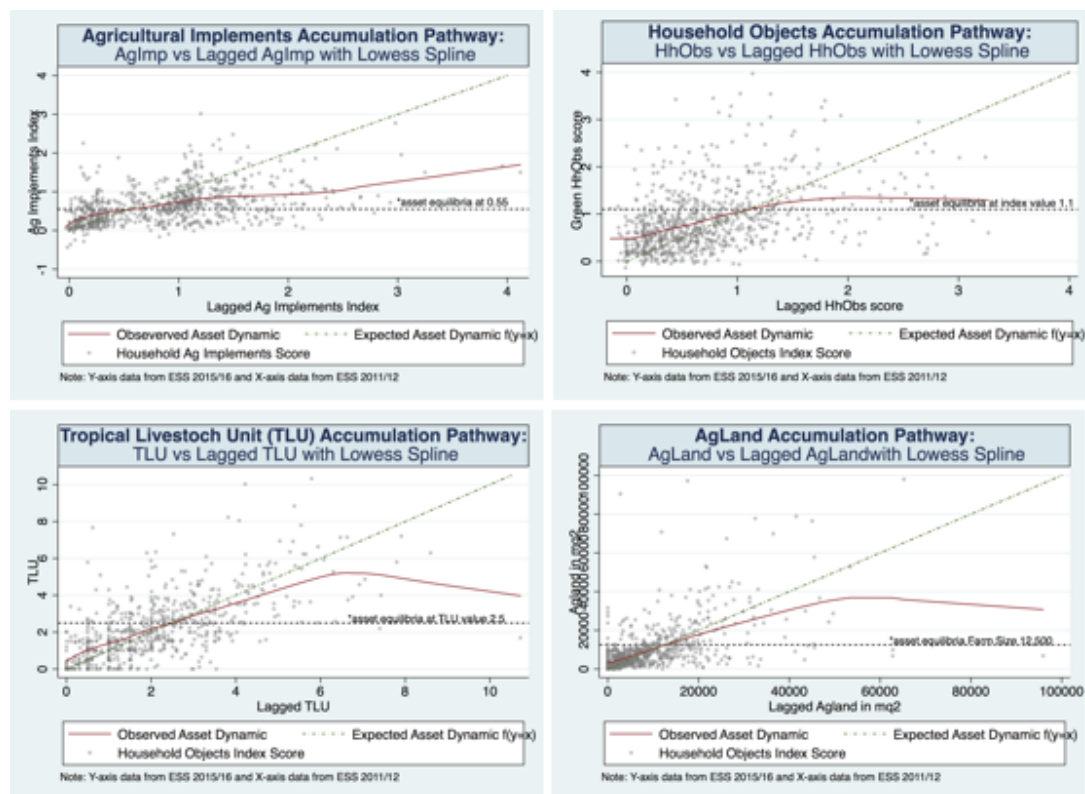
The characteristic convex curve of the locally weighted spline is observable in each of the four traditional asset measures (see Figure 4.3) as well as the green asset Menset (see Figure 4.4), indicating a single asset equilibrium. Over the time lag of approximately 4 years, households initially below the asset equilibrium tended, on average, to increase their assets toward this inflection point, while those with higher amounts of the asset accumulated more slowly or lost assets, on average, during the period. The spline observed in the plot of AgImp is not as smoothly convex as other assets. Though this indicates more complicated asset dynamics (perhaps due to the inclusion of a few semicommercial larger farms with more modern equipment for a subpopulation), it most likely does not indicate a specific poverty trap. A truly bifurcated asset dynamic indicating a trap would cross the 45-degree line at least twice, which is not observed here.

A household at the AgImp equilibrium point of an asset score of 0.55 might have, for example, a traditional plow or an axe and sickle. Although different for each household, the farmers in this range have the basics for tending their garden or field. At the equilibrium for HHObjs, these families have blankets and typically two other

items such as a mattress or sewing machine. The TLU equilibrium of 2.5 and the equilibrium farm size of 12500 m² are slightly above the mean values for the data set but align to a common-sense logic. Having a mating pair of larger animals or a small flock of goats or sheep is intuitively sustainable. The elegant simplicity of this approach is evident by the ready and clear reflection of rural livelihoods in the assets and asset levels.

Figure 4.3

Asset Dynamics

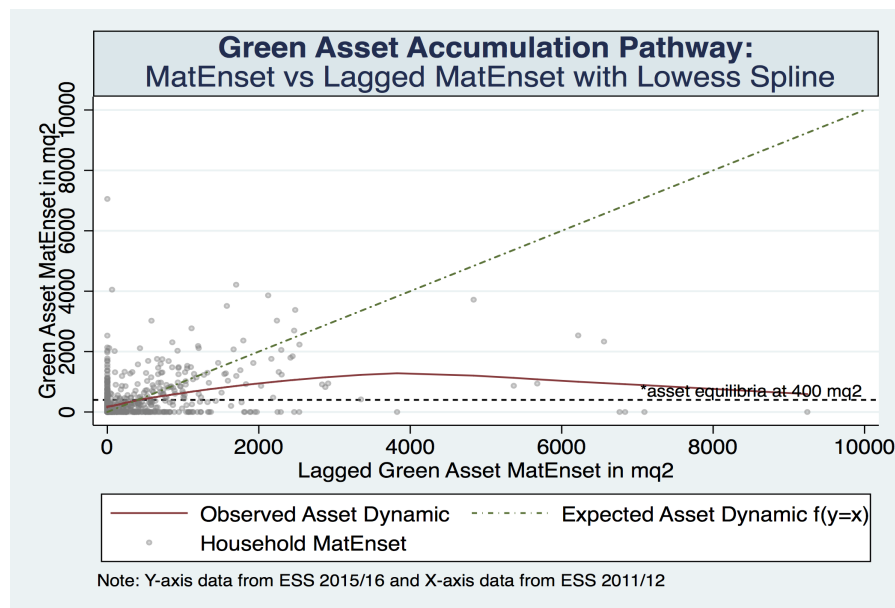


The green asset measure of Menset has a strikingly similar convex curve in observed convergent asset dynamics but displays a remarkably low equilibrium level

of only 400 m² (see Figure 4.4). If the onset is spaced roughly two meters apart during the final transplantation (Zappacosta et al., 2007), this would imply approximately 100 plants fill the space at the Menset equilibrium level. Over the comparison period of 4 years, this implies those with smaller areas onset and fewer than 100 mature onset plants tend to increase the stock and Menset area while those who initially had large stands of Menset in the first wave of the panel tended to decrease the amount. Although there are some larger growers, the majority of households had a relatively small Menset garden at or near this equilibrium level of approximately 20-by-20 meters. Although modest in area, Demeke (1986) estimated only 60 mature onset plants are required annually to feed an average-sized family. Therefore, the Menset equilibrium level represents an 18-month standing stock of staple food.

Figure 4.4

Green Asset Accumulation Pathway



4.4.2 Marginal effect of mature onset on food security measures from spatially informed longitudinal mixture models

The Menset is a remarkably consistent indicator of a broad range of positive food and nutrition security outcomes for households in the SNNPR region. Longitudinal hierarchical mixed effects models fit over the three waves of the ESS panel consistently showed increased Menset associated with relatively positive MINS, FIES, STUNT and HDD (see Table 4.4). The coefficients are listed in the rows of Table 4.4 with superscript indicating measured level of significance. Standard errors are low, well-below one standard deviation, indicating strong fit of the model to the data. The model statistical distributions are noted with superscripts to note the use of normal distribution for the scaled dependent outcome variable HDD, a Poisson distribution for count dependent outcome variables of MINS and FIES with a logit function for binary dependent outcome variable STUNT.

High values of log likelihood, further strengthened by the large sample size, suggest a strong congruence of observations and model (see Table 4.5). The Wald statistic is highly significant indicating support for inclusion of all selected covariates (see Table 3.4). The likelihood ratio test is highly significant and rejects the null hypothesis in favor of inclusion of the random coefficients for both location and household.

Table 4.2

Coefficients and Their Level of Significance for the Base Longitudinal Mixture Models

	Months of Insufficient Food Provision+ (MINS) / Std. Error	Food Insecurity Experience Score (FIES) / Std. Error	Household with stunted child(ren)# (STUNT) Odds Ratio / Std. Error	Household Diet Diversity (HDD) / Std. Error
Mature enset (hectares)	-2.78***/0.92	-4.45***/0.83	-2.33*/1.1	2.64***/0.91
Female-headed Household	NS	NS	-1.53***/0.22	-0.34***/0.08
Household Objects Index (HObjjs)	-0.28***/0.06	-0.22***/0.06	NS	0.47***/0.05
Interaction term (HObjjs*Menset)	NS	NS	NS	-0.01***/0.01
Agricultural Implements Index (AgImp)	-0.22**/0.09	-0.37***/0.09	NS	NS
Tropical Livestock Unit (TLU)	-0.18***/0.03	NS	-0.12***/0.04	0.06***/0.02
Farm Size (Sqmt)	NS	NS	NS	NS
Consumption (q2)	-0.21***/0.09	-0.21***/0.08	-0.12/0.18	0.48***/0.09
Consumption (q3)	-0.40***/0.1	-0.43***/0.09	-0.37/0.2	1.00***/0.1
Consumption (q4)	-0.58***/0.11	-0.44***/0.11	-0.52**/0.21	1.07***/0.11
Consumption (q5)	-0.75***/0.13	-0.48***/0.13	-0.72***/0.23	1.73***/0.12
Constant (alpha)	-0.9*/0.43	3.06***/0.84	-2.72***/0.47	4.31***/0.21

* $p < .10$

** $p < .05$

*** $p < .01$

NS = not significant

+ poisson distribution used because count dependent variable

logit regression used because binary dependent variable

Table 4.3*Goodness of Fit Statistics for Panel Mixture Models*

	Log Likelihood	Wald statistic	Likelihood ratio-test	Random slope component / Std. error (location)	Random intercept component / Std. error (location)	Random intercept component / Std. error (Household)
Months of Insufficient Provisioning (MINS)+	-1892.26	197.17** *	1344.19***	1.21/0.15	3.08/0.37	0.48/0.05
Food Insecurity Experience Score (FIES)+	-3146.1	102.5***	6810.79***	1.71/0.19	4.62/0.51	1.22/0.06
Household with stunted child(ren) (STUNT)#	-1175.39	71.95***	134.91***	NS	0.61/0.12	1.35/0.13
Household Diet Diversity (HDD)	-2640.98	454.42** *	442.89***	1.4/.13	1.63/0.21	0.12/0.03

* $p < .10$ ** $p < .05$ *** $p < .01$

NS = not significant

+ poisson distribution used because count dependent variable

logit regression used because binary dependent variable

Mature enset had a consistently positive, albeit small, effect at the identified asset equilibrium of 400 m² on measures of food insecurity MINS, FIES, and HDD. The predicted marginal changes in food and nutrition security measures for Menset at different field sizes of 400 m², one-half hectare, and one hectare for households in the poorest consumption quintile are presented in Table 4.6. Although there are few households with one hectare of Menset that would imply a more commercially oriented operation, positive food security effects of much smaller enset gardens was

observed. A rough calculation, considering three quarters of households tend to have an enset garden and the population of SNNPR, would imply at least 10 million people live in a household with an enset garden at or above the 400 m² level and, therefore, have 18 months of staple food stored as a green asset in the garden. For the MINS indicator, this would then, in turn, imply 30 million fewer days of hunger or replace the requirement of 30-thousand metric tons of cereals.

Table 4.4

Summary of Predicted Marginal Effects of Mature Enset on Food Insecurity Measures for the Poorest Quintile

	Months of insufficient food provision+ (MINS)	Food insecurity experience score+ (FIES)	Household with stunted child(ren)# (STUNT) Odds ratio	Household diet diversity (HDD)
Mature enset				
400 square meters (asset equilibrium)	-0.12 months	-0.22 FIES points	-9% difference -22% change	0.11 food groups
5000 square meters	-0.95 months	-2.22 FIES points	-29% difference -68% change	1.32 food groups
10000 square meters	-1.18 months	-4.45 FIES points	-39% difference -92% change	2.64 food groups

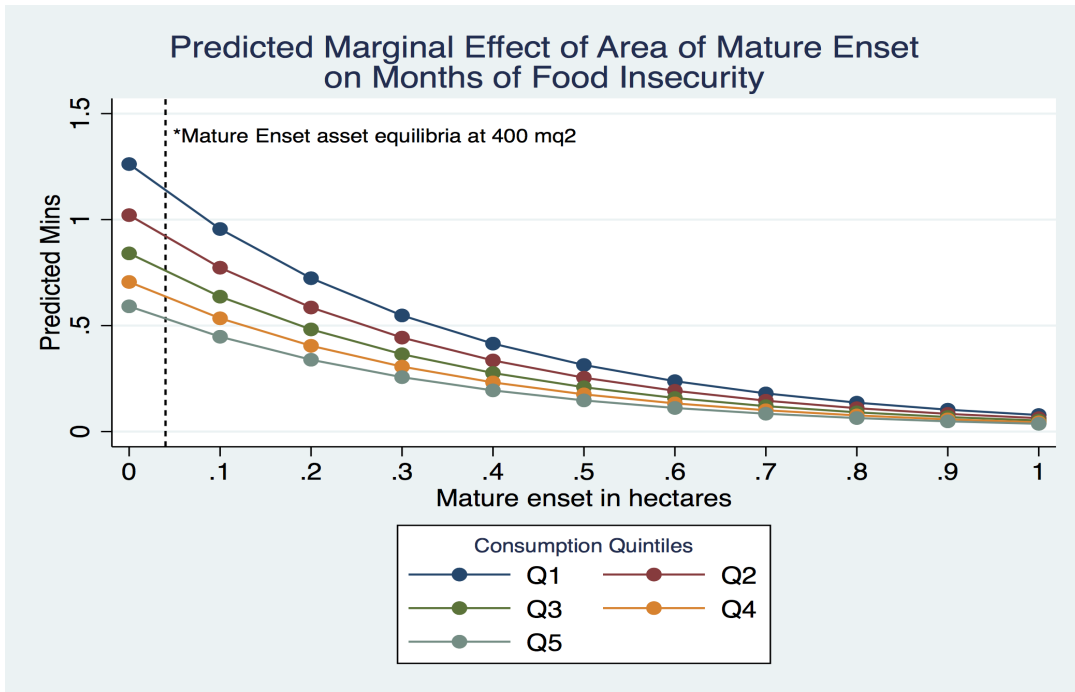
The effect of an enset garden on nutrition was striking. The nutrition measure of STUNT, reporting the odds ratio of a household having a stunted child, reported a 9% difference for households with a 400 m² compared to those without an enset garden. This difference represents an extraordinarily large reduction in overall prevalence (percentage change) of STUNT by 22%. The nonlinear model predictions of the

effect showed a reduction of 68% for one-half hectare of Menset and 92% for one hectare. Perhaps the most important perspective to maintain in reviewing these results is that these are marginal effects reflecting improvements above and beyond all the other sources of income and benefits from other types of assets. The results for each FNS indicator are presented highlighting small nuances in the model that were necessary because of the nature of the dependent indicators and varying significance of the independent variables.

Hunger in rural areas often varies considerably by season (Chambers et al., 1981). MINS is an indicator of the stability of food security and, therefore, critical for policy or programming decision making that ensures year-round access to sufficient food. Menset had a marked impact on reducing MINS for all wealth levels represented by CQuint but is remarkable for the impact on the poorest households (see Figure 4.5). The five levels of CQuint represent progressively wealthier households where Q1 is the poorest 20% of households and Q5 is the richest 20% of households as measured by total per person consumption. For a quick approximation in visual interpretation of the graphs, consider Q1 and Q2 as households living below the poverty line. Of particular note, a stronger Menset effect for the poorest households is clearly visible as enset garden size increases. MENSET of 400 m² results in only an average reduction of a 3-4 days of food insecurity for the poorest households in SNNPR, while a still relatively modest one-third hectare of Menset is estimated to reduce food insecurity by almost a month.

Figure 4.5

Marginal Effect of MENSET on MINS

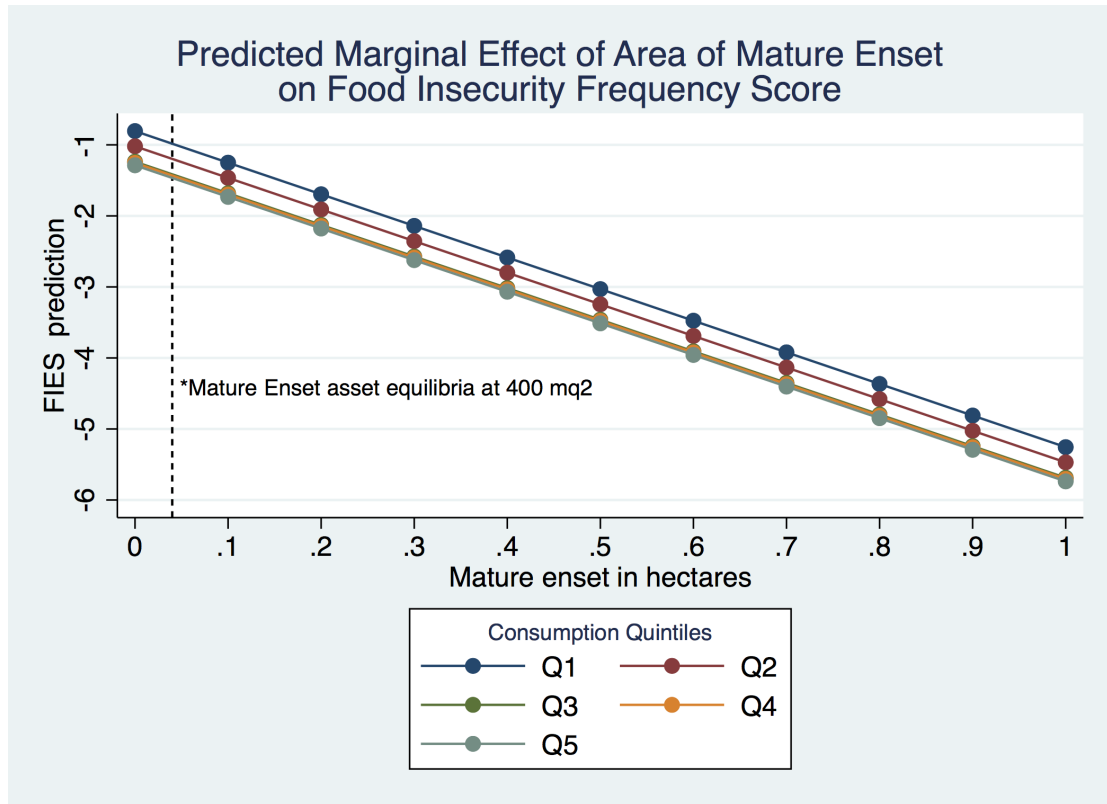


Increasing Menset reduced the estimated FIES for all levels of wealth.

Considering the mean FIES score is 3.1, a 400 m² Menset garden would imply a 10% reduction in food insecurity experience severity. This signifies the difference between a household being forced to skip meals as opposed to a less difficult situation requiring adjustment of portion sizes. The model estimates that all food insecurity as measured by FIES would be eliminated in households with a half-hectare or more of Menset (see Figure 4.6).

Figure 4.6

Marginal Effect of MENSET on FIES

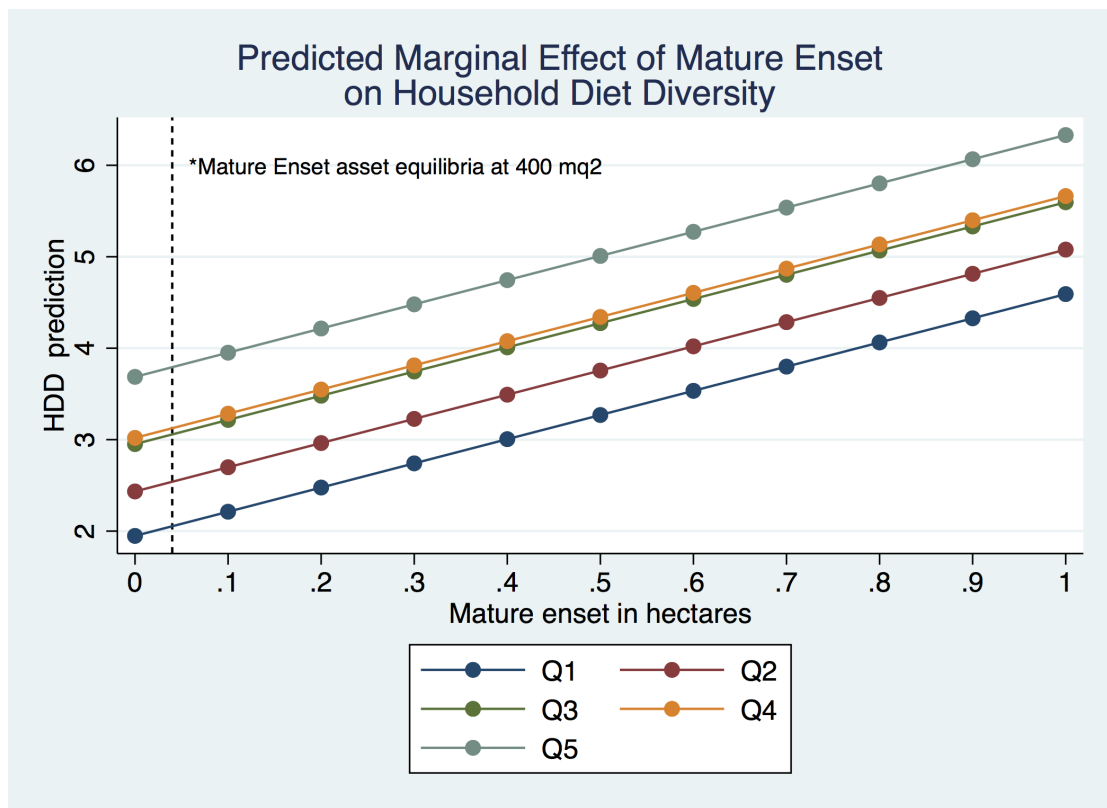


The higher quality diets of wealthier households are clearly evident in Figure 4.7. The wealthiest households consumed on average two full food groups more than the poorest households. Menset was estimated to increase the number of food groups for all wealth levels, but it would indeed take a very large Menset garden of over 7000 m² for the poorest households to achieve the diet of the richest households without an enset garden at all. Although the trend is positive for food security, the way HDD groups foods may not in fact reflect the impact of Menset on diet diversity. Even if 10 different types of vegetables were grown alongside the enset, that is only two HDD food groups. Purchasing on the market, as is likely in the wealthiest

CQuint, of relatively economically accessible items like oil, sugar, salt, or dried legumes would all count individually as additional HDD food groups. Nonetheless, HDD confirms the same positive trend as the complementary measures of food security.

Figure 4.7

Marginal Effect of MENSET on HDD



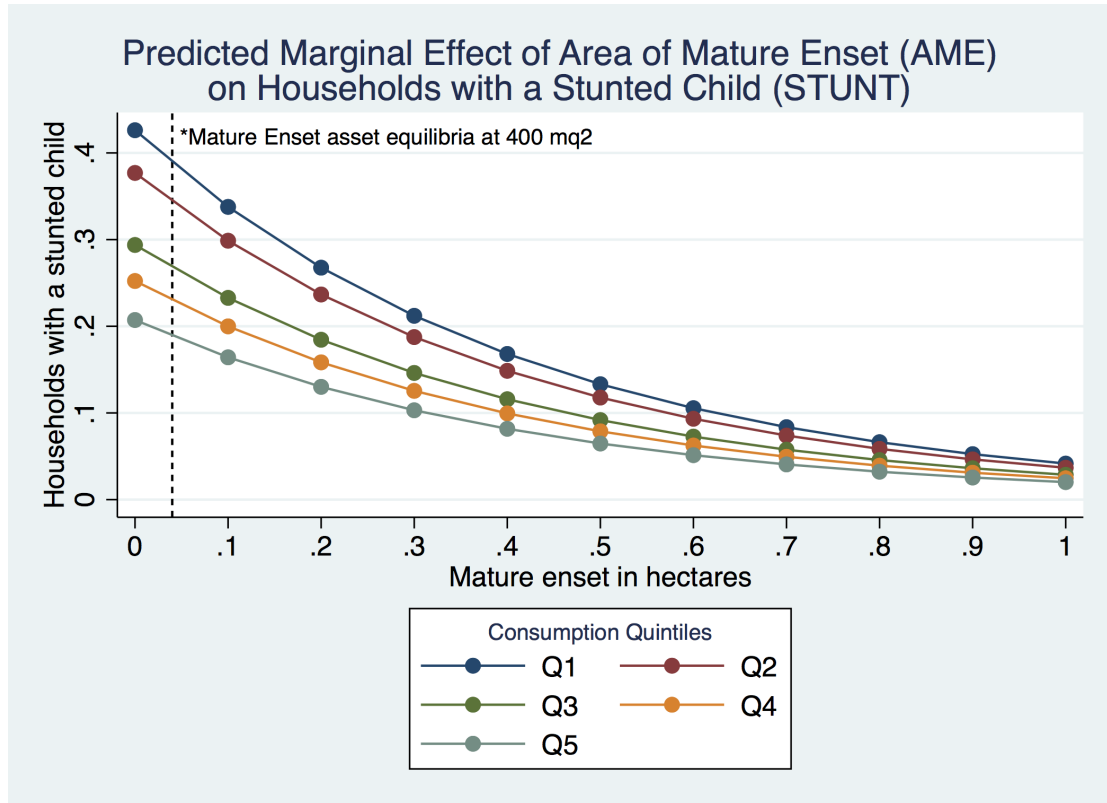
Anthropometric measures of children, when taken for a sample population, are an outcome measure of FNS. They are the result of a wide variety of contributing factors that range from consumption and recent illness to infrastructure and education

attainment by the parents (Golden, 1994). Although changes in weight can occur relatively rapidly in small children, linear growth and its failure reflect the FNS-related well-being of a child over a longer period of time with a particularly large contribution of a healthy transition from breast milk to solid food. The indicator for failure to grow compared to a reference population was measured as a ratio of height for age for children 6-59 months and called stunting.

Of the FNS measures considered here, the relationship Menset to STUNT is perhaps the most dramatic (see Figure 4.8). The stunting rate for SNNPR data on individual children measured was 44%—near the national average for Ethiopia of 42% in 2015/16. Often, more than one stunted child was present in the same house, so this would explain the lower figure of 28.46% when stunting was aggregated to households with a stunted child (STUNT). Stunting is closely related to overall poverty, and this is reflected in the significant difference between STUNT of 42.62% of the lowest consumption quintile to the lower rate of 20.72% for the wealthiest consumption quintile with no Menset. A rapid decline of 22% was observed between households with the 400 m² of Menset when compared to households without Menset. The trend continued to the point where the difference in STUNT prevalence for the poorest quintile, with a still modest 3000 m² of Menset, was cut by more than half and essentially equal to a wealthy household without ensent.

Figure 4.8

Marginal Effects of MENSET on STUNT



4.5 Discussion and Conclusion

The observation recorded in the 17th century by Jeranimo Lobo, that households “with a single enset plant do not fear hunger” (Lobo et al., 1640/1984, p. 245) appears to be hyperbole. However, even modest gardens with mature enset did have a consistently significant observable positive relationship with common measures of food and nutrition security. Well-being benefits were more substantial for poorer households. The marginal effect of mature enset was strong and significant after controlling for differences in wealth measured by consumption-based flow

poverty, a diversity of asset holdings, and initial well-being differences of individual households and community locations. Enset is a green asset that has fundamentally differentiated value to food and nutrition security above and beyond other types of assets or consumption flows. The dynamic green asset equilibrium of 400 m², a 20-by-20-meter plot, did not correlate to households being above the poverty line but did signal a shorter and less severe experience of food insecurity, more diverse diets, and better nutrition.

Similar to Kwak and Smith (2013), this research revealed a single dynamic equilibria for all assets investigated where a wide majority of households remained in overall poverty as measured by consumption and possessed essentially none of the more valuable personal transportation, manufactured, and electronic items other than mobile phones. Nevertheless, mature enset stands out with a considerable positive effect on well-being from a food and nutrition security perspective. Households at or above the dynamic equilibrium for this resilient green asset, at the foundation of this locally adapted and ancient food system, were significantly less likely to be hungry. Mature enset alone was the only asset that was significant ($p < .001$), except for STUNT ($p < .05$), in models of all four food and nutrition security outcomes.

The standing stock of 18 months of staple food in the garden, represented by dynamic equilibrium threshold for Menset, can be characterized as having the safety net properties of a food bank, similar to the compounding interest and flexibility of a more traditional financial bank account. The 18-month supply of staple food represented by the Menset dynamic threshold implies this contextually optimal stock was intended to last from the point it was measured after planting in the main rainy

season through that year's harvest of annual crops as well as being fully available through the following year up to the subsequent harvest. Similar expectations have been recorded for the Hausa people of the Sahel region who employ a traditional, sophisticated, and effective cereal storage system that is sealed for opening at the beginning of the lean season but can also preserve grain for multiple years (Watts, 2013).

Unlike a cereal storage system, enset continues to grow in value while held for future use. It also provides an ongoing stream of fodder, fiber, and fuel to meet household requirements. Chambers et al. (1989) recounted the ability of trees growing fast enough in India that farmers were able to pay off debts with accrued interest over a period of less than 10 years and avoid costs and challenges associated with available financial borrowing in the area. Enset is a green asset that represents for many households a food security insurance policy that also pays dividends.

The expectation of enset as a green asset store of value influenced the choice of an intentional 2-step methodological approach. Of primary interest was the identification and interpretation of the dynamic asset equilibrium point. The threshold of diminishing marginal returns was reached for the green asset measure *Menset* without a strong correlation with indicators of monetary flow. That threshold provided insight about the nature of food security or alternative value pathways represented by the enset growing food system. The observations of Lybert et al. (2004)—that maintenance of a minimum breeding stock to recovery from a worst-case scenario and Morrow et al.'s (2018) observation of increasing investment in other forms of assets and well-being—are both compelling. Dessalegn (1995) called

enset a “strategic crop” that was cultivated as a sort of natural insurance to maintain food security so that remaining land could be dedicated to higher value—but also riskier—crops.

As a food system based on a green asset, the second methodological step allowed for investigation of how diversification of assets, including TonF and other perennial crops, may provide new pathways to a broader range of well-being or resilience outcomes. Thus, the two-part methods allowed for discussion of both the constraints on the green assets as well as their connection to strategies of insuring and diversifying a rural household’s portfolio of livelihood assets. Furthermore, comparison of the potential relationship between green assets and different food security characteristics, reflected by different measures, may provide insight into the influence and relative importance of these undercounted autochthonous TonF and perennial plants in previously asset-related food insecurity and poverty studies.

For research considering issues of resilience and sustainability, inclusion and consideration of the of green assets in poverty and food insecurity was a practical way to address some of the limitations of previous development economics-focused research on concentrations of deprivation in rural areas raised by Haider et al. (2018). These limitations include cross-scale interactions, path dependencies, the role of external drivers, and socioecological diversity. Socioecological path dependencies—that may reset or transform understanding of assets that are, in actual fact, more generatively related to food systems—are important to food security on a broader diversity of small farms and requires new investigations into understudied, unique, and often indigenous food systems that include green assets. Furthermore, articulated

research on food systems, food socionatures, and poverty/food insecurity traps face the ongoing challenge of boundary setting to adequately identify groups and places—along with key elements and feedbacks—responsible for observed outcomes.

Autochthonous plants—such as green assets, animals, or perhaps even distinguishing historical food-related practices—help make food socionatures identifiable; that is the first step toward measuring their value, function, and outcomes. For example, enset is grown nowhere outside the enset region and likely originated in that place (S. A. Brandt et al., 1997). *Ceteris Paribus* everywhere and “every when”—as a starting assumption ignoring issues of scale and boundaries—is not appropriate to sustainability, complexity, or resilience-focused investigations or policy that by their nature imply complex environmental and social feedbacks (Patton, 2010).

Green assets may help delineate meaningful coevolved social-techno-historical-environmental spaces not necessarily reflected in political, purely social, purely environmental, or arbitrary boundaries. Boundary setting remains a primary challenge in understanding cross-scale interaction and discriminating internal from external drivers essential to identifying (a) potential pathways, (b) approaches to reaching the most marginalized, and (c) policy leverage points for improved outcomes. Green assets more generally also imply a greater consideration of noncommodified plants—along with other underrecognized nonhuman animal and human stores of value—that may better reflect, or reflect in ways that are not typically counted, how characteristics of specific food socio-natures contribute to well-being status including food and nutrition security.

Perhaps understood as food sovereignty or typical regional foods in richer countries like Italy or Japan, there appears to be a great deal still not understood about the persistent autarky of staple self-provisioning regimes among farms outside mainstream globalized development in Africa and their potential relation to sustainability. This bias is particularly glaring in Ethiopia as the only center of origin for cultivated crops in Africa (Vavilov, 2009), and it has implications about how assets are valued and whether elements such as green assets are even counted. Sustainability, resilience and food security-related poverty research may get fresh insight to long-standing conundrums from novel food socionature perspectives that focus on autochthonous, springing-from-the-earth, systems and assets (Haraway, 2016; Leach et al., 2020).

Underconsideration of green assets like enset may negatively affect the explanatory power—and even the ostensive validity—of asset-related findings where these elements may play important roles in livelihoods, resilience, and desirable well-being outcomes. Overlooked and understudied enset, as perhaps the most important livelihood element of the enset growing area, was not included in the aforementioned asset index or analysis by Kwak and Smith (2013). This highlights the fundamental challenge of appropriate context-informed asset selection and asset index creation that must be addressed for researchers to find asset poverty equilibrium thresholds and to avoid overlooking unfamiliar types of assets (Michelson et al., 2013). Selecting the correct assets and approach to reducing dimensionality in an index remains a significant challenge to useful, rather than simply data-driven, applications of asset-

based approaches more widely and may be helpful in appropriately interpreting the results (Barrett et al., 2016).

Applying an asset index, also without including enset, to a 10-year panel data set for 15 Ethiopian villages, Liverpool-Tasie and Winter-Nelson (2011) found “weak” evidence of two equilibria levels at and near the asset poverty line in enset-growing villages. These assets did predict future well-being better than consumption measures, but locations with different infrastructure or proximity to markets were equally, if not more significantly, important influences on asset poverty dynamics as compared to livestock, social capital, or tools. This highlights another major challenge for asset-based models because asset based longitudinal analysis must take into account different “starting places” in terms of geography, livelihood, or life cycle (Barrett, 2014). In a recent study using the first two rounds of ESS data, the same data set used in this paper, Kashi Kafle et al. (2017) found higher assets predicted more stable consumption and a diet that included more nutrient rich foods. Their study also did not include enset or trees but, rather, televisions and electric stoves owned by few households that would most accurately characterize wealthier communities with access to electricity.

Building resilient well-being outcomes—operationalizing sustainable and human development theory—requires political will or individual determination to make space and allow time for the activation of local capacities, resources, and know how (Gatto, 2020). This very mechanism was reported in a livelihood transformation study in the highlands of Kenya where Barret (2011) reported increasing water,

nutrient, and land constraints were successfully navigated by those households that could replant their farms with tea and wait 2 years for the first harvest.

Socioecological diversity was a key concern raised in a recent critical sustainability-focused review of rural poverty trap research where Haider et al. (2018) encouraged broadening asset-based approaches to consider context of cross scale dynamics, external drivers, and complexity introduced by path dependencies. In a novel study, Scoones (2015) applied multidisciplinary approaches to articulate the not-necessarily-commercial purposes and desired outcomes of the Ethiopian enset-based food system. Scoones found the integrated goal of the farming system—where maintaining well-fed livestock in turn contributed to a higher level goal of expanding the rich soil (called “darkoa” in the study area)—supported the enset garden where other trees, perennials, and vegetables were planted. The size and quality of the soil in the enset garden was the measure of the farm’s wealth.

Resilient pathways to food security imply expanding the scope of ideas rather than limiting programs and policy to risky, dogmatic, income-centric approaches—such as the potential social disruption of alienating millions from their land by converting small farms into commercially viable big farms (Collier & Dercon, 2014) or waiting on generational change for the increasingly unlikely scenario that general economic growth liberates the most marginalized communities currently trapped in a deteriorating cycle of hunger and poverty (Kuznets, 1955; Sachs, 2006; Sachs et al., 2004). If the green revolution idea of western technology transfer has generally failed to improve food security for a significant number of small farms in Africa in 70+ years, perhaps it is high time to consider the issue from a completely new, or perhaps

more appropriately very old, perspective on how small farms can build on assets appropriate in context first to ensure food security as the basis for wider gains against poverty and improvement in well-being.

Chapter 5: Rooting the Future: On-Farm Trees' Contribution to Household Energy Security and Asset Creation as a Resilient Development Pathway—Evidence from a 20-Year Panel in Rural Ethiopia

5.1 Introduction and Relevant Literature

Firewood, twigs, leaves, crop residue, and dung are the primary sources of solid biomass energy used for cooking by over 2.5 billion people (International Energy Agency, 2017). Lack of access to electricity and use of modern cooking solutions are widely used indicators of energy poverty and the focus of global efforts, such as the United Nations' Sustainable Development Goal target 7.1 (United Nations General Assembly, 2017). National-level energy security policy and research are increasingly aligned with sustainable development concepts, including diversification, resilience, and environmental/climate friendliness (Ang et al., 2015; Yergin, 2006). Key issues for developing country energy security are (a) unequal access and (b) risks, including volatility of international markets (Kaygusuz, 2012).

With less than 1% of the population having access to electricity during the early 1990s, Ethiopia has dramatically improved access to electricity to over 40%.^{vi} Like many developing countries, the improvement has been uneven, with urban residents enjoying a 90% rate of electricity access while rural areas estimate between 5% and 25% access. This lack of access to electricity leaves approximately 90% of total energy needs met with biomass (International Energy Agency, 2017; Mondal et al., 2016). Household demands for biomass as fuel in rural Ethiopia results in less biomass available for other productive uses, such as fodder for animals or fertilizer to

increase crop productivity (Bishaw, 2001). Recent evidence from the Nile Basin of Ethiopia indicates burning dung has measurable negative impacts on crop productivity, but this can be countered by increased availability of firewood from on-farm trees to replace dung as a household fuel that can, instead, be applied as fertilizer—thereby increasing yields (Mekonnen et al., 2017).

Indicators of physical access to modern energy sources are associated with the concept of an energy ladder where households will switch to electricity or fossil fuels as the most modern fuel available for purchase within their means (Leach, 1992). Other quantitative energy poverty measures traditionally emphasize the concept of a deficit where a household's economic access to a sufficient amount of fuel for basic needs is calculated in a similar way and correlated with conventional consumption-based measures of poverty, such as the poverty line (Pachauri & Spreng, 2003).

In contrast, recent policy-relevant empirical studies of household fuel choice emphasize contextual factors that reveal a large role for cultural preferences in cooking methods and diverse reasons for using or stacking different fuel sources (Masera et al., 2000). For example, Ruiz-Mercado and Masera (2015) found an open fire used for cooking also serves as a gathering spot for social interactions, healing or spiritual practices, and practical purposes, such as drying clothes. Wood fires for cooking were found to be preferred by wealthier urban households in Ethiopia, as is the case in Italy or other countries where people enjoy grilled foods, even for those with access to modern alternatives (Mekonnen & Köhlin, 2009).

Focusing on the agency of the energy poor, local context, and household preferences can be coherently considered in research on how energy relates to well-

being (Day et al., 2016). This focus on the relation of energy to immediate environment, agency, and the circumstances of the household has been widely researched in cooler climates where poor quality energy-inefficient housing compounds issues of high cost and limited access to preferred sources of energy for vulnerable households. This concept of fuel poverty has underlined the importance of considering the environmental context of the household, including the quality of the dwelling space, as key to drawing links between energy-focused policies and programs with resulting well-being outcomes (Liddell, 2012).

Biomass on farms in rural settings has diverse and integral uses, such as fertilizing fields, fodder for animals, and constructing shelter. When households are forced to burn biomass for cooking or heating at the expense of their livelihood or shelter—at rates contrary to their longer term well-being—household energy insecurity may contribute significantly to increasing vulnerability. Some direct well-being impacts of this energy related vulnerability have been extensively studied—including poor health outcomes due to indoor pollution, particularly associated with burning crop residue and dung, along with inefficient open fires for cooking (Bruce et al., 2000). Poor health, lower productivity, and missed education outcomes have been correlated with energy poverty and have been explored in many studies (González-Eguino, 2015). Time spent collecting biomass from depleted environmental sources reduces the time available for children to obtain an education or—particularly for women who bear the major burden of collection—to contribute in other meaningful ways to the household’s livelihood and well-being (Scheurlen, 2015).

The long-term cumulative effects of biomass poverty-related negative outcomes—coupled with the associated overexploitation of the environment to meet energy requirements—interact in a negative feedback cycle resulting in persistent poverty in degraded areas (Duraiappah, 1998). By contrast, a positive feedback cycle was identified in a recent paper from the World Bank, concluding that the effects on poverty of environmental quality are greater than the effects of environmental quality on income alone so that poor households would actually disproportionately benefit from improvements in environmental quality (Heger et al., 2018). Particularly relevant for sub-Saharan Africa, what remains largely understudied are the potentially negative medium-term effects on household well-being and resilience of burning biomass that could have otherwise been employed to building livelihood assets, supporting household well-being, and improving the immediate environment (Mbow et al., 2014; Mendum & Njenga, 2018).

On-farm trees are commonly planted worldwide to meet household fuel, fiber, and food requirements with a capacity to promote longer-term desirable outcomes of resilience and well-being, such as food security (Garrity et al., 2010; Vira et al., 2015; Zomer et al., 2009). Notably, on-farm trees have been largely understudied compared with annual crops or intact forests (Schnell et al., 2015; Verburg et al., 2011; Zomer et al., 2014). An analysis of Earth satellite imaging demonstrated that more than 43% of global agricultural land in 2010 had more than 10% tree cover, and failure to include these trees in global environmental monitoring efforts may lead to a significant undercounting of biomass and environmental services, such as carbon sequestration (Zomer et al., 2016).

A systematic review of articles from 1950 to 2015 identified only 74 papers that have examined the relationships among trees, livelihoods, and food production and only nine studies that have investigated longer term data sets covering more than 7 years (Reed et al., 2017). Furthermore, the authors found weak empirical evidence for, and few studies on, the effects of trees on desirable livelihood and food security outcomes beyond production and income (Reed et al., 2017). As a result, the policy relevance for identifying alternative pathways that could promote the use of trees in sustainable development policies and programs has been limited.

Trees and other environmental assets have not been included in typical demographic, health, and poverty surveys, neglecting a very significant source of income, assets, and resilience for poor farmers (Bakkegaard et al., 2016; Cavendish, 2000; Jagger & Rana, 2017; Rasmussen et al., 2017; Sorrenti, 2017). Increasingly, there have been calls to address the lack of quantitative and panel evidence by a more systematic inclusion of resilience and environmental assets in agricultural adaptation monitoring systems measuring socioeconomic and well-being outcomes (Dinesh, 2016).

Rather than proposing new indicators or embarking on new data collection programs, Rasmussen et al. (2017) argued more can be done to leverage existing datasets with innovative analytical approaches that link environmental, economic, and sociocultural factors when researching sustainable agriculture. Similarly, existing representative population data sets have been suggested as the best source for monitoring socioeconomic effects of large international environmental programs (Jagger & Rana, 2017).

Cross-sectional data represents the primary means for monitoring socioeconomic and some health contributions of policy or programs, such as efforts related to sustainable development goals. However, these data often lack the time series dimension of panel data useful for multidimensional and econometric research on the capacity of alternative pathways to produce desirable outcomes and resilience, particularly over the medium and long term (Alkire & Samman, 2014; Scott & Mariotti, 2014). An integrated use of panel econometric modeling and exploratory, multivariate analysis may effectively contribute to clarifying latent relationships among actors' behaviors/preferences and the local background context, evidencing more clearly the interplay between environmental sustainability and economically resilient developmental paths. To date, this type of analysis has been limited by that lack of available longer term panels with an appropriate diversity of variables.

One of the few longer-term time series panel datasets with both on-farm trees and socioeconomic data is the Ethiopian Rural Household Survey (ERHS). Ethiopia, as a matter of national policy, is at the forefront of integrating trees into its sustainable development plans. The country is in the process of transitioning its development pathway from near total deforestation to the adoption of a new climate-resilient green economy built on a strong sustainability policy. This policy change suggests a direct link between trees and livelihood and food security outcomes, despite the limitations of the evidence base (Government of Ethiopia, 2011). To date, generic best practices derived from case studies, randomized control trials on test plots, and imported technology that typically drive “top-down policy” have generally

focused on community forests and not provided a fully adequate evidence base that includes on-farm or other trees (Carlsson et al., 2004).

More generally in the literature, traditional tree-oriented well-being studies have primarily focused on communal forests and the shared economic benefits (Angelsen et al., 2014; Cavendish, 2000; Fisher, 2004; Mamo et al., 2007; McKean & Ostrom, 1995; Reardon & Vosti, 1995; Reddy & Chakravarty, 1999; Vedeld et al., 2007). However, to date, studies of private and communal wood lots in Ethiopia have had a limited scope and have typically aimed at understanding the productive constraints in increasing yields or the potential challenges to sustainable production (Bekele, 2011; Pukkala & Pahjonen, 1990).

Until recently, specific studies on household behaviors related to on-farm trees in Ethiopia have been limited to the rural demand for biomass or the links between agricultural investment and land tenure with permanent crops and trees (Dercon & Ayalew, 2007; Newcombe, 1987). Research by Gebremariam et al. (2009) focused on tree materials from forests and farms as a source of income-generating activities for small enterprises but did not consider how this income further contributed to livelihoods and well-being.

In new research from Southern Ethiopia, proposing a contextually nuanced pathway from trees to desirable food security outcomes, Baudron et al. (2017) found complex biomass flowing to the household—rather than direct harvest from the forest—contributed most to increased diet diversity. In other words, taking into account fuel requirements, exchange of different biomass products and the range of rural household capacities and assets is essential to accurate characterization of

development capacity pathways. A recent mixed methods case study from Ethiopia documented the substitution of dung with firewood from on-farm trees for cooking fuel increased the availability and application of dung as fertilizer, resulting in subsequent increased crop productivity (Worku et al., 2018). A key research challenge remains in further articulation of the pathways that planting on-farm trees' contribution of fuel, food, and income to a broader range of well-being and livelihood outcomes over the medium and longer term.

Two trees in Ethiopia, *Eucalyptus globulus* and *Ensete ventricosum* (enset), have a long history of being planted on farms. Searching for a solution to a fuel wood shortage that threatened the sustainability of the capital, Addis Ababa, the regime of Emperor Menelik II imported a variety of eucalyptus seedlings to be tested in a trial plantation in 1894–95 (Horvath, 1968). Eucalyptus matures in 5–10 years, can rapidly accumulate biomass, and has been estimated to vary in fuel wood production of between 10 and 30 m³/ha/year in Ethiopia (Pukkala & Pohjonen, 1990).

According to Turnbull and Booth (2002), “Many people in Ethiopia are absolutely dependent on eucalyptus as a source of fuel and house building material” (p. 5). In a wide-ranging review of the available literature, Davidson (n.d.) concluded eucalyptus is similar to other trees in characteristics, such as shade or soil erosion, but is distinct primarily because of its low nutrient uptake. Davidson further concluded negative criticism of the high total annual water requirements is an unwarranted artifact of limited analysis that does not take into account surprisingly high rates of biomass creation as a ratio of water use.

Negative criticism of eucalyptus resulted in a policy banning eucalyptus in parts of Ethiopia in the late 1990s due to concerns about negative impacts on crop yields (Jagger et al., 2005). Although the water use can be a problem in dry contexts, it seems that the allelopathic properties of eucalyptus may have been overstated because most tests were undertaken in laboratory conditions on crop seeds or sprouts rather than in real-life farm conditions (Davidson, n.d.).

The first written scientific description of enset dates from 1867 (Wittmack, 1867), but cultural and linguistic evidence supports the proposition that enset has been an important basis of the food system in the highlands of Ethiopia for thousands of years (Blench & Dendo, 2003). Enset is harvested 5–8 years after planting; it is a drought resistant fodder source for animals and food source for humans with nutrient characteristics similar to potatoes (Mohammed et al., 2013). Enset is a notable example of a productive asset for producing food while also a significant environmental asset protecting from soil erosion on the steep slopes where it is grown. Although once widely cultivated, the introduction of annual seed crops by Ethio-semites is speculated to have led to enset cultivation being replaced on flat land where it is easier to plow (Blench & Dendo, 2003).

Flows of income measured on a survey would be unlikely to capture the accumulated value that is stored in either eucalyptus or enset that increase their store of value as they grow from year to year. Seeking a dependent variable to be used in modelling, attention was paid to identification of variables that are both (a) correlated with the TonF and (b) represent a plausible functional connection between eucalyptus and enset with the dependent welfare or well-being variable.

Of the more than 50 potential correlations reviewed as possible dependent variables, dwelling value (DV) showed the highest correlation with on-farm eucalyptus trees during an initial exploratory and later stepwise statistical procedure. Dwelling value had other attractive qualities such as (a) increasing on a similar time scale as trees, (b) being an obvious indicator of resilience over the medium-term correlated with typical measures of well-being, (c) paralleling on a conceptual level where a home that roots a family, and (d) lacking prior investigation in the literature. Mediating relationships, potential but not necessary connections, between on-farm trees and dwelling value were identified. Trees provided both raw materials and income for investing in home improvement. More information on the trees themselves from both the survey and secondary data informed the functional dependency relationship to DV as construction materials. Similarly, livestock as an asset related to enset cultivation and reduced crop residue burning, had a direct connection—as enset not only is a store of biomass for human consumption but also as fodder. Finally, DV and livestock were identified as the first and second largest stores of wealth for ERHS households, further ensuring their relevance as dependent variables.

Dwelling value—as defined in this study specifically, as the data were collected in ERHS—is worth a short discussion here, as DV is not a commonly used nor consistently defined variable. The value of “Part of Dwelling” was estimated separately for “roof” and “outside walls.” Initially in 1994, the ERHS asked participants to estimate the cost of replacement for the parts of their dwelling. In each subsequent round, respondents were asked “did you spend anything on building a

new house or improving your house and other buildings,” and this amount was added to the initial replacement cost and any previous improvements. Dwelling value as a variable in other studies has two characteristics we see in the ERHS data.

The first characteristic of DV is that it is self-assessed with most of the small literature dedicated to assessing the difference of home owners’ ability to value their property against what the market will bear (Tur-Sinai et al., 2020). By contrast, a more commonly used economic variable of “property value” is usually determined by recent sales data alone and often used in research on what home buyers value most. A limited number of studies related to environmental health have used these data to see how the market reacts to air pollution or flood risk (Beltrán et al., 2018; Bruce et al., 2000). A market valuation from sales data or professional assessor would not be feasible in rural Ethiopia.

The second characteristic is that DV tends to focus on replacement value. Market values are harder to estimate for homeowners than the more objective and easy-to-quantify replacement value (Agarwal, 2007). The only analogous information about DV in Africa is available only for microinsurance initiatives that work with replacement value of homes in South Africa (Matul et al., 2010). DV appears to be easy to collect and is a relatively accurate self-assessed indicator of asset value. An early paper researching the value of squatter dwellings in the Philippines found owner estimates and professional appraisers’ estimates were not significantly different, with knowledge of the construction materials being the most important factor in the estimation (Jiminez, 1982). Although not yet common in many resilience or rural development studies, this investigation explored a range of assets, including DV, that

are most valuable to the poor and correlated with their livelihood well-being outcomes.

Progress in sustainability science requires that the contributions of understudied productive and environmental assets vital to rural contexts, such as on-farm eucalyptus and enset trees, be included in research on livelihood and well-being outcomes of resilient development pathways. Agricultural mosaics now cover much of the world; thus, measurement and modelling approaches that take trees, permanent crops, and a diversity of smallholder land uses into account are required to achieve local sustainable governance of these landscapes and resources (Coe et al., 2014; Gliessman, 2013, 2014; Kareiva et al., 2007). Little space is available to extend agriculture without greater deforestation, and improving empirical information is critical to supporting alternative sustainable development pathways that meet the increasing demand for food, energy, and water—without further environmental damage (Foley et al., 2011; Gibs et al., 2010).

On-farm trees are concurrently productive and environmental assets, found worldwide, with the capacity to promote longer term desirable outcomes of resilience and well-being such as food security (Garrity et al., 2010; Mbow et al., 2014; Vira et al., 2015). Notably, on-farm trees have been largely understudied compared with annual crops or intact forests (Schnell et al., 2015; Verburg et al., 2011; Zomer et al., 2014). Environmental assets, such as trees, are undercounted, their contributions underestimated, and unintentional costs over the long term are largely unarticulated in the conventional evidence base for development and agricultural policy. This undervaluation is the result of standard agro-socio-economic research and indicators

that habitually concentrate on short-term production and consumption (Griggs et al., 2013; Rockström et al., 2017; Shepherd, 2015). The research presented in this paper is intended to contribute novel insights to the growing literature on how to value on-farm trees to well-being and resilience from a unique 20-year panel dataset in a rural agricultural mosaic context.

The research reported in this paper focused on an investigation of the potential contribution of on-farm trees to increase the amount of biomass available to rural Ethiopian households and the capacity of on-farm trees to directly and indirectly transform this biomass to increase assets that practically improve livelihoods and well-being. From a broader perspective, this research was also used to explore any evidence that planting more on-farm trees has the capacity to avert a vicious cycle of environmental degradation with associated poor well-being outcomes and, rather, set rural households on a pathway for resilience and sustainability. The purpose of the work was to explore the relationships between local environment, assets, and well-being. Specifically, the research explored the relationship between on farm tree planting, home biomass management, and two socially important development outcomes. A rather large amount of descriptive data about the study area was researched to provide the necessary context for model development and interpretation of the econometric results.

5.2 Methodology

5.2.1 The Ethiopian Rural Household Survey Dataset

In Ethiopia during the latter part of the 20th century, access to a low level of assets was a common experience for rural households that suffered setbacks from natural disasters, such as the massive 1984 drought, alongside a politically driven leveling of assets by policies, such as a program of land redistribution. The Ethiopian Rural Household Survey (ERHS), therefore, started with a pseudo-baseline, or at least a nearly equal starting point for most households, in 1989 to observe the emergence of different livelihood strategies and resilient development pathways in the subsequent 20-year period. Rural households had largely been depleted of assets (Corbett, 1988). Some families returned to their homesteads after forced migration due to the drought, conflict, or a villagization policy (McDowell & De Haan, 1997). All households were allocated land through a new system based on an ability to farm and the size of the household (Holden & Yohannes, 2002). As presented in the descriptive statistics below, this common starting point is clearly evident with remarkably little variation in types of assets or household plot size. This was a period during which many households initiated a process of rebuilding livelihoods, creating assets, and planting trees with the hope of better times ahead.

Since trees take years, or sometimes decades, to mature, medium-to-long-term data collection is required for research that begins with planting seedlings and seeks to measure the outcomes of those trees when mature. This relatively long maturation period slows research on trees and may explain in part why they are understudied in comparison to annual crops. This issue is even more acute when attempting to

research the impact of planting trees in real-world contexts and communities (Scherr, 1991).

The ERHS panel is, therefore, unique because it brings together observations of livelihood strategies—including planting trees, raising livestock, or establishing annual crops—with the measurement of assets and household characteristics in a 20-year panel dataset (Dercon & Hoddinott, 2004). In 1989, the first round of sampling was completed in six drought-affected communities. In 1994, and for the seven subsequent rounds, an additional nine villages were added to the panel. For this study, the research focused on 1,475 households representing the variety of agricultural systems across Ethiopia and who were consistently surveyed at 5-year intervals in 1994, 1999, 2004, and 2009 (Dercon & Hoddinott, 2004).

More than 40 journal articles, 10 book chapters, and numerous working papers and conference presentations have analyzed the ERHS panel data. Stefan Dercon, an author of at least half of these documents, has used econometric techniques in investigating the effect of shocks, seasonality, and infrastructure on consumption, livelihoods, and vulnerability—among other themes (Dercon & Christiaensen, 2011; Dercon et al., 2009; Dercon et al., 2005; Dercon & Krishnan, 2000). Other authors have written about the relationships among gender, education, assets, access to credit, and food aid with poverty-related variables that also primarily focus on consumption (Carroll, 2006; Sepahvand, 2009; Tefera et al., 2012; Weir & Knight, 2007).

The ERHS dataset and approaches to dealing with known issues are well documented. For example, the attrition rate for the sample was low, at about 1% per

year, and Dercon (Dercon & Hoddinott, 2004) suggested inclusion of location or time-fixed effects have proven adequate to control any attribution bias. A critical consideration during analysis of ERHS data was that all questions and modules were, unfortunately, not completely consistent for all rounds. Some of the ERHS variables were measured in each round and were, therefore, appropriate for modeling with econometric approaches. However, other important modules, such as household energy sources, decision making around planting trees, or certain types of risk exposure, could only be used as descriptive statistics to inform the model development or interpret results because they were only part of the household survey in a single round.

Although the ERHS data has been a source for a considerable number of studies with clear policy implications, new analysis can provide meaningful insights into understudied elements and test the relevance of alternative modeling or measurement methodologies. For instance, there is no example in the literature referencing the ERHS data that investigates DV as an asset indicator. Rogg (2006) compared different household and agricultural assets measured in the local currency, birr, and found in the 2004 ERHS dataset the average Ethiopian household had 350 birr in durable assets, 1,722 birr invested in livestock, and 736 birr in food stocks. For that same period, as the descriptive statistics show, the average DV is calculated as 2,448 birr. This simple example of new analysis shows, for the first time in the literature, that a rural African household's dwelling is, at least in this case, the household's most valuable asset.

Livelihood and environmental assets that develop over the medium-term have not been fully investigated using the ERHS data or, more generally, in the well-being and sustainable development literature. Thus, new analysis of existing datasets continues to be a valuable method of addressing this oversight in terms of timescale and overly narrow consideration of rural household and community assets. To date, only two analyses, one qualitative and one quantitative, have used the ERHS tree data. An ERHS study site was included in a qualitative analysis of eucalyptus planting and the visible landscape changes after the policy change, resulting in a greater sense of tenure security for the farmers (Kebede, 2002). In the quantitative analysis, the share of land allocated to trees and shrubs was a proxy for the willingness of households to invest in their farms and was correlated with perceived tenure insecurity (Dercon & Ayalew, 2007). No other research has investigated the ERHS information about on-farm trees or examined trees as contributing to well-being or asset accumulation by rural households.

5.2.2 Descriptive Statistics and Exploratory Cross-Lagged Model to Confirm Reciprocal Relationship

In this section, the descriptive statistics that informed the development of the econometric model are presented. A rather lengthy study site description is presented to provide the necessary local context for the choices made in the econometric model development and interpretation of the econometric results. Household-level energy insecurity provided a useful context for establishing relationships between on-farm trees, biomass use, and the development of assets. Extensive use of descriptive

statistics was made because understanding the rural Ethiopian context is critical to the development of the model and interpretation of results. In turn, assets are presented alongside a wider set of well-being and resilience outcomes to illustrate correlations as the basis for a potential resilient development pathway related to planting trees and on-farm biomass management. Finally, the directionality of the reciprocal (i.e., causal) relationship between on-farm trees and asset creation were confirmed in an exploratory cross-lagged model.

From the beginning of the ERHS panel, survey respondents have identified the importance of assets for managing risks. The three most frequent responses—when asked to describe “the type of households that had suffered the least in times of famine” between 1984 and 1994—were those with household/farm tool assets, savings, and owned livestock. In fact, by a ratio of 10:1, 238 respondents identified household/farm tool assets to be associated with suffering less during famine as compared to only 24 respondents identifying food stocks as a key asset. Old age, illness, and many dependents were the most frequently reported characteristics to describe households that suffered the most during times of famine. After these vulnerable group descriptions, the next most frequently reported characteristic of households that suffered the most during famine were those without enough livestock or fixed assets.

On-farm trees, and assets generally, increased over the study period (see Table 5.1). Eucalyptus and enset are by far the most common on-farm trees reported in the ERHS dataset. Households reported owning these trees 4 to 5 times more often than the next most frequently reported avocado and gesho trees. No other species of trees

were reported by more than 2% of respondents. Furthermore, only enset and eucalyptus trees were planted on-farms in large numbers, while single tree plantings were most common for nearly all other trees types reported. Although the precise species name was not recorded in the ERHS dataset, it is known that most of the trees generally referred to as eucalyptus are *Eucalyptus globulus* and enset trees are *Ensete ventricosum*. The mean number of eucalyptus trees per household more than tripled over the study period, while the mean number of enset trees per household dipped and then increased by 30% by 2009.

The increasing number of households reporting both eucalyptus and enset trees decreased between 1999 and 2004 during a period with a serious drought. Regional governments restricted eucalyptus trees at this time because of concern that they would reduce land productivity and yields (Jagger & Pender, 2003). Although this regulation could have led to underreporting or fewer trees planted, it is likely that the drought was responsible for fewer trees being planted, seedlings dying, and trees being cut down to meet household energy and income requirements. ERHS respondents reported steady investment and increases in DV between each survey round. Although the number of animals per household reflected in the tropical livestock unit indicators doubled over the study period, fewer households reported having animals in each round.

Table 5.1*Two Most Common On-Farm Trees and Two Most Valuable Household Assets*

	Eucalyptus trees households with trees (mean number of trees)	Enset trees households with trees (mean number of trees)	Dwelling value households reporting (mean in Birr)	Tropical livestock unit households with livestock (mean in TLU)
1994	519 (200)	422 (298)	1,475 (1282)	1,469 (2.44)
1999	869 (250)	493 (280)	1,475 (1860)	1,335 (2.82)
2004	595 (311)	395 (260)	1,475 (2448)	1,279 (2.9)
2009	859 (611)	431 (381)	1,475 (3824)	1,275 (5.02)

Households reported their personal reasons for growing trees in the 1999 round of the ERHS survey. Sale of on-farm trees as firewood or construction material was reported as the most common reason for planting eucalyptus. Enset was most commonly consumed as human food (see Table 5.2).

Table 5.2*Reason to Plant Eucalyptus and Enset Trees*

Reason to plant	Eucalyptus # households	Enset # households
Sell as firewood	495	24
Sell as construction material	440	19
For own firewood	193	3
For own construction material	264	13
Consumed as food	4	424
Animal fodder	0	11

Note. # indicates the number of households (1475 total household observations) that reported at least one on-farm tree of this type.

A functioning seedling market was evident in all the ERHS communities except for one poor and remote village called Dinki (Weir & Knight, 2007). Most

households for the period 1994–1999 reported planting seedlings from the market or their own nursery (see Table 5.3). There appeared to be a small preference for female-headed households for acquiring seedlings from community nurseries and slightly fewer relying on their own nurseries. A relatively small number of households received their seedlings from the Ethiopian Government Ministry of Agriculture (MOA) or nongovernmental organizations (NGOs). By contrast, 78% of enset seedlings came from the household’s own nursery with only 12% of enset seedlings bought at the market and negligible access from other sources.

Table 5.3

Source of Eucalyptus Seedlings, 1994-2009

	Male-headed household	Female-headed households
Bought from market	36% (188/523)	35% (57/163)
Own nursery	34% (179/523)	29% (47/163)
Community nursery	14% (74/523)	21% (34/163)
MOA nursery	10% (54/523)	12% (19/163)
NGO nursery	2% (12/523)	1% (1/163)
Other	3% (17/523)	3% (5/163)

Household-level energy security involves trade-offs of on-farm biomass use. On the whole, ERHS households reported collecting most of their fuel from on-farm energy sources such as dung, firewood, and crop residue (see Table 5.4). All households, except for a single household using dung for fuel, reported using more than one source of energy indicating a propensity to mix or trade-off between different energy sources. Dung and crop residue are important on-farm sources of energy along with twigs and leaves. There is a cultural component to the cooking of the staple bread injera where a mix of fuels is used, including dung, which extends

the duration of fire at a low heat (Gamtessa, 2003). Roughly equal numbers of households collected firewood from their own land, unmanaged open access areas, and managed forests. Approximately two-thirds, or 1,053 households, purchased some kerosene at the market. Additionally, two households reported using biogas as part of an unspecified project implemented by FAO in the ERHS village of Adele Keke.

Table 5.4

Source of Energy by Number of Households in 1995

	Own land	Open access	Community forest	State forest	Market	Other
Firewood	334	348	238	39	31	24
Dung	338	99	18	0	0	3
Charcoal	8	7	12	2	37	0
Twigs	201	160	101	14	3	8
Leaves	113	42	38	2	5	0
Crop residue	228	40	0	0	13	5

Note: The numbers indicate the number of households (1475 total household observations) that reported collecting these energy sources (row) from these areas (column).

Competing productive uses for dung and crop residue were more frequently reported than their use as fuel (see Table 5.5). Despite being the most commonly reported cooking fuel, dung was more commonly collected for use as fertilizer or a construction material. Crop residue was most commonly used for livestock fodder. As noted in Table 5.2, wood can be used as a construction material, source of income, or as the preferred household fuel source. These trade-offs at household level to ensure energy security have clear implications for the availability of biomass to support other

household efforts to increase the productivity of the land, health of the livestock, or improve their dwelling.

Table 5.5

Use of Crop Residue and Dung

Collect dung or crop residue	Dung for fertilizer	Crop residue as fodder	Dung for construction	Crop residue for construction
1,036	841	669	427	293

Note: The numbers indicate the number of households (1,475 total household observations) that reported collection and different uses for crop residue or dung.

Collection of biomass for household energy needs was clearly gendered activity for the ERHS survey participants. Although adult males collected firewood at similar rates as adult females, adult females and other members of the households were more likely to collect other types of biomass (see Table 5.6). Adult women primarily collected dung and crop residue while children and other members of the household collected twigs and leaves. Overall, it is clear women and children bore the large part of the effort in biomass collection.

Table 5.6

Fuel Collection Actors Disaggregated by Gender

	Adult male %	Adult female %	Children or other family members %	Total %
Fire wood	28.36	30.27	41.36	100.00
Dung	12.57	56.98	30.45	100.00
Crop residue	17.42	49.24	33.33	100.00
Twigs	15.53	37.88	46.59	100.00
Leaves	14.53	29.05	56.42	100.00

One of the most striking statistics about biomass collection reported by ERHS households is that collecting firewood on-farm required less than half the time for collecting firewood from other sources. The average time for collecting firewood from their “own land” was 26.12 minutes while collecting firewood from open access, community forest, or state forest required an average of 61.48, 70.38, and 60.64 minutes, respectively.

Trade-offs in biomass use to ensure sufficient fuel for basic household energy security has implications for the household efforts to improve well-being, resilience, and create assets. Biomass collection on farm can clearly save time that can be made available for other activities. Several authors have indicated time saving, along with increased fuel availability and land productivity, are all pathways to improved food security and diet diversity (Sola et al., 2016; Worku et al., 2018).

Here are presented the correlations of the ERHS households’ most valuable assets in 1994 and 2009 with common measures of well-being including a diet diversity score (see Table 5.7). Based on sample heterogeneity and small deviations from normality in the sampled variables, a nonparametric correlation technique (Spearman rank analysis) was used instead of a more classical technique adopting Pearson product moment correlation coefficients (Duvernoy et al., 2018). Nonparametric Spearman analysis was suitable to identify both linear and nonlinear pairwise correlations between variables (Colantoni et al., 2015), giving more value to an exploratory analysis of (apparent and latent) relationships between dwelling value (or tropical livestock units) and selected contextual variables (Salvati & Serra, 2016).

Table 5.7*Dwelling Value and Tropical Livestock Unit*

	Dwelling value, Spearman's Rho (p value)		Tropical livestock unit, Spearman's Rho (p value)	
	1994	2009	1994	2009
Household size	.29 *	.27 *	.36 *	.33 *
Household dietary diversity score	.27 *	.30 *	.36 *	.36 *
Head of household years of education	-.00	.15 *	.15 *	.20 *
Average years of education all HH members	.15 *	.15 *	.23 *	.23 *
Per capita expenditure	.06 *	.31 *	.21 *	.30 *
Land owned	-.07 *	.06 *	.58 *	.48 *
Land planted	-.03	.11 *	.59 *	.62 *
Household asset index	.05	-.17 *	.36 *	-.17 *
Agricultural asset index	.04	-.02	.46 *	-.03

Note. * indicates significant at $p < .05$; sample size is 1475 observations.

From the beginning to the end of the ERHS panel, there were strong, significant correlations between the asset measures and well-being indicators such as diet diversity, average education, and per capita expenditures. The tropical livestock unit (TLU) variable was strongly correlated with measures of land owned and planted. In 1994, the TLU was more significantly correlated with an indexed measure of household and agricultural assets—but not as strongly in 2009. Dwelling value was not correlated with land access or the asset indexes in any consistent significant way. There may be issues with that asset index due to insufficiently appropriate assets being included in the questionnaires or types of common assets changing over time.

Assets often help households better manage shocks by providing a store of value or opportunity to adapt strategies to minimize loss of well-being (Horvath, 1968; McDowell & De Haan, 1997). Dwelling value and TLU were correlated with

fewer crop-related and fewer total shocks reported by the households (see Table 5.8). As is often the case, having more of an asset such as livestock will make a household more exposed to shocks affecting that asset category as seen in the ERHS 1994 data with livestock-related shocks. Nonetheless, dwelling value and TLU were both correlated with desirable outcomes from drought where households report eating more meals. Households also were less likely to report being forced to miss meals or eat less preferred foods as a coping strategy. TLU was also significantly correlated with lower likelihood of selling a productive asset. Assets appeared to be generally associated with desirable well-being and resilience outcomes in the ERHS dataset. Developing a model to measure how much on-farm trees can shift the trade-offs for household level energy security and support building these key assets.

Table 5.8

Correlation of Assets and Reported Shock Exposure and Drought-Related Effects in 1994

	Dwelling value Spearman's Rho (p -Value)	Tropical livestock Unit Spearman's Rho (p -Value)
Number of reported shocks	-.22 *	-.01
Crop-related shocks	-.19 *	-.20 *
Livestock-related shocks	-.22 *	.16 *
Drought-number of meals	.13 *	.36 *
Drought-reduced number of meals	-.12 *	-.25 *
Drought-ate less preferred wild foods	-.17 *	-.28 *
Drought-sold productive assets	-.01	-.15 *

Note. * indicates significant at $p < 0.05$; sample size is 1475.

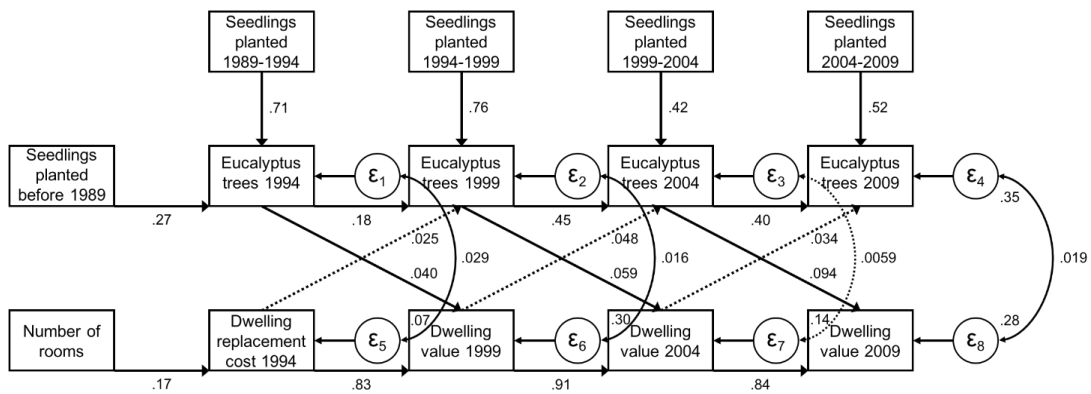
5.2.3. Recursive Dependency Implied with an Exploratory Cross-Lagged Variable Model

The econometric modelling was built around a core recursive relationship between the number of eucalyptus trees grown on farm and the value of the

dwelling—represented by replacement cost along with improvements and repairs of the walls and roof. A simple cross-lagged model demonstrates clearly the unidirectional relationship of maturing eucalyptus to dwelling value—with no significant feedback relationship (see Figure 5.1). In other words, there was a significant relationship of households growing more trees and having more valuable houses but no significant relationship of more valuable households through their presumed wealth necessarily growing more trees.

Figure 5.1

Cross-Lagged Model Relating Standardized Log Measures of Eucalyptus Trees and Seedlings to Dwelling Value



In Figure 5.1, solid lines represent significant relationships at $p < .001$. There is strong serial correlation of the key variables and also significant correlation of the cross-lagged variables in only one direction from the trees toward dwelling value. The cross-lags in the direction from dwelling value to trees were all not significant ($p = 0.20, 0.68, 0.83$). Errors were all significantly correlated except for the survey round in 2004. The coefficients between variables are included in the figure and were

calculated with a maximum likelihood estimator. As these coefficients can be interpreted as amount of variance explained, trees explain a relatively large and significant amount of the non-serial-related variance in dwelling value.

5.2.4 Random Effects Econometric Models

Illustrating the dichotomy between building assets with biomass or burning it for fuel, trees directly contributed lumber for dwelling construction and, at the same time, provided firewood as the most preferred energy source for ERHS survey participants. The first econometric model developed sought to estimate the contribution of trees to dwelling value over time for the participating ERHS households. Both crop residue and dung were commonly used for both fuel and construction, but the preferred use for crop residue was as fodder for livestock. Developing a second model linked biomass with asset creation focused on the directional correlation reported between harvesting crop residue as fodder to maintain livestock. On-farm trees were also included in the model as an indirect support to livestock as a substitute fuel source, thereby, increasing the availability of crop residue.

5.2.5 (Model 1) Dwelling Value: Contribution of On-Farm Tree to the Households' Most Valuable Asset

To estimate the contribution of on-farm trees to household assets in the ERHS panel dataset, the generalized two-stage least squares approach with random effects was followed. Beginning with a model that included endogenous and exogenous

variables with unit specific and time varying error components, the model is stated as (Balestra & Varadharajan-Krishnakumar, 1987; Baltagi, 2013):

$$y_{i,t} = Y_{i,t}\gamma + X_{i,t}\beta' + Z_i + \mu_i + v_{i,t} \quad (1)$$

where:

$y_{i,t}$ is the dependent variable representing assets; dwelling value in model 1 and tropical livestock unit in model 2;

$Y_{i,t}$ is vector of endogenous time varying variables correlated with v_i ;

$X_{i,t}$ is a vector of exogenous time varying variables;

Z_i is a vector of time constant exogenous variables;

γ is a vector of coefficients accounting for the partial effect of instruments;

β' is a regression coefficient estimated following the matrix method described by Balestra and Varadharajan-Krishnakumar (1987);

μ_i is a random effects estimator for the time constant error identically distributed over the panel;

and

$v_{i,t}$ is the idiosyncratic error with a zero mean and uncorrelated with $X_{i,t}$.

In Model 1, the standardized log of dwelling value is the dependent variable.

Two of the most commonly planted on-farm trees, eucalyptus and enset, were selected as the initial independent variables. Additional time constant and time varying explanatory variables were identified to increase the explained variance and to act as controls in the model. A reverse stepwise procedure was adopted with the aim to remove multicollinear variables from analysis and reduce the overall redundancy with the goal of a parsimonious final model illustrating the key relationships of interest. Many variables in livelihoods and well-being research are highly multicollinear, zero-inflated, and generally associated with overall consumption-based measures of poverty and, therefore, were not included in the models presented here (see Table 5.9 for a summary of the variables selected for use in the model). Some variables that would have been potentially interesting lacked sufficient data—such as income from selling timber—because they were not included in all rounds of the ERHS.

Table 5.9*Variables Included in the Model*

Variable (Standardized Natural Log)	Between standard deviation	Within standard deviation	Variable
Dwelling value (dependent)	0.92	0.39	$Y_{i,t}$
Number of eucalyptus trees (endogenous time varying)	0.82	0.57	$Y_{1,i,t}$
Number of enset trees (endogenous time varying)			$Y_{2i,t}$
Number of eucalyptus seedlings planted in the previous 5–10 years (instrumental time varying)	0.75	0.66	γ_1
Number of enset seedlings planted in the previous 5 years (instrumental time varying)			γ_2
Crop residue harvested (independent time varying)	0.74	0.67	$X_{1,i,t}$
Household size (independent time varying)	0.81	0.59	$X_{2,i,t}$
Mean replacement cost (independent context explanatory)	0.62	0.0	$Z_{1,i}$
Female-headed households (independent context explanatory)	0.42	0.0	$Z_{2,i}$
Constant (independent context explanatory)	1.00	0.0	$Z_{3,i}$

Time-constant characteristics are less common in a dataset that spans 20 years for rural households where growing families change composition, infrastructure is developed, or innovation may have been introduced. At the same time, characteristics such as education level of the head of the household are zero-inflated in the ERHS dataset with very few educational opportunities available because of the social challenges described in the previous section. Using a reverse stepwise procedure found the inclusion of the following time-constant characteristics at the household

and community level serve as valuable independent variables in the model to control for unit level and context level variability: (a) female-headed household, (b) number of rooms in the house, and (c) mean replacement value of dwelling in 1994.

Again, following the reverse stepwise procedure, the standardized log of crop residue produced by the household and the household size were identified as additional time-varying explanatory variables. It is important to note that dummy variables representing time fixed effects were tested in the model and were all found to be insignificant. Although these time-fixed effects have been found to be significant for other econometric analyses of outcomes related to consumption where inflation or the small survey dropout rate may have been more important (Dercon & Ayalew, 2007), these time effects seem to have exerted less effect on the medium-term variables of interest dwelling value and trees planted.

A Durbin X^2 test indicated the standardized log of the number of eucalyptus trees and enset trees, when regressed against dwelling value, were endogenous with a Durbin X^2 statistic of 10.719 at a significant p value of .005. Therefore, selecting among the potential instruments that were not significantly correlated with the error residuals, a lagged variable for the number of eucalyptus seedlings planted in the previous 5- to 10-year period—and recent enset seedlings planted in the previous 0-5 years to the model—were identified as instruments. These instruments were particularly attractive because there was a clear causal relation between planting seedlings and the eventual number of mature on-farm trees. Yet, seedlings appear to have been sufficiently available equally to wealthier households with higher value dwellings and those less well-off and, therefore, consistent with the tests indicating

the number of seedlings planted as an exogenous variable. A significant Wu-Hausman test indicated eucalyptus and enset seedlings may in fact have been used as instruments to reduce endogeneity with an F statistic value of $F(2, 5892) = 5.36$ and a significant p value of .005. The variables used to parameterize the equation are summarized, along with their between and within standard deviations, in Table 5.10. The Wald X^2 test for eucalyptus and enset as instruments were both significant at probability X^2 less than .0001.

With the variables identified for the model, the appropriateness of using the random effects approach was tested. A Breusch-Pagan LM Lagrangian multiplier test was highly significant, indicating preference for a model with specific individual effects instead of a pooled OLS estimator with a χ of 4397.35 with a probability $> \chi$ of .000. Random effects were specifically indicated while fixed effects were rejected by a Hausman test that was not significant, rejecting the hypothesis of systematic differences with a X^2 of 5.83 with a probability $> X^2 = 0.212$.

Table 5.10

Correlation of Variables Used in Model 2 With Residual Error as an Indication of Endogeneity

Standardized log variable	Variable type	Correlation with residual error
Crop residue	$Y_{1,i,t}$ (Endogenous time varying)	.030 *
# of enset tree	$Y_{1,i,t}$ (Endogenous time varying)	-.036 *
# of eucalyptus trees	$X_{i,t}$ (Exogenous time varying)	.005
Household size	$X_{i,t}$ (Exogenous time varying)	.017
Self-reported primary use of crop residue for fodder	Z_i Time constant	-.008
Longitude of ERHS community	Z_i Time constant	-.007
Female-headed household	Z_i Time constant	-.048 *

Note. # indicates the number of households (1475 total household observations) that reported tree type; * indicates significant at $p < .05$.

5.2.6 (Model 2) Tropical Livestock Units: Direct Contribution of Crop Residue and Indirect Contribution of On-Farm Trees Contribution to the Households' Second Most Valuable Asset

The same modeling approach as described in Equation (1) was used. The standardized log of TLU was the dependent variable. Crop residue was an independent variable of primary interest along with the other variables from Model 1: household size, eucalyptus, and enset trees. Three time constant variables were also identified: (a) female-headed households, (b) self-reported primary use of crop residue for fodder dummy variable, and (c) longitude of ERHS community.

The number of eucalyptus trees, household size, and longitude were employed as instruments for the three endogenous variables in the generalized two-stage least squares calculations. The Wald test X^2 for the three first-stage regressions for crop residue, enset trees and female-headed households were 1,891, 2,408, and 498, respectively. All had a probability less than X^2 with p values less than .0001.

5.3 Results

On-farm eucalyptus trees over time significantly contributed to an increase in dwelling value. The generalized 2-step least squares (GT2SLS) random effects model resulted in a strong effect of on-farm eucalyptus trees that accounted for the largest variation in dwelling value once the time constant median value of dwellings in the village was controlled (see Table 5.11). The overall R^2 for the model was .342 with a Wald X^2 value of 1730.66 and probability $> X^2$ equal to .000. The causal direction of the correlation of eucalyptus tree planting and dwelling value, indicated in the cross-lagged model above, was confirmed with the significant results of a first stage of the G2SLS regression for all variables at a p value of .04 or less—except for the number of rooms. This resulting second stage partial estimation of the number of eucalyptus trees can be described in a qualitative sense as mature eucalyptus trees that have survived at least 5 years. The resulting coefficient of 0.25 of the standardized log value for the contribution of these mature trees, therefore, explained essentially 25% of the variability in dwelling value accounted for in the model. In other words, planting eucalyptus trees accounted for about 9% of the dwelling values reported in the ERHS data set.

The other time-constant variables included in the model explained variation in dwelling value in line with expectations. A higher number of rooms indicated a higher dwelling value with a significant coefficient of 0.12. By contrast, female-headed households reported a significantly lower dwelling value, with a negative coefficient of -0.94 . Larger household size and higher levels of crop residue also

positively contributed to dwelling value, with coefficients of 0.09 and 0.034, respectively

After inclusion of the instrumental variables in the first stage, the number of enset trees no longer significantly contributed to dwelling value with a p value of .28. This is consistent with the descriptive statistics that would indicate wealthier households may have had more enset trees and higher reported dwelling values, but enset was primarily planted to meet food requirements while eucalyptus was planted to meet energy and construction needs. Using seedlings as an instrument, effectively controlling for the endogeneity, was consistent with the descriptive statistics that indicated richer households at any one moment had a higher probability of more on-farm trees, but households did not need to be wealthy in the first place to plant trees. Later in the discussion, this theme of access to seedlings and contribution of on-farm trees to increased dwelling value will be addressed in greater depth.

Table 5.11

Results of Model 1 of On-Farm Tree Contribution to Dwelling Value

Standardized log values	Coefficient	Standard error
Households with trees of eucalyptus trees	.25 *	.05
Household size	.09 *	.018
Crop residue	.03 *	.009
Mean initial dwelling value in local area	.71 *	.035
Number of rooms	.12 *	.015
Female-headed household	-.09 *	.037
Number of observations	5900	
Overall R ²	.34	

Note. * indicates significant at $p < .05$.

On-farm trees may have substituted as a preferred source of energy and allowed for more crop residue to be used as fodder for livestock (see Table 5.12). Over time, increased availability of dung as fertilizer may increase crop productivity. The pathway between on-farm trees and increased TLU may involve more related variables, but it still provided significant results from the GTSLS Model 2.

Table 5.12

Results of Model 2 of On-Farm Tree Contribution to Tropical Livestock Unit

Standardized log values	Coefficient	Standard error
Crop residue	1.030 *	.05
Households with trees enset trees	.161 *	.08
Female headed households	-.695	.39
Collect crop residue and dung	.120 *	.03
Number of observations	5900	
Overall R-square	.310	

Note: * indicates significant at $p < .05$.

The first-stage results indicated strongly significant instruments for the endogenous variable crop residue at $p < .001$ for inclusion of eucalyptus trees, household size, longitude, and self-reported collection of crop residue and dung (see Table 5.13). Only household size and longitude were significant in the first stage for predicting female-headed households.

Table 5.13*Results of the First Stage Regression of Instruments on Crop Residue in Model 2*

Standardized log values	Coefficient	Standard error
Households with Trees eucalyptus trees	.144 *	.01
Household size	.344 *	.01
Collect crop residue and dung	.194 *	.02
Longitude of location	.237 *	.01
Number of observations	5,900	

Note. * indicates significant at $p < .05$.

5.4 Discussion

Trees on farms contribute to household-level energy security that, over time, allows biomass that is not burnt for cooking and heating to be transformed through more productive uses into valuable assets that support sustainable livelihoods and well-being. This development pathway logic is consistent with research demonstrating how poor households access forest resources to improve shelter or obtain assets (C. M. Shackleton & Shackleton, 2004; C. M. Shackleton et al., 2007). In a similar way to how household assets may be used to cope with risks, the forest itself is used as an environmental asset that provides a safety net of alternative resources during times of shocks such as droughts that affect rural agricultural livelihoods (M. Arnold et al., 2011; Powell et al., 2011).

Demonstrated with two econometric models, on-farm trees significantly increased the value of rural Ethiopian households' two most valuable private assets, their dwelling and livestock. The model results indicate strong significant correlations for tree variables, R^2 values above 0.3, and highly significant Wald chi-square tests that support the validity for the proposed models. Reverse stepwise regression

eliminated many variables that were likely multicollinear and added little additional information to the bottom-line relationship of trees to household level energy security and assets. A direct pathway to increased dwelling value, where on-farm timber from eucalyptus is used to repair and improve the home, is consistent with self-reported descriptive statistics and modeled results. The number of eucalyptus trees on a farm is the largest predictor of dwelling value after the initial time constant control variable. Inclusion of female headed households resulted in a negative coefficient with dwelling value improvement in the model results—perhaps reflecting the overall challenges for female-headed households to build assets.

Dwelling value, as both a store of value for the poor and an indicator of resilience, significantly correlated with a wide range of livelihood well-being outcomes and should be included more regularly in household surveys in rural areas. Property value, analogous to DV in this study, has long been acknowledged as the most important household asset in industrialized countries where houses are consistently worth more than 85-90% of annual household income (e.g., Kain & Quigley 1974).

The World Bank (2015) acknowledged the poor quality and overall extremely limited amount of information about the informal housing sector, accounting for over three quarters of urbanizing African cities. Even less is known about housing values in rural areas, their role in rural livelihoods, and their overall contribution to well-being and resilience. The ERHS collected both the type of materials used in the housing and the estimated cost for replacing the roof, walls, or flooring. In each subsequent round, the panel household was asked what improvements were made and

how much they cost. This provides a unique panel chronicling the investment in household dwelling unavailable from any other source for rural Africa.

Donovan and Butry (2010) drew a consistent and clear connection between property value and treed property in developed countries. Zhu and Zhang (2008) found strong correlation at the neighbourhood level with satellite estimates of tree cover and housing value. Potential future research linking dwelling value, well-being, and trees may (a) better inform evidence-based policy on the distribution of well-being-related assets of poor rural households and (b) lead to adjustments in policies and programs to promote the functional use of trees and treelike perennials to improved housing.

A second indirect pathway demonstrated in a first stage of the regression a significant contribution of eucalyptus trees to increased availability of crop residue that, in turn, is the largest determinant of increased livestock values represented by the TLU variable. This is consistent with the self-reported importance of crop residue for animal fodder for these rural households. Recent work by Baudaron et al. (2017) followed a similar pathway logic from biomass to assets to well-being. They investigated the impact on food security related to distance to forests and found the biomass flows as fodder and fertilizer to be the likely mechanism behind the positive relationship between forest access and increased dietary diversity. Although the logic is similar, it is important to note Baudaron et al.'s conclusions were drawn from identified association of food security-related outcomes with spatial proximity to a natural forest, and the results focused on the econometric modeling of outcomes for on-farm trees.

Female-headed ERHS households had a strongly negative relationship with increased livestock ownership in the model results—perhaps reflecting cultural norms regarding large animal ownership. The gender disparities identified in both increased dwelling value and increased livestock ownership for female-headed households should be subjects of further research.

In addition to these clearly evident pathways, there may be multiple other indirect pathways—such as using crop residue to thatch roofs or selling firewood to finance construction and repair costs—to be explored in other datasets with these variables consistently measured. The enabling effect of on-farm trees to promote feedback between the widespread use of animal dung for fertilizer and the higher availability of crop residue the following year is not quantitatively captured in either existing ERHS data sets, but it probably has an unmeasured effect on the crop residue variable in the models. In fact, increased dung available for fertilizer has been a primary justification for rural afforestation programs and policy in Ethiopia over many years (Newcombe, 1987). The bottom-line finding is that having biomass above and beyond the minimum requirement for cooking and heating creates opportunity for asset creation on small farms, and on-farm trees were shown to be a popular and effective way to increase on-farm biomass availability in Ethiopia between 1989 and 2009.

ERHS households reported a preference for using dung and crop residue for productive uses as fertilizer and fodder rather than as fuel. At the same time, many households reported the use of dung and crop residue for cooking fuel, and most of this biomass was collected on their own farms. This represents a clear sign of energy

insecurity when a household burns a fuel they prefer to use for another purpose and could potentially be a robust indicator to enhance measurement of household energy insecurity to complement fuel/energy poverty measures. Recent case study research from the highlands of Ethiopia, using mixed methods, confirmed the continued existence of this chronic household energy insecurity as a negative feedback of biomass removal from the environment leading to less biomass being regenerated and available to the community (Worku et al., 2018).

Firewood remained, overall, the most frequently used energy source for the ERHS households but was often collected in open access areas or in communal forests as well as from on-farm sources. Households collecting in open access areas tended to collect less firewood than those with an on-farm or communal forest source. Also, this fuel collection takes more time. This was particularly evident for women collecting fuel in open access areas and likely indicates ongoing environmental degradation (Kes & Swaminathan, 2006). Households that had access to communal forests seemed to report using similar amounts of preferred fuels as those households with on-farm trees.

Communal forests have been a focus for research and policy related to meeting biomass requirements for fuel and construction by the Ethiopian government and international organizations since the 1970s, but these projects faced challenges with reported tree survival rate of less than 20% (Bishaw, 2001). Following this tradition, most literature relating trees to well-being outcomes—with specific interest in food security—has focused on communally managed woodlots and forested areas rather than on-farm trees. Access to communal forests has been associated with

greater dietary diversity (Johnson et al., 2013). By contrast, deforestation has also been associated with poor dietary outcomes of households and children (Ickowitz et al., 2014; Jones et al., 2017).

Research from Southern Ethiopia suggests in much the same way that it is the biomass flows to the household, rather than the direct harvest of food products from the forest, that contribute to the dietary diversity (Baudron et al., 2017). These dietary correlations are also found in the ERHS data, but with private control of on-farm trees; private tree ownership implies a similar, but distinct, capacity pathway for contributing to a wide range of livelihood outcomes. From the 20-year panel, there was a high survival rate implied by the cross-lagged data between seedlings and trees—as well as trees between rounds. Although communal forest and on-farm trees may address household energy insecurity as a pathway to improve well-being, on-farm trees may suffer less of the access and maintenance challenges in communal forest management.

As authors have emphasized the role of communal and national forests as environmental assets that promote desirable well-being and resilience outcomes, the findings of this research suggest on-farm trees promote many of those same outcomes but through the transformation of environmental assets into livelihood assets even more directly related to the outcomes of interest. As put forth in the fuel poverty literature, the quality of housing has a significant impact on both the amount of fuel required and the enjoyment of well-being benefits from obtaining sufficient fuel (Boardman, 1991; Bouzarovski & Petrova, 2015). This research found strong

correlations of improved consumption, education, and diet diversity with more valuable Ethiopian homes in better repair.

This research also found significant correlations of dwelling value with less risk exposure. Dwelling value and livestock assets, in particular, were strongly significantly correlated with improved coping with drought. In fact, the promotion of common environmental assets and on-farm trees may be complementary, rather than substitutive, goals. Recent research from a watershed management area in Ethiopia confirmed household-level trees were major contributors to achieving project goals by meeting community fuel and fodder needs while relieving pressure on existing forests and, at the same time, increasing productivity by increasing dung availability for fertilizer (Worku et al., 2018).

As competition and policy trade-offs for management of food–energy–water resources are predicted to increase dramatically in the coming decades, broadening the evidence base through research on the links between well-being, environmental assets, and socioecological processes is fundamental to improving the understanding of resilience dynamics and creating better informed policies (Cartwright & Hardie, 2012; Hoff, 2011; Kareiva et al., 2007). However, intuitive, empirical evidence, similar to that presented in this study, is rare in large part because of a paucity of coherent and appropriate panel data for studying the important role of trees and environmental assets in the outcomes socioecological systems from existing observational datasets (Angelsen et al., 2014; Bakkegaard et al., 2016; Jagger & Rana, 2017; Rasmussen et al., 2017). For example, most households in the ERHS data set procured their seedlings at a market. The community without a market that

sold seedlings did not have many on-farm trees, with only two households reported eucalyptus trees grown from seedlings provided by the Ministry of Agriculture. Novel empirical results and identification of an alternative resilient development pathway require datasets with a diversity of variables—such as informal seedling markets and a diversity of seeds and other nonindustrial inputs—that more broadly represent the essential elements of rural agricultural livelihoods, markets, and the foundational socioecological system on which they rely.

J. M. Arnold et al. (2006), in their sweeping survey of research on woodfuel, concluded renewed attention to woodfuel and timber as coproducts of agriculture and agro-forestry activities is overdue. Further research on biomass as the foundation of household energy security pathways promises new insights into the role of seeds and seedlings and other environmental assets that contribute to rural livelihoods. Research that bridges productive and environmental assets should be encouraged and include a measurement of medium and longer-term outcomes. A particularly exciting area for further investigation is the dual nature of trees and permanent crops as productive and environmental assets providing a wide range of socioeconomic benefits and environmental services (Miller et al., 2018).

Taken as a whole, a broad range of positive effects on well-being, livelihoods, and resilience can be observed over the medium term, from access to seedlings to cultivation of on-farm trees. Meaningful improvement in well-being, livelihoods, and assets takes time. Female-headed households may face increased challenges regarding energy security, or asset creation in general, which requires further investigation. Additional research is required on the role of tree-oriented investment by rural

households in the accumulation of assets and the observed improvements in well-being and resilience outcomes over the medium and longer term.

The research is limited in similar ways to more general ongoing challenges of sustainability science as a whole. In the investigation, the research was limited for econometric modeling to the panel data collected in the ERHS, whose primary purpose was to characterize the productive agricultural aspects and their relation to largely consumption-based food security measures. Although modules on gender, decision making, shocks, or energy use appeared in some rounds, other important sustainability information was missing almost entirely, such as data on environmental assets, environmental services, or governance of common spaces. The use of household panel data also limited analysis of environmental and contextual issues at the landscape or regional level that typically strengthen sustainability focused research. The use of statistical tests for inclusion of variables in the econometric model is necessarily reductionist and insights potentially could be made by further investigation of some of the borderline significant variables using a different approach, such as factor analysis or beginning with other environmental assets than on-farm trees. Limiting the focus to the core relationship of the most common trees to the most valuable assets was pursued for clarity in presentation of the main findings. However, it is certainly possible to see the value of future investigations into a broader set of variables with more sophisticated statistical techniques, such as three-stage least squares models.

This work contributes to a number of promising opportunities for future research. There is great potential for researching the comparative benefits of different

trees, including native species, on farms and their benefits, but that will require a sampling frame that is able to capture a representative sample in this context where most trees are rare and with most species reported by only one or two households out of 1,475.

Use, income, and distribution of benefits from on-farm tree products in different farming systems could potentially contribute to better understating of the cost benefit and appropriateness of policies promoting on-farm or common area tree planting in different contexts. This could also include more investigation of gender and wealth dynamics at the intra-household level. Much of the interest in biomass management research is related to agricultural and food security outcomes.

The inclusion of nutritional analysis could potentially integrate these related lines of inquiry around cooking, nutrition-sensitive agriculture, and nutritional well-being outcomes. The potential of natural assets as instruments including soil, seedlings, and seeds, requires further investigation to see the value of potential widespread application of these instruments in different contexts.

Finally, and most importantly, environmental outcome-related lines of inquiry about on-farm trees—such as reduced soil erosion due to larger availability of biomass or the valuation of improved environmental services at different spatial scales—could be pursued. Unfortunately, the data available over longer time periods, such as the 20-year ERHS panel, are limited in these respects and may require novel approaches to explore. This research supports calls for socioeconomic datasets to include a wider variety of environmental indicators and information about trees, fiber, and permanent crops.

5.5 Conclusion

Asset creation related to adequate on-farm biomass and on-farm trees provides a compelling pathway for linking environmental and productive asset creation in the rural context to desirable well-being and resilience outcomes. This research used panel econometric modelling approaches to measure the effect of planting the two most common on-farm trees, eucalyptus and enset, on dynamics of the two most valuable rural Ethiopian household assets—dwellings and livestock.

Contextually appropriate instruments, including seedlings, successfully reduced endogeneity of asset-related variables in a generalized two-stage least squares modeling approach. Planting eucalyptus resulted in significant positive increases in dwelling value where timber from the trees themselves potentially represent a large part of the investment over time. A small, but significant, coefficient for crop residue confirmed the positive relationship between on-farm trees, annual crops, and increases in dwelling value. On the other hand, available crop residue was highly correlated with increasing values for livestock. Both eucalyptus and enset tree planting increased crop residue in the ERHS dataset putatively through expanding overall biomass on the farm through provision of the more preferred wood fuel, twigs and leaves. Despite indications on-farm trees saved time for fuel collection for both men and women, a dummy variable for female-headed households presented a negative correlation, indicating beneficial outcomes of on-farm trees were not as pronounced for these households. This requires further research into the specific challenges of asset creation for female-headed households.

Combining observations of fuel preference, fuel source, and fuel use may provide new indicators of household level energy security. Increases in the burning of biomass, that the household sees as more productive for another use, would be a clear sign of stress. At the community or population level, this may be an indication of eroding socioecological resilience and the sign of a negative energy environment feedback loop. Further research with data sets that include these three dimensions of household energy insecurity should be undertaken to better understand if this relationship holds true in different contexts.

The measurements indicated on-farm trees may increase households' most important asset dwelling value by 9% and significantly contribute to additional TLUs. Extrapolated nationally, the contribution of on-farm trees to rural households' assets would represent billions of USD in value. Mixed method research from large integrated watershed programs supports the observation of on-farm tree contributions to meet household energy requirements, relieve pressure on common areas, and, perhaps, protect forests or other environmental assets. As large programs of work on sustainable development will necessarily be taking place in rural areas now dominated by agricultural mosaic landscapes featuring many on-farm trees, better accounting for their contributions and exploration of approaches to multiply their benefits may make considerable progress to reaching sustainable development goals.

Chapter 6: Conclusions

6.1 Summary

TonF, like many assets, grow in value over time and, like other assets, contribute to flows of value that can build resilience as a foundation for desirable and sustainable well-being outcomes. As biomass stores of value, TonF are unique assets in that they represent an almost pure capture of what Blaikie and Brookfield (1987) called the “‘value’ contained in the natural source of all energy in the ecosystem, the sun’s energy and of the stored products of that energy” (p. 5). Although timber from trees can sell for a good price depending on the market or species, trees and treelike perennials are versatile productive livelihood assets that can contribute on an ongoing basis as (a) fodder for animals in the dry season, (b) readily available combustible materials for daily cooking, and (c) a wide variety of ecological and cultural services.

Rural livelihoods are intimately linked to local food systems that typically revolve around a few key natural assets such as livestock or nutrient-rich soil. Livelihoods and food systems are sustainable when appropriate cultural knowledge, technology, and a diversity of supporting regenerative assets are interlinked to create resilient positive feedback cycles such as crop residue feeding livestock whose manure in turn replenishes the soil. Modeling systems and resilience is largely about identifying and measuring key elements, boundaries, and constraints that can be coherently presented as what Blaikie and Brookfield (1987) called a “chain of explanation” or what Leach et al. (2010) characterized as a pathway.

Although the normative references and ontological framings between chains and pathways may put emphasis on different values, they functionally play similar

roles in the investigation process. The research presented in this dissertation formalized these along the lines of Cartwright's (1989, 2007) “capacity bootstrapping” that helps to select and organize variables for econometric-type longitudinal modeling. Cartwright’s approaches are sure to see an increased interest as longitudinal data is becoming more available as an evidence base for policy development and program design.

Small farms face many constraints, and the biomass constraint, along with TonF more generally, is understudied. The ubiquity of trees and treelike perennials on farms, particularly in the tropics and on small holdings, indicates their presumed broadly applicable value—at least from the farmer’s perspective. As Chambers and Leach (1989) pointed out, foresters’ concern with conservation and timber, coupled with the agriculturalists’ focus on commodity crops, have left research of TonF woefully neglected. Tiffen (1996) identified trees as one of the significant reserves of capital for resource poor farmers in Kenya that is a consistent “blind spot” (p. 180) for international experts assessing rural livelihoods that often promote external interventions rather than approaches to strengthening existing local farming systems.

Sustainability studies and research on resilience emphasize the nexus of food, energy and environmental security, and this debate will decide the policy approach to balancing agriculture with the environment in hopes of feeding between 9 and 10 billion people by 2050. This thesis made use of spatially informed longitudinal methods to measure the contribution of trees to building assets and maintaining desirable food security and well-being outcomes using previously rare, but newly available, panel datasets from Ethiopia that include socioeconomic, agricultural, and

tree data. The work, presented as three independent studies, reveal biomass poverty is often indicated by household energy insecurity and/or lack of on-farm trees, and chronic biomass poverty is the result of an inability to maintain a sufficient level of essential green assets, such as trees and perennial crops, contributing to poor resilience and well-being outcomes on small farms in different areas of Ethiopia.

On the other hand, medium and longer term asset accumulation supports improved well-being when strategies make use of farm forests, other on-farm trees, and perennials. Thus, the overall thesis is confirmed. Trees on farms in rural Ethiopia indicate a fundamental store of value—building a households’ assets over time through improved biomass management—for resilient small farm livelihoods that ensure food security and related well-being.

In Chapter 3, TonF contribution to improved food security—for small-holder farmers growing single-season rain-fed staple crops who disproportionately experience persistent seasonal food insecurity—was investigated in the Amhara Region of Ethiopia. In the more arid areas of the tropics, characterized by pronounced wet and dry seasons, irrigation and other techno-centric solutions have proven difficult to mobilize at the necessary scale to address systemic incongruities between peak supplies of energy, labor, and water with peak demands for income, food, biomass, and services that support well-being to avoid predictable recurrent annual periods of hunger and deprivation of for millions of people across rural Africa.

By rooting down to reach year-round water, trees produce biomass to meet household fuel, fodder, fiber, and food needs during the long slack season, when work is scarce, and the lean season, when high prices exacerbate suffering from

exhausted food stores. Biomass poverty occurs when households do not produce or manage biomass in optimal ways to support their farming or broader agriculture-based livelihood strategies and is indicated by burning crop residue or other biomass that has more desirable uses.

Ethiopia has experienced policy changes that have encouraged farmers to invest in TonF and has also recently collected a population representative three-wave panel data set that, for the first time, includes information on agriculture, TonF, socioeconomic, and well-being outcomes like food security. This is the first data set of its kind that is population representative for the Amhara Region of Ethiopia that has witnessed on-farm afforestation and where little remaining forest cover remains in common areas.

Employing a longitudinal hierarchical mixture model that controls for key determinants of food security such as wealth, gender of head of household and location, this research quantified the marginal contribution of farm forests, defined as small multipurpose stands of trees, to reduction of food insecurity duration. This research found a mean-sized farm forest of 1000 m² reduced the mean reported duration of food insecurity by nearly half, ranging from approximately 7-15 days with the greatest reductions in food insecurity duration for female-headed and the poorest households. Focusing on TonF, including multispecies farm forests as sources and stores of biomass with multiple uses, rather than an overly narrow accounting restricted to commodified fruit or nut production, revealed the critical biomass-related counter seasonal functionality and contribution to household well-being that farm forests make to improved food security. Sustainable intensification is an important

policy goal to reduce hunger and spare land while building resilience to potential increased seasonality under climate change. Farm forests represent a potentially powerful solution to the stubborn issue of seasonal hunger as well as being a possible indicator of successful sustainable intensification and livelihood outcomes more generally.

In Chapter 4, measuring and modeling food and nutrition security outcomes from the autochthonous treelike perennial *Ensete ventricosum* (Welw.) Cheesman was examined as a resilient pathway for small farms in Ethiopia. Food insecurity is worsening on resource-constrained small farms in Africa even as incomes rise for mostly urban households in countries such as Ethiopia pursuing agriculture-led green development. Among the more than 500 million small farms globally, food systems exist that successfully support nutritional requirements of densely populated rural areas. Regrettably, research into locally adapted alternative resilient pathways to food security has previously lacked appropriate data sets and interest in cross disciplinary investigation to inform a broader set of well-being-sensitive policy and program options.

Enset, the most under-studied staple food crop in the world, is a treelike perennial plant cultivated for millennia that currently sustains 20 million Ethiopians. Called the “tree against hunger,” because of providing a year-round source of food and postulated drought resistance, some farmers also refer to enset as their bank (S. A. Brandt et al., 1997). Asset-based approaches have proven useful in understanding poverty dynamics and chronic vulnerability to hunger. This research tested the

hypothesis that these treelike perennials act as resilient green assets intended both for subsistence and as a strategic crop to ensure food security in a worst-case scenario.

Agroforestry case studies have identified positive environmental and agricultural production effects of on-farm trees and treelike perennials such as enset, but only recently has a population-representative panel data set with appropriate socioeconomic well-being indicators been available in the enset growing region to investigate their potential impact on poverty, nutrition, and food security. This research applied asset-based and hierarchical mixed modelling approaches to measure the (marginal) effect of enset on indicators of food security while controlling for other common types of assets. This research found consistent, significant, and positive food security outcomes related to relatively small amounts of mature enset on farms and demonstrated potential for increasing these benefits. An unexpectedly large impact on chronic child malnutrition merits further investigation.

As food security and nutrition are the economic and well-being foundation for wider gains from agriculture-led green development, these findings underline the role of trees on farm and treelike perennials, such as enset. Resilient green assets are often marginalized in conventional agriculture, but they are part of a potentially transformational heritage of nature-based and regenerative solutions found in humanity's ancient and diverse food systems.

Chapter 5 began with consideration of how, globally, most rural people cook with firewood or other sources of biomass. When biomass with more productive uses is instead burned, it is a sign of household level energy insecurity. Using crop residue and dung for fuel reduces the availability of fertilizer and fodder and directly

contributes to poor health outcomes. Ethiopia is largely deforested, and many of Ethiopia's trees are now on farms rather than in forests. The objective of this research was to investigate the relationship of on-farm trees to household-level energy security, rural livelihoods, and well-being.

Using an econometric model with 20-year panel data from rural Ethiopia, this research found on-farm trees contribute to building the household's most valuable asset—their home. By contributing to household-level energy security, this research found on-farm trees increased crop residue availability for maintaining the rural household's second most valuable asset—their livestock. Large development efforts, including integrated water management projects and investment programs from the World Bank, are increasingly recognizing contributions of TonF, and environmental quality in general, as important contributing factors to meeting sustainable development outcomes. Asset creation related to on-farm trees and improved home biomass management provides a compelling pathway for building resilience, maintaining well-being, and reinforcing the foundation of rural livelihoods.

By adding measurable value, independent of standard wealth metrics to well-being outcomes, TonF in Ethiopia both indicate and contribute to resilient livelihoods and normative characterizations of sustainability status. Trees on farms investigated in this dissertation have demonstrated in analysis the “particular system qualities” that sustain “human wellbeing, social equity and environmental integrity” (Leach et al., 2010, p. 5), proposed as the normative definition of sustainability. Therefore, TonF should be further investigated as possibly more universal indicators of sustainability.

Food security is also considered one of the most fundamental well-being outcomes that indicate basic functional resilience of socioeconomic systems (Upton et al., 2016). TonF in the studies of this dissertation have also demonstrated a consistent positive marginal impact on food security measures over time and, therefore, merit further investigation as possibly robust measures of resilience as well. More studies of novel indicators of resilience and sustainability are fundamental to achieving the paradigm shift Rockström et al. (2017) argued is necessary to move agricultural and food systems away from goals related to income or production—that by their nature promote short-term strategies of unsustainable inputs or farm area expansion on marginal land—to more resilience and sustainable intensification.

Evident in this dissertation research and aligned with other emerging resilience and sustainability focused investigations, a finer distinction should be made between cyclical or trending increases and decreases of tree cover as food systems evolve from industrial agriculture expansion through commercial plantations or forest clearance for pastures and commodity crops. There are clear climatic and environmental factors, such as altitude, that favor woody species, but factors such as fire and livestock management or land use regulation and enforcement now largely determine where trees grow. These same management techniques and regulations applied in common areas are unlikely to be suitable for smallholders with various rights under different land and tree tenure systems. An overly simplistic dichotomy of forested common areas and private cleared farmlands is neither true nor contributing to policy and interventions that sustainably improve resilience of rural communities or well-being of vulnerable households. Better policy requires improved data, that

makes finer distinctions more rooted in local realities, and inclusive analysis that may consider scientific perspectives that embrace 19th-century ontologies, in context, along with a broader consideration of perhaps differently situated assumptions and other sources of knowledge relevant in that place. This may inform better policy mechanics and more sustainability and reliance-focused policy goals.

Well-being outcomes, including food security, are likely to be improved as assets in general—and, specifically, green assets of living biomass—can be acquired by vulnerable and poor rural households. Stores of value in assets in this dissertation research were correlated with improved resilience outcomes related to food security and may also be more sensitive—as well as easier to collect accurately—compared to monetary flow values of welfare; this is consistent with the development economics literature by Carter and Barret (2006), among others.

Green assets as value stores of living green biomass have additional attractive qualities related to sustainability. Green assets are regenerative and may provide either direct or indirect services to other farm crops, livestock, or household income generating activities, in addition to the contributions of food or income. These green asset investigations reported in this dissertation—and studies from other authors considering the importance of living livelihood assets such as livestock (Lybbert et al., 2004) or soil (Scoones, 2010)—indicate pathways that capture natural regenerative flows of energy and growth that can be transformed and stored as assets and can make a considerable difference in the resilience of rural livelihoods and associated well-being outcomes.

6.2 Future Research

6.2.1 Future research on potential of remote sensing to retrieve on-farm tree related metrics of resilience and sustainability

Measuring and monitoring TonF from remote sensing is perhaps one of the most intriguing applications of these dissertation findings for future search. A new paper published in *Nature* by M. Brandt et al. (2020) has used remote sensing to identify and count trees out of forests that led to unexpected large estimations in the semi-arid and desert areas of the Sahel and Sahara. Observations from remote sensing cannot directly measure resilience or sustainability any more than they can directly measure physical characteristics like mass or tree height. Metrics from the images are calibrated with ground-truth measurements. The type of work in this dissertation on indicators of resilience and sustainability—that correspond to objects like TonF that can be seen by sensors on satellites, airplanes, and drones—are exactly the type of foundational work needed to provide a ground truth for the complex task that will be measuring and monitoring resilience and sustainability.

Resilience as a topic is not yet common in the leading remote sensing journals with only five articles in the journal *Remote Sensing*, four articles in the *International Journal of Remote Sensing*, and 11 in *Remote Sensing of Environment* as of 2014.^{vii} Interestingly, only one article used “resilience” in the title with regard to a study about coral reef degradation (Knudby et al., 2013). A different sensor was used in most other articles and included IKONOS, Hyperion, Landsat 7, Aster, MERIS, MODIS, AVHRR, SPOT Digital Globe World View 2, and airborne LIDaR. About half the articles analyzed time series of vegetation indices to derive a trend or

comparison that could be interpreted from a resilience perspective. Typical of this work was comparing vegetation response in protected and nonprotected areas in Italy or post-Apartheid homelands to other resource management areas in South Africa (Lanfredi et al., 2004; Wessels et al., 2004).

Figure 6.1

Number of Publications on Resilience and Remote Sensing by Year

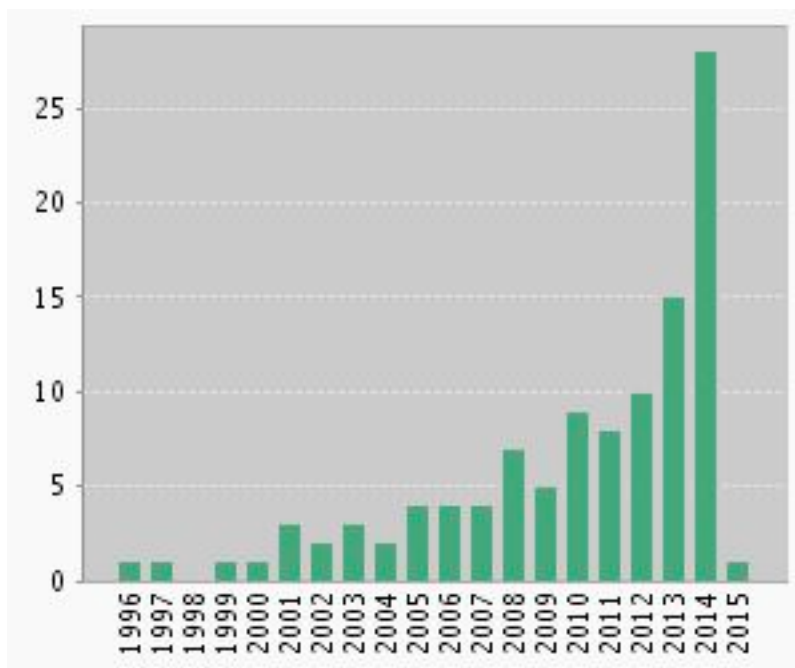
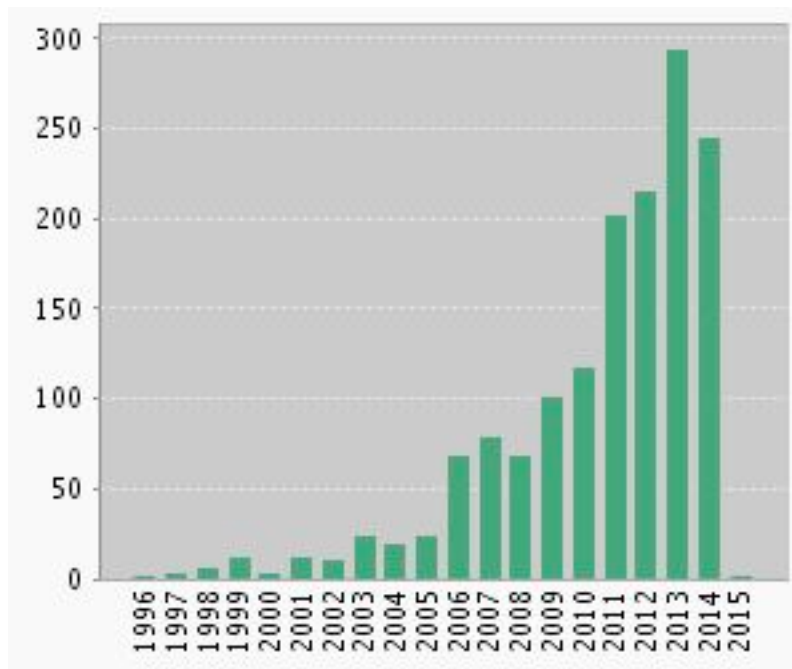


Figure 6.2

Citations of Papers on Resilience and Remote Sensing by Year



Although few articles have been published in remote sensing journals, some authors in a wide variety of other journals have incorporated remote sensing into their studies primarily on ecological resilience. There has been a marked increase in publishing on resilience and remote sensing since 2010—tripling the 5-year average number of publications in 2013 and more than sextupling the number in 2014. Citations have shown a similar upward pattern, with more than 200 citations in each of the past several years.

Variety describes the literature on resilience and remote sensing to date based on the 110 articles retrieved through a Web of Science search on the topics of “resilience” and “remote sensing.” These articles were published in no less than 80 different journals. A topic search does not scan the entire content of the article but

looks for the terms that may be included in keywords, title, and the abstract where it is expected that methods such as remote sensing would be mentioned. Well over 500 authors had contributed to the articles, but only a handful (five) had contributed to two articles. In contrast to the ecological resilience literature where coauthorship and cross citation of related articles are published in key journals, the topic of resilience and remote sensing appears to be immature and not yet coalescing into a coherent dialogue. Nonetheless, a few key themes around methods and research subjects can be identified.

Authors from a variety of disciplines—including physical geography, human geography, ecology, sustainability science and disaster research—have identified remote sensing as an untapped source for data to improve modeling or empirical evidence base for applied research and management. Studies involved in the quantification of ecosystem services require explicit spatial data to improve model predictions. A key pathway linking ecological resilience to human well-being is the provision of ecological services, which is another area where several authors have pointed out possible improvements in parameterization of models to include remote sensing-derived metrics for plant traits, species, biodiversity, abundance of functional components, biomass and carbon storage, disturbance, soil characteristics, evapotranspiration, hydrological variables, landscape structure, and ecosystem functioning (Andrew et al., 2014; Feld et al., 2009; Tallis et al., 2012).

Although the focus on the use of remote sensing to improve mapping of ecosystem services is more recent, ecologists have been stating their requirements for more remote sensing for monitoring changes in “nature society resilience” for more

than 10 years (Parr et al., 2003). In a detailed and specific explanation of the required indicators, Law (2014) mapped out how improved data could lead to better management of resilience for forests. Carpenter (2013), identified in a letter to *Science* explaining the importance of spatial signatures to pushing both the theory and application of resilience forward, specifically mentioned the potential of satellite remote sensing to serve immediate research questions.

Clearly, consensus on how to monitor and measure resilience and sustainability incorporating the use of remote sensing data will require a great deal more research. Nonetheless, findings of this dissertation support the novel potential of TonF as indicators for resilience sustainability and have identified some of the pathways, processes, and conditions that may constrain or multiply the observed well-being impacts trees on farms. Next steps would include locating appropriate geolocated data sets and seeking out the geographies and contexts where remote retrieval of metrics based on trees on farms have the potential to also measure and monitor changes in resilience and sustainability.

6.2.2 Future research on a wide variety of topics to be prioritized

This dissertation has sparked many new lines of inquiry. Through presenting the work at conferences and engaging a wide range of experts across many disciplines to ensure the quality of the work in this dissertation, an almost limitless list of future research has emerged and prioritization as well as sharing the research opportunities will be key to broader contribution of these initial modest findings. The following list includes key areas for future research:

- Analysis of new longitudinal and synoptic observations of biomass and TonF as indicators of resilience and sustainability;
- Use of novel longitudinal farmer-centred data sets that are potential available through social media and big data;
- Integrative research focused on enset-based and other autochthonous food systems on other significant value gaps related to nutrition and food security;
- Mapping of global hot spots for TonF related induced intensification; and
- Additional literature review of recent discourse on natural use value and biomass.

Ethiopia has enjoyed one of the most rapidly growing economies in the world for many years as the second largest African country by population. Although macro socioeconomic indicators were on a positive trend, there was also contradictory evidence that the prosperity was not having a positive impact on the rural population known to be vulnerable from a history of food insecurity punctuated with famine-like conditions as recently as 2003 and again when 10-million people were affected by drought in 2015. Over this same period, clear, consistent afforestation of the landscape, primarily on private land, was contemporaneous to destruction of forests in common areas and the establishment of large-scale commercial plantations. These complex and multidirectional signals are typical of the challenges in gathering information and providing consonant, relevant, and just sources of evidence to inform policy dialogues in Ethiopia and in all countries seeking to balance growth with resilience and sustainability. The interdisciplinary research on subjects and places that

are overlooked and contested, such as TonF in Ethiopia, encourage a deeper level of exploration that seeks to provide newly appropriate problem framing of sustainability challenges that potentially can bring previously obscured knowledge, approaches, and cycles out into this most essential of discussions on how to ensure resilience and wellbeing for the planet, people, and the systems that sustain it all. There is a superabundance of under-investigated located socio-natures and food and farm systems with potentially the same superabundance of overlooked solutions and underappreciated knowledge. Geographers redoubling efforts to bring the best of the disciplinary tools and approaches is sine qua non to adequately and appropriately situating the multidisciplinary multiperspective multimethod investigations required to address to these important resilience and sustainability questions.

End Notes

ⁱ Crowther's biomes are based on World Wildlife Foundation's ecoregions outside the United States based on the United States Forest Service's Bailey's ecoregions. Crowther uses slightly different terminology of "Mediterranean Forest" rather than the original "Mediterranean forest, woodland and scrub" that covers the highly anthropomorphic agricultural mosaic of Southern Europe and North Africa likely lowering the estimated number of trees that are out of forests.

ⁱⁱ Later further articulated and published in World Development journal in 1989 (Chambers and Leach, 1989).

ⁱⁱⁱ Hierarchical linear mixed models, depending somewhat on the specific instance or example, can be referred to as variance components models or nested random effects models.

^{iv} Two examples of maize and apples may clarify the distinction being made for green assets and other types of plants in a food system. Maize is widely representative of the coevolved socio-techno-nature of the American supermarket as popularized by Pollan(2006), but it does not conform easily to asset-like qualities of trees and perennials as stores of value that can grow over time and grow profitably on small farms. Apples are a tree, but they are almost universally treated as a commodity substituted with any other commodity meeting nutritional or cultural definitions of fruit in an industrialized supply chain. Neither, by the definition adopted in this study, would be considered autochthonous Green Assets.

^v Chambers, Leach and Conroy (n.d.) in a technical report for the United Nations Food and Agricultural Organization noted development economics focus income, agricultural science focus on yields, and forestry science focus on industrial production or conservation leads to neglecting "whatever is important to the poor."

^{vi} World Bank Sustainable Energy for all database: Ethiopia.
<https://data.worldbank.org/indicator/EG.ELC.ACCS.ZS?view=chart>

^{vii} Web of Science. Thompson Reuters. Accessed September through December 2014.
<http://apps.webofknowledge.com.libproxy.tulane.edu:2048>

Bibliography

- Abay, K., & Hirvonen, K. (2017). Does market access mitigate the impact of seasonality on child growth? Panel data evidence from northern Ethiopia. *The Journal of Development Studies*, 53(9), 1414–1429.
- Abebe, T., & Bongers, F. (2012). Land-use dynamics in enset-based agroforestry homegardens in Ethiopia. In B. Arts, S. van Bommel, M. Ros-Tonen, M., & G. Verschoor (Eds.). (2012). *Forest-people interfaces: Understanding community forestry and biocultural diversity*. Wageningen Academic Publishers. <https://doi.org/10.3920/978-90-8686-749-3>
- Agrawal, A. (2001). Common property institutions and sustainable governance of resources. *World Development*, 29(10), 1649–1672.
- Agarwal, S. (2007). The impact of homeowners' housing wealth misestimation on consumption and saving decisions. *Real Estate Economics*, 35(2), 135–154. <https://doi.org/10.1111/j.1540-6229.2007.00185.x>
- Ahmed, A. U., Hill, R. V., Smith, L. C., Wiesmann, D. M., & Frankenberger, T. (Eds.). 2007. *The world's most deprived: Characteristics and causes of extreme poverty and hunger* (2020 Discussion Paper No. 43). Food Policy Research Institute.
- Alia, D., Coomes, D., Knauer, J., Merfeld, J., Sun, I., Weaver, E., Wineman, A., Biscaye, P., Anderson, C. L., & Reynolds, T. (n.d.). *Do.File by the Evans School Policy Analysis & Research Group (EPAR) for the construction of a set of agricultural development indicators using the Ethiopia Socioeconomic Survey (ESS) LSMS-ISA*. https://github.com/EvansSchoolPolicyAnalysisAndResearch/335_Agricultural-Indicator-Curation/tree/master/Ethiopia%20ESS
- Alkire, S., & Samman, E. (2014). *Mobilising the household data required to progress toward the SDGs* (OPHI Working Papers 72). University of Oxford.
- Ammerman, A. J., & Cavalli-Sforza, L. L. (1971). Measuring the rate of spread of early farming in Europe. *Man*, 6(4), 674–688. <https://doi.org/10.2307/2799190>
- Ang, B. W., Choong, W. L., & Ng, T. S. (2015) Energy security: Definitions, dimensions and indexes. *Renewable and sustainable energy reviews*, 42, 1077–1093. <https://doi.org/10.1016/j.rser.2014.10.064>
- Angelsen, A., Jagger, P., Babigumira, R., Belcher, B., Hogarth, N. J., Bauch, S., Börner, J., Smith-Hall, C., & Wunder, S. (2014). Environmental income and rural livelihoods: A global-comparative analysis. *World Development*, 64, S12–S28. <https://doi.org/10.1016/j.worlddev.2014.03.006>

- Andrew, M. E., Wulder, M. A., & Nelson, T. A. (2014). Potential contributions of remote sensing to ecosystem service assessments. *Progress in Physical Geography*, 38(3), 328–353. <https://doi.org/10.1177/0309133314528942>
- Arnold, J. M., & Dewees, P. A. (2014). *Farms Trees and farmers: Responses to agricultural intensification*. Routledge.
- Arnold, J. M., Köhlin, G., & Persson, R. (2006). Woodfuels, livelihoods, and policy interventions: Changing perspectives. *World Development*, 34, 596–611. <https://doi.org/10.1016/j.worlddev.2005.08.008>
- Arnold, M., Powell, B., Shanley, P., & Sunderland, T. (2011). Forests, biodiversity and food security. *The International Forestry Review*, 13, 259–264.
- Ayana, A. N., Arts, B., & Wiersum, K. F. (2013). Historical development of forest policy in Ethiopia: Trends of institutionalization and deinstitutionalization. *Land Use Policy*, 32, 186–196.
- Babulo, B., Muys, B., Nega, F., Tollens, E., Nyssen, J., Deckers, J., & Mathijs, E. (2009). The economic contribution of forest resource use to rural livelihoods in Tigray, Northern Ethiopia. *Forest Policy and Economics*, 11(2), 109–117.
- Bakkegaard, R. K., Agrawal, A., Animon, I., Hogarth, N., Miller, D., Persha, L., Rametsteiner, E., Wunder, S., & Zezza, A. (2016). *National socioeconomic surveys in forestry: Guidance and survey models for measuring the multiple roles of forests in household welfare and livelihoods*. Rome. FAO. <https://openknowledge.worldbank.org/handle/10986/28115>
- Balestra, P., & Varadharajan-Krishnakumar, J. (1987). Full information estimations of a system of simultaneous equations with error component structure. *Econometric Theory*, 3, 223–246. <https://doi.org/10.1017/S0266466600010318>
- Baltagi, B. (2013). *Econometric analysis of panel data* (5th ed.). John Wiley & Sons.
- Banerjee, S. G., & Morella, E. (Eds.). (2011). *Africa's water and sanitation infrastructure: Access, affordability, and alternatives*. The World Bank.
- Barbier, E. B., & Hochard, J. P. (2018). The impacts of climate change on the poor in disadvantaged regions. *Review of Environmental Economics and Policy*, 12(1), 26–47. <https://doi.org/10.1093/reep/rex023>
- Barrett, C. B. (2008a). *Food systems and the escape from poverty and ill-health traps in sub-Saharan Africa*. In P. Pinstrup-Andersen (Ed.), *The African food system and its interaction with human health and nutrition*. Cornell University Press.
- Barrett, C. B. (2008b). Smallholder market participation: Concepts and evidence from Eastern and Southern Africa. *Food Policy*, 33(4), 299–317. <https://doi.org/10.1016/j.foodpol.2007.10.005>

- Barrett, C. B. (2010). Measuring food insecurity. *Science*, 327(5967), 825–828.
<https://doi.org/10.1126/science.1182768>
- Barrett, C. B. (2014). Assisting the escape from persistent ultra-poverty in rural Africa. In W. Falcon & R. L. Naylor (Eds), *Frontiers in food policy: Perspectives on sub-Saharan Africa*. In *Stanford University's Global Food Policy and Food Security Symposium Series [Proceeding of the Stanford Symposium Series on Global Food Policy and Food Security in the 21st Century]*. Stanford, CA, United States.
- Barrett, C. B., Garg, T., & McBride, L. (2016). Well-being dynamics and poverty traps. *Annual Review of Resource Economics*, 8, 303–327.
- Baudron, F., Duriaux Chavarria, J. Y., Remans, R., Yang, K., & Sunderland, T. (2017). Indirect contributions of forests to dietary diversity in Southern Ethiopia. *Ecology and Society*, 22(2).
- Baulch, B., & Hoddinott, J. (2000). Economic mobility and poverty dynamics in developing countries. *The Journal of Development Studies*, 36(6), 1–24.
- Bayliss-Smith, T. (1981). Seasonality and labour in the rural energy balance. In Chambers, R., Longhurst, R., & Pacey, A. (Eds.), *Seasonal dimensions to rural poverty* (pp. 30–38) Frances Pinter.
- Bekele, M. (1992). *Forest history of Ethiopia from early times to 1974* [PhD thesis]. University of Wales.
- Bekele, M. (2011). *Forest plantations and woodlots in Ethiopia*. Africa Forest Forum. http://www.afforum.org/sites/default/files/English/English_112.pdf
- Bernoulli, D. (2005). Hydrodynamica. In I. Grattan-Guinness (Ed.), *Landmark writings in western mathematics* (G. Mikhailov, Trans., pp. 131–142). Elsevier. (Original work published 1738)
- Beltrán, A., Maddison, D., & Elliott, R. J. R. (2018). Is flood risk capitalised into property values? *Ecological Economics*, 146, 668–685.
<https://doi.org/10.1016/j.ecolecon.2017.12.015>
- Biasutti, M. (2019). Rainfall trends in the African Sahel: Characteristics, processes, and causes. *WIREs Climate Change*, 10(4). <https://doi.org/10.1002/wcc.591>
- Bilinsky, P., & Swindale, A. (2010). *Months of adequate household food provisioning (MAHFP) for measurement of household food access: Indicator guide*. Food and Nutrition Technical Assistance, Academy for Educational Development. https://www.fantaproject.org/sites/default/files/resources/MAHFP_June_2010_ENGLISH_v4.pdf

- Bishaw, B. (2001). Deforestation and land degradation in the Ethiopian highlands: A strategy for physical recovery. *Northeast African Studies*, 1, 7–25, <https://doi.org/10.1353/nas.2005.0014>
- Blaikie, P., & Brookfield, H. (1987). *Land degradation and society*. Methuen.
- Blench, R., & Dendo, M. (2003, April 10–12). *Enset culture and its history in highland Ethiopia* [Conference session]. Cushitic and Omotic Conference, Leiden, The Netherlands, pp. 1–3.
- Boardman, B. (1991). *Fuel poverty: From cold homes to affordable warmth*. Belhaven Press.
- Boissière, M., Beyessa, M., & Atmadja, S. (2019). *Guiding principles for sustainable bamboo forest management planning Benishangul-Gumuz Regional State (BGRS)*. FAO & CIFOR. <https://www.cifor.org/knowledge/publication/7220/>
- Bonnefille, R., & Hamilton, A. (1986). Quaternary and late tertiary history of Ethiopian vegetation. *Symb. Bot. Ups*, 26(2), 48–63.
- Borrell, J. S., Biswas, M. K., Goodwin, M., Blomme, G., Schwarzacher, T., Heslop-Harrison, J. S., Wendawek, A. M. Biswas, M. K., Goodwin, M., Blomme, G., Schwarzacher, T., Heslop-Harrison, J. S. (Pat), Wendawek, A. M., Berhanu, A., Kallow, S., Janssens, S., Molla, E. L., Davis, A. P., Woldeyes, F., Willis, K., Demissew, S., & Wilkin, P. (2019). Enset in Ethiopia: A poorly characterized but resilient starch staple. *Annals of Botany*, 123(5), 747–766. <https://doi.org/10.1093/aob/mcy214>
- Borrell, J. S., Goodwin, M., Blomme, G., Jacobsen, K., Wendawek, A. M., Gashu, D., Lulekal, E., Asfaw, Z., Demissew, S., & Wilkin, P. (2020). Enset-based agricultural systems in Ethiopia: A systematic review of production trends, agronomy, processing and the wider food security applications of a neglected banana relative. *Plants, People, Planet*. 2(3), 212–228. <https://doi.org/10.1002/ppp3.10084>
- Boserup, E., (2017). *The conditions of agricultural growth: The economics of Agrarian change under population pressure*. Routledge. (Original work published 1965)
- Bouzarovski, S., & Petrova, S. (2015). A global perspective on domestic energy deprivation: Overcoming the energy poverty–fuel poverty binary. *Energy Research & Social Science*, 10, 31–40. <https://doi.org/10.1016/j.erss.2015.06.007>
- Brandt, M., Tucker, C. J., Kariryaa, A., Rasmussen, K., Abel, C., Small, J., Chave, J., Rasmussen, L. V., Hiernaux, P., Diouf, A. A., Kergoat, L., Mertz, O., Igel, C., Gieseke, F., Schöning, J., Li, S., Melocik, K., Meyer, J., Sinno, S., . . . Fensholt, R. (2020). An unexpectedly large count of trees in the West African Sahara and Sahel. *Nature*. <https://doi.org/10.1038/s41586-020-2824-5>

- Brandt, S. A., Spring, A., Hiebsch, C., McCabe, J. T., Tabogie, E., Diro, M., Wolde-Michael, G., Yntiso, G., Shigeta, M., & Tesfaye, S. (1997). Tree against hunger: Enset-based agricultural systems in Ethiopia. *American Association for the Advancement of Science*. <http://hdl.handle.net/123456789/1284>
- Bruce, N., Perez-Padilla, R., & Albalak, R. (2000). Indoor air pollution in developing countries: A major environmental and public health challenge. *Bulletin of the World Health Organisation*., 78, 1078–1092.
- Burney, J. A., & Naylor, R. L. (2012). Smallholder irrigation as a poverty alleviation tool in sub-Saharan Africa. *World Development*, 40(1), 110–123. <https://doi.org/10.1016/j.worlddev.2011.05.007>
- Burney, J. A., Naylor, R. L., & Postel, S. L. (2013). The case for distributed irrigation as a development priority in sub-Saharan Africa. *Proceedings of the National Academy of Sciences*, 110(31), 12513–12517.
- Carletto, G., Jolliffe, D., & Banerjee, R. (2015). *From tragedy to renaissance: Improving agricultural data for better policies*. The World Bank.
- Carlsson, F., Köhlin, G., & Mekonnen, A. (2004). *Contingent valuation of community plantations in Ethiopia: A look into value elicitation formats and intra-household preference variations* (Working Papers in Economics 151). Gothenburg University.
- Carpenter, S. R. (2013). Complex systems spatial signatures of resilience. *NATURE*, 496(7445), 308–309.
- Carroll, S. (2006). *Divorce norms, intrahousehold bargaining, and household outcomes in rural Ethiopia* [Senior thesis]. Stanford University.
- Carter, M. R., & Barrett, C. B. (2006). The economics of poverty traps and persistent poverty: An asset-based approach. *The Journal of Development Studies*, 42(2), 178–199.
- Carter, M. R., Little, P. D., Mogue, T., & Negatu, W. (2007). Poverty traps and natural disasters in Ethiopia and Honduras. *World Development*, 35(5), 835–56. <https://doi.org/10.1016/j.worlddev.2006.09.010>
- Carter, M. R., & May, J. (2001). One kind of freedom: Poverty dynamics in post-Apartheid South Africa. *World Development* 29(12), 1987–2006.
- Cartwright, N. (1989). *Nature's capacities and their measurement*. Clarendon Press; Oxford University Press.
- Cartwright, N. (2007). *Hunting causes and using them: Approaches in philosophy and economics*. Cambridge University Press.
- Cartwright, N., & Hardie, J. (2012). *Evidence-based policy: A practical guide to doing it better*. Oxford University Press.

- Cavendish, W. (2000). Empirical regularities in the poverty-environment relationship of rural households: Evidence from Zimbabwe. *World Development*, 28, 1979–2003. [https://doi.org/10.1016/S0305-750X\(00\)00066-8](https://doi.org/10.1016/S0305-750X(00)00066-8)
- Central Statistics Agency of Ethiopia World Bank Group. (2017). *Basic information document—Ethiopian socio-economic survey* (LSMS Living Standards Measurement Survey). <http://microdata.worldbank.org/index.php/catalog/2783/download/39570>
- Chambers, R. (1984). *Rural development: Putting the last first*. Longman.
- Chambers, R. (1997). *Whose reality counts*. Intermediate Technology Publications.
- Chambers, R., & Conway, G. (1992). *Sustainable rural livelihoods: Practical concepts for the 21st century*. Institute of Development Studies.
- Chambers, R., & Leach, M. (1989). Trees as savings and security for the rural poor. *World Development*, 17(3), 329–342. [https://doi.org/10.1016/0305-750X\(89\)90206-4](https://doi.org/10.1016/0305-750X(89)90206-4)
- Chambers, R., Leach, M., & Conroy, C. (1993). *Trees as savings and security for the rural poor*. International Institute for the Environment and Development. <http://www.mekonginfo.org/assets/midocs/0002165-environment-trees-as-savings-and-security-for-the-rural-poor.pdf>
- Chambers, R., & Longhurst, R. (1986). Trees, seasons and the poor. *IDS Bulletin*, 17(3), 44–50.
- Chambers, R., Longhurst, R., & Pacey, A. (1981). *Seasonal dimensions to rural poverty*. Frances Pinter.
- Chambers, R., Saxena, N. C., & Shah, T. (1989). *To the hands of the poor: Water and trees*. Intermediate Technology Publications.
- Christiaensen, L. (2017). Agriculture in Africa – telling myths from facts: A synthesis. *Food Policy*, 67, 1–11. <https://doi.org/10.1016/j.foodpol.2017.02.002>
- Cissé, J. D., & Barrett, C. B. (2018). Estimating development resilience: A conditional moments-based approach. *Journal of Development Economics*, 135, 272–284.
- Cleveland, W. S. (1979). Robust locally weighted regression and smoothing scatterplots. *Journal of the American Statistical Association*, 74(368), 829–836. <https://doi.org/10.1080/01621459.1979.10481038>
- Coe, R., Sinclair, F., & Barrios, E. (2014). Scaling up agroforestry requires research “in” rather than “for” development. *Current Opinion in Environmental Sustainability*, 6, 73–77.

- Colantoni, A., Mavrakis, A., Sorgi, T., & Salvati, L. (2015). Towards a ‘polycentric’ landscape? Reconnecting fragments into an integrated network of coastal forests in Rome. *Rendiconti Accademia Nazionale dei Lincei*, 26, 615–624.
- Collier, P., & Dercon, S. (2014). African agriculture in 50 Years: Smallholders in a rapidly changing world? *World Development*, 63, 92–101.
- Committee on World Food Security. (2012). Coming to terms with terminology: Food security, nutrition security, food security and nutrition, food and nutrition security. *Proceedings of the 39th Session of the Committee on World Food Security*.
- Conroy, C. (1992). Trees as insurance against contingencies: Case of Panchmahals District, Gujarat. *Economic and Political Weekly*, 27(43/44), 2381–2387.
- Conroy, C. (1993). Eucalyptus sales by small farmers in eastern Gujarat. *Agroforestry Systems*, 23(1), 1–10.
- Conway, G. (1998). *The doubly green revolution: Food for all in the twenty-first century*. Cornell University Press.
- Coomes, O. T., Takasaki, Y., & Rhemtulla, J. M. (2011). Land-use poverty traps identified in shifting cultivation systems shape long-term tropical forest cover. *Proceedings of the National Academy of Sciences*, 108(34), 13925–13930. <https://doi.org/10.1073/pnas.1012973108>
- Corbett, J. (1988). Famine and household coping strategies. *World Development*, 16, 1099–1112. [https://doi.org/10.1016/0305-750X\(88\)90112-X](https://doi.org/10.1016/0305-750X(88)90112-X)
- Crosby, A. W. (2004). *Ecological imperialism: The biological expansion of Europe, 900-1900* (2nd ed.). Cambridge University Press.
- Crowther, T. W., Glick, H. B., Covey, K. R., Bettigole, C., Maynard, D. S., Thomas, S. M., Smith, J. R., Hintler, G., Duguid, M. C., Amatulli, G., Tuanmu, M.-N., Jetz, W., Salas, C., Stam, C., Piotta, D., Tavani, R., Green, S., Bruce, G., Williams, S. J., . . . Bradford, M. A. (2015). Mapping tree density at a global scale. *Nature*, 525(7568), 201–205. <https://doi.org/10.1038/nature14967>
- Darbyshire, I., Lamb, H., & Umer, M. (2003). Forest clearance and regrowth in northern Ethiopia during the last 3000 years. *The Holocene*, 13(4), 537–546. <https://doi.org/10.1191/0959683603hl644rp>
- Dasgupta, P. (1997). Nutritional status, the capacity for work, and poverty traps. *Journal of Econometrics*, 77(1), 5–37.
- Davidson, J. (n.d.). *Ecological aspects of eucalyptus plantations*. <http://www.fao.org/docrep/005/ac777e/ac777e06.htm>

- Day, R., Walker, G., & Simcock, N. (2016). Conceptualising energy use and energy poverty using a capabilities framework. *Energy Policy*, *93*, 255–264. <https://doi.org/10.1016/j.enpol.2016.03.019>
- Dercon, S., & Ayalew, D. (2007). *Land rights, power and trees in rural Ethiopia*. University of Oxford.
- Dercon, S., & Christiaensen, L. (2011). Consumption risk, technology adoption and poverty traps: Evidence from Ethiopia. *Journal of Development Economics*, *96*, 159–173.
- Dercon, S., Gilligan, D. O., Hoddinott, J., & Woldehanna, T. (2009). The impact of agricultural extension and roads on poverty and consumption growth in fifteen Ethiopian villages. *American Journal Agricultural Economics*, *91*, 1007–1021. <https://doi.org/10.1111/j.1467-8276.2009.01325.x>
- Dercon, S., & Hoddinott, J. (2004). *The Ethiopian Rural Household Surveys: Introduction*. International Food Policy Research Institute
- Dercon, S., Hoddinott, J., & Woldehanna, T. (2005). Shocks and consumption in 15 Ethiopian villages, 1999–2004. *Journal of African Economics*, *14*, 559–585. <https://doi.org/10.1093/jae/eji022>
- Dercon, S., & Krishnan, P. (2000). In sickness and in health: Risk sharing within households in rural Ethiopia. *Journal of Political Economics*, *108*, 688–727. <https://doi.org/10.1086/316098>
- Dessalegn, R. (1995). Resilience and vulnerability: Enset agriculture in southern Ethiopia. *Journal of Ethiopian Studies*, *28*(1), 23–51.
- Devereux, S., Sabates-Wheeler, R., & Longhurst, R. (2013). *Seasonality, rural livelihoods and development*. Routledge.
- Devereux, S., Vaitla, B., & Swan, S. H. (2008). *Seasons of hunger: Fighting cycles of quiet starvation among the world's rural poor*. Pluto Press in association with Action Against Hunger, ACF International Network.
- deWaal, A. (1989). *Famine that kills: Darfur, Sudan, 1984-85*. Clarendon Press.
- Dinesh, D. (2016). *Adaptation measures in agricultural systems: Messages to the SBSTA 44 Agriculture Workshops (CCFAS Working Paper 145)*. CGIAR.
- Dorosh, P. A., & Minten, B. (2020). *Ethiopia's agrifood system: Past trends, present challenges, and future scenarios*. International Food Policy Research Institute. <https://doi.org/10.2499/9780896296916>
- Drèze, J., & Sen, A. (1989). *Hunger and public action*. Oxford University Press.

- Duraiappah, A. K. (1998). Poverty and environmental degradation: A review and analysis of the nexus. *World Development*, 26, 2169–2179. [https://doi.org/10.1016/S0305-750X\(98\)00100-4](https://doi.org/10.1016/S0305-750X(98)00100-4)
- Duriaux- Chavarría, J., Baudron, F., Gergel, S. E., Yang, K. F., Eddy, I. M. S., & Sunderland, T. (2020). More people, more trees: A reversal of deforestation trends in Southern Ethiopia. *Land Degradation & Development*, 2020, 1–12. <https://doi.org/10.1002/ldr.3806>
- Duvernoy, I., Zambon, I., Sateriano, A., & Salvati, L. (2018). Pictures from the other side of the fringe: Urban growth and peri-urban agriculture in a post-industrial city (Toulouse, France). *Journal of Rural Studies*, 57, 25–35.
- El-Khawas, S. A., & Sheheta, M. M. (2005). The allelopathic potentialities of acacia nilotica and eucalyptus rostrata on monocot (*Zea mays* L.) and dicot (*Phaseolus vulgaris* L.) plants. *Biotechnology (Faisalabad)*, 4(1), 23–34. <https://doi.org/10.3923/biotech.2005.23.34>
- Eshetu, S. B., Pretzsch, J., & Mekonnen, T. B. (2018). Financial Analysis of Smallholder Farmers Woodlot and Homestead Agroforestry Systems and its Implications for Household Income Improvement, the Case of Hawassa Zuria District, Southern Ethiopia. *Journal of Agricultural Science and Food Research*, 9(236), 2.
- Ethiopian Ministry of Water and Energy. (2013). *Biomass energy strategy*. http://www.euei-pdf.org/sites/default/files/field_publication_file/Ethiopia_Biomass_Energy_Strategy_and_Action_Plan_Final_2014_02_06.pdf
- Fafchamps, M. (1992). Cash crop production, food price volatility, and rural market integration in the third world. *American Journal of Agricultural Economics*, 74(1), 90–99.
- Fairhead, J., & Leach, M. (1996). *Misreading the African landscape: Society and ecology in a forest-savanna mosaic* (Vol. 90). Cambridge University Press.
- Feuerbacher, A., McDonald, S., Dukpa, C., & Grethe, H. (2020). Seasonal rural labor markets and their relevance to policy analyses in developing countries. *Food Policy*, 93, 101875. <https://doi.org/10.1016/j.foodpol.2020.101875>
- Feld, C. K., Martins da Silva, P., Paulo Sousa, J., De Bello, F., Bugter, R., Grandin, U., Hering, D., Lavorel S, Mountford O, Pardo I, Pärtel M. (2009). Indicators of biodiversity and ecosystem services: A synthesis across ecosystems and spatial scales. *Oikos*, 118(12), 1862–1871. <https://doi.org/10.1111/j.1600-0706.2009.17860.x>

- Filmer, D., & Pritchett, L. H. (2001). Estimating wealth effects without expenditure data—or tears: An application to educational enrollments in states of India. *Demography*, 38(1), 115–132. <https://doi.org/10.1353/dem.2001.0003>
- Fisher, M. (2004). Household welfare and forest dependence in Southern Malawi. *Environment and Development Economics*, 9, 135–154. <https://doi.org/10.1017/S1355770X03001219>
- Foley, J. A., Ramankutty, N., Brauman, K. A., Cassidy, E. S., Gerber, J. S., Johnston, M., Mueller, N. D., O’Connell, C., Ray, D. K., West, P. C., Balzer, C., Bennett, E. M., Carpenter, S. R., Hill, J., Monfreda, C., Polasky, S., Rockström, J., Sheehan, J., Siebert, S., . . . Zaks, D. P. M. (2011). Solutions for a cultivated planet. *Nature*, 478(7369), 337–342. <https://doi.org/10.1038/nature10452>
- Frankenberger, T. (2013). *Background paper for the expert consultation on resilience measurement for food security*. <https://tulane.box.com/s/ro98lbh58ssfeekir4m8>
- Frelat, R., Lopez-Ridaura, S., Giller, K. E., Herrero, M., Douxchamps, S., Djurfeldt, A. A., Erenstein, O., Henderson, B., Kassie, M., Paul, B. K., & others. (2016). Drivers of household food availability in sub-Saharan Africa based on big data from small farms. *Proceedings of the National Academy of Sciences*, 113(2), 458–463.
- Fyfe, R. M., Woodbridge, J., & Roberts, N. (2015). From forest to farmland: Pollen-inferred land cover change across Europe using the pseudobiomization approach. *Global Change Biology*, 21(3), 1197–1212. <https://doi.org/10.1111/gcb.12776>
- Galway, L. P., Acharya, Y., & Jones, A. D. (2018). Deforestation and child diet diversity: A geospatial analysis of 15 sub-Saharan African countries. *Health & Place*, 51, 78–88. <https://doi.org/10.1016/j.healthplace.2018.03.002>
- Gamtessa, S. F. (2003, July 11–12). *Household’s consumption pattern and demand for energy in urban Ethiopia* [Conference session]. The International Conference on Development Studies in Ethiopia, Addis Ababa, Ethiopia.
- Garrity, D. P. (2004). Agroforestry and the achievement of the Millennium Development Goals. *Agroforestry Systems*, 61(1–3), 5–17.
- Garrity, D. P., Akinnifesi, F. K., Ajayi, O. C., Weldesemayat, S. G., Mowo, J. G., Kalinganire, A., Larwanou, M., & Bayala, J. (2010). Evergreen agriculture: A robust approach to sustainable food security in Africa. *Food Security*, 2(3), 197–214

- Garrity, D. P., Dixon, J., & Boffa, J.-M. (2012). Understanding African farming systems. *Food Security in Africa: Bridging Research and Practise*. Australian International Food Security Center.
https://aifsc.aciar.gov.au/sites/default/files/images/understanding_african_farming_systems_report_for_aifsc_conference.pdf
- Gatto, A. (2020). A pluralistic approach to economic and business sustainability: A critical meta- synthesis of foundations, metrics, and evidence of human and local development. *Corporate Social Responsibility and Environmental Management*, 27(4), 1525–1539. <https://doi.org/10.1002/csr.1912>
- Gebremariam, A. H., Bekele, M. & Ridgewell, A. (2009). *Small and medium forest enterprises in Ethiopia*. IIED.
- General Assembly, United Nations. (2017). Resolution “A/RES/71/313 Work of the Statistical Commission pertaining to the 2030 Agenda for Sustainable Development . 6 July 2017.” <http://undocs.org/A/RES/71/313>
- Gibbs, H. K., Ruesch, A. S., Achard, F., Clayton, M. K., Holmgren, P., Ramankutty, N., & Foley, J. A. (2010). Tropical forests were the primary sources of new agricultural land in the 1980s and 1990s *Proceedings of the National Academy of Sciences*, 107, 16732–16737. <https://doi.org/10.1073/pnas.0910275107>
- Gilbert, C. L., Christiaensen, L., & Kaminski, J. (2017). Food price seasonality in Africa: Measurement and extent. *Food Policy*, 67, 119–132.
- Gill, G. J., & Gerard, J. (1991). *Seasonality and agriculture in the developing world: A problem of the poor and the powerless*. Cambridge University Press.
- Giller, K. E., Witter, E., Corbeels, M., & Tittonell, P. (2009). Conservation agriculture and smallholder farming in Africa: The heretics’ view. *Field Crops Research*, 114(1), 23–34. <https://doi.org/10.1016/j.fcr.2009.06.017>
- Gliessman, S. (2013). Agroecology: Growing the roots of resistance. *Agroecology and Sustainable Food Systems*, 37, 19–31.
- Gliessman, S. (2014). *Agroecology: The ecology of sustainable food systems* (3rd ed.). CRC Press. <https://doi.org/10.1201/b17881>
- Goetz, S. J., Hansen, M., Houghton, R. A., Walker, W., Laporte, N., & Busch, J. (2015). Measurement and monitoring needs, capabilities and potential for addressing reduced emissions from deforestation and forest degradation under REDD+. *Environmental Research Letters*, 10(12), 123001. <https://doi.org/10.1088/1748-9326/10/12/123001>
- Government of Ethiopia. (2011). *Ethiopia’s climate-resilient green economy (CRGE) green economy strategy*. FDRE.
<https://www.undp.org/content/dam/ethiopia/docs/Ethiopia%20CRGE.pdf>

- Government of Ethiopia Agricultural Transformation Authority. (n.d.). *AGRA Ethiopia Operational Plan*. Alliance for Green Revolution in Africa. <https://agra.org/wp-content/uploads/2017/12/agra-ethiopia-final.pdf>
- Golden, M. H. N. (1994). Is complete catch-up possible for stunted malnourished children? *European Journal of Clinical Nutrition*, 48(1), 58–71.
- González-Eguino, M. (2015). Energy poverty: An overview. *Renewable and Sustainable Energy Reviews*, 47, 377–385. <https://doi.org/10.1016/j.rser.2015.03.013>
- Griggs, D., Stafford-Smith, M., Gaffney, O., Rockström, J., Öhman, M. C., Shyamsundar, P., Steffen, W., Glaser, G., Kanie, N., & Noble, I. (2013). Policy: Sustainable development goals for people and planet. *Nature*, 495, 305–307.
- Grootaert, C., & Kanbur, R. (1995). The lucky few amidst economic decline: Distributional change in Côte d’Ivoire as seen through panel data sets, 1985–88. *The Journal of Development Studies*, 31(4), 603–619.
- Habtewold, T., Sandford, S., & Kindness, H. (1994). The gender, structure and landraces in peasant Ensete plantations in north Omo. *FRP Technical Pamphlet (Ethiopian Institute of Agricultural Research)*. <http://hdl.handle.net/123456789/1266>
- Haider, L. J., Boonstra, W. J., Peterson, G. D., & Schlüter, M. (2018). Traps and sustainable development in rural areas: A review. *World Development*, 101, 311–321. <https://doi.org/10.1016/j.worlddev.2017.05.038>
- Hansen, M. C., & Loveland, T. R. (2012). A review of large area monitoring of land cover change using Landsat data. *Remote Sensing of Environment*, 122, 66–74. <https://doi.org/10.1016/j.rse.2011.08.024>
- Hansen, M. C., Potapov, P. V., Moore, R., Hancher, M., Turubanova, S. A., Tyukavina, A., Thau, D., Stehman, S., Goetz, S. J., Loveland, T. R., & others. (2013). High-resolution global maps of 21st-century forest cover change. *Science*, 342(6160), 850–853.
- Haraway, D. J. (2016). *Staying with the trouble: Making kin in the Chthulucene*. Duke University Press.
- Harlan, J. R. (1969). Ethiopia: A center of diversity. *Economic Botany*, 23(4), 309–314.
- Harris, D., & Orr, A. (2014). Is rainfed agriculture really a pathway from poverty? *Agricultural Systems*, 123, 84–96.

- Hazell, P. (2020). Importance of smallholder farms as a relevant strategy to increase food security. In S. Gomez, L. R. Paloma, & L. Kamel (Eds.), *The role of smallholder farms in food and nutrition security* (pp. 29–43). Springer.
- Heger, M., Zens, G., & Bangalor, M. (2018). *Does the environment matter for poverty reduction? The role of soil fertility and vegetation vigor in poverty reduction*. The World Bank.
<http://documents1.worldbank.org/curated/en/732471533299978428/pdf/WPS8537.pdf>
- Hoddinott, J., & Quisumbing, A. (2010). Methods for microeconomic risk and vulnerability assessment. In R. Fuentes-NievaPapa & A. Seck (Eds.), *Risk, shocks, and human development* (pp. 62–100). Springer.
- Hoddinott, J., & Yohannes, Y. (2002). *Dietary diversity as a food security indicator* [Paper presentation]. Food Consumption and Nutrition Division Discussion Paper 136. <https://www.ifpri.org/publication/dietary-diversity-food-security-indicator-0>
- Hoff, H. (2011, November 16-18). *Understanding the nexus* [Background paper]. Bonn 211 Conference: The Water, Energy and Food Security Nexus, Bonn, Germany. Stockholm Environment Institute.
<https://www.sei.org/publications/understanding-the-nexus/>
- Hoffmann, V., & Gatobu, K. M. (2014). Growing their own: Unobservable quality and the value of self-provisioning. *Journal of Development Economics*, *106*, 168–178. <https://doi.org/10.1016/j.jdeveco.2013.08.006>
- Holden, S., & Yohannes, H. (2002). Land redistribution, tenure insecurity, and intensity of production: A study of farm households in Southern Ethiopia. *Land Economics*, *78*, 573–590. <https://doi.org/10.2307/3146854>
- Holland, P. W. (1986). Statistics and causal inference. *Journal of the American Statistical Association*, *81*(396), 945–960.
<https://doi.org/10.1080/01621459.1986.10478354>
- Holm, R., Singini, W., & Gwayi, S. (2016). Comparative evaluation of the cost of water in northern Malawi: From rural water wells to science education. *Applied Economics*, *48*(47), 4573–4583.
<https://doi.org/10.1080/00036846.2016.1161719>
- Horvath, R. J. (1968). Addis Abeba's eucalyptus forest. *Journal of Ethiopian Studies*, *6*, 13–19. <https://www.jstor.org/stable/41965767>
- Hughes, J. D., & Thirgood, J. V. (1982). Deforestation, erosion, and forest management in Ancient Greece and Rome. *Forest & Conservation History*, *26*(2), 60–75. <https://doi.org/10.2307/4004530>

- Ickowitz, A., Powell, B., Salim, M. A., & Sunderland, T. C. (2014). Dietary quality and tree cover in Africa. *Global Environmental Change*, *24*, 287–294. <https://doi.org/10.1016/j.gloenvcha.2013.12.001>
- International Energy Agency. (2017). *Energy access outlook 2017: From poverty to prosperity*. Author.
- Jagger, P., & Pender, J. (2003). The role of trees for sustainable management of less-favored lands: The case of eucalyptus in Ethiopia. *Forest Policy and Economics*, *5*(1), 83–95.
- Jagger, P., Pender, J., & Gebremedhin, B. (2005). Trading off environmental sustainability for empowerment and income: Woodlot devolution in northern Ethiopia. *World Development*, *33*, 1491–1510. <https://doi.org/10.1016/j.worlddev.2004.10.010>
- Jagger, P., & Rana, P. (2017). Using publicly available social and spatial data to evaluate progress on REDD+ social safeguards in Indonesia. *Environmental Science & Policy*, *76*, 59–69. <https://doi.org/10.1016/j.envsci.2017.06.006>
- Jalan, J., & Ravallion, M. (2002). Geographic poverty traps? A micro model of consumption growth in rural China. *Journal of Applied Econometrics*, *17*(4), 329–346.
- Jat, M. L., Chakraborty, D., Ladha, J. K., Rana, D. S., Gathala, M. K., McDonald, A., & Gerard, B. (2020). Conservation agriculture for sustainable intensification in South Asia. *Nature Sustainability*, *3*(4), 336–343. <https://doi.org/10.1038/s41893-020-0500-2>
- Johnson, K. B., Jacob, A., & Brown, M. E. (2013). Forest cover associated with improved child health and nutrition: Evidence from the Malawi demographic and health survey and satellite data. *Global Health: Science and Practice*, *1*(2), 237–248.
- Jones, A. D., Acharya, Y., & Galway, L. P. (2017). Deforestation and child diet diversity: A geospatial analysis of 15 sub-Saharan African countries. *Lancet*, *51*, 78–88. <https://doi.org/10.1016/j.healthplace.2018.03.002>
- Kafle, K., McGee, K., Ambel, A., & Seff, I., (2017). Once poor always poor? Exploring consumption- and asset-based poverty dynamics in Ethiopia. *Ethiopian Journal of Economics*, *25*(2), 37–76. <https://doi.org/10.22004/AG.ECON.259503>
- Kareiva, P., Watts, S., McDonald, R., & Boucher, T. (2007). Domesticated nature: Shaping landscapes and ecosystems for human welfare. *Science*, *316*, 1866–1869. <https://doi.org/10.1126/science.1140170>

- Kassa, H., Bekele, M., & Campbell, B. (2011). Reading the landscape past: Explaining the lack of on-farm tree planting in Ethiopia. *Environment and History*, 17(3), 461–479.
- Kaygusuz, K. (2012). Energy for sustainable development: A case of developing countries. *Renewable and Sustainable Energy Reviews*, 16, 1116–1126, <https://doi.org/10.1016/j.rser.2011.11.013>
- Kebede, B. (2002). Land tenure and common pool resources in rural Ethiopia: A study based on fifteen sites. *African Development Review*, 14(1), 113–149.
- Kes, A., & Swaminathan, H. (2006). Gender, time use, and poverty in sub-Saharan Africa. In C. M. Blackden, & Q. Wodon (Eds.), *Gender, time use and poverty in sub-Saharan Africa*. The World Bank.
- Kraay, A., & McKenzie, D. (2014). Do poverty traps exist? Assessing the evidence. *Journal of Economic Perspectives*, 28(3), 127–148. <https://doi.org/10.1257/jep.28.3.127>
- Krishna, A. (2011). *One illness away: Why people become poor and how they escape poverty*. Oxford University Press.
- Knudby, A., Jupiter, S., Roelfsema, C., Lyons, M., & Phinn, S. (2013). Mapping coral reef resilience indicators using field and remotely sensed data. *Remote Sensing*, 5(3), 1311–1334. <https://doi.org/10.3390/rs5031311>
- Kuznets, S. (1955). Economic growth and income inequality. *The American Economic Review*, 45(1), 1–28.
- Kwak, S., & Smith, S. C. (2013). Regional agricultural endowments and shifts of poverty trap equilibria: Evidence from Ethiopian panel data. *The Journal of Development Studies*, 49(7), 955–975.
- Lal, R. (2007). Constraints to adopting no-till farming in developing countries. *Soil and Tillage Research*, 94(1), 1–3. <https://doi.org/10.1016/j.still.2007.02.002>
- Lamb, A., Green, R., Bateman, I., Broadmeadow, M., Bruce, T., Burney, J., Carey, P., Chadwick, D., Crane, E., Field, R., Goulding, K., Griffiths, H., Hastings, A., Kasoar, T., Kindred, D., Phalan, B., Pickett, J., Smith, P., Wall, E., . . . Balmford, A. (2016). The potential for land sparing to offset greenhouse gas emissions from agriculture. *Nature Climate Change*, 6(5), 488–492. <https://doi.org/10.1038/nclimate2910>
- Lanfredi, M., Simoniello, T., & Macchiato, M. 2004. Temporal persistence in vegetation cover changes observed from satellite: Development of an estimation procedure in the test site of the Mediterranean Italy. *Remote Sensing of Environment*, 93(4), 565–576. <https://doi.org/10.1016/j.rse.2004.08.012>

- Law, B. E. (2014). Regional analysis of drought and heat impacts on forests: Current and future science directions. *Global Change Biology*, 20(12), 3595–3599. <https://doi.org/10.1111/gcb.12651>
- Leach, G. (1992). The energy transition. *Energy Policy*, 20, 116–123. [https://doi.org/10.1016/0301-4215\(92\)90105-B](https://doi.org/10.1016/0301-4215(92)90105-B)
- Leach, M., Nisbett, N., Cabral, L., Harris, J., Hossain, N., & Thompson, J. (2020). Food politics and development. *World Development*, 134, 1–19. <https://doi.org/10.1016/j.worlddev.2020.105024>
- Leach, M., Raworth, K., & Rockström, J. (2013). *Between social and planetary boundaries: Navigating pathways in the safe and just space for humanity*. Chapter 6. In World Social Science Report 2013: Changing Global Environments. OECD Publishing and UNESCO Publishing. <https://www.oecd.org/publications/world-social-science-report-2013-9789264203419-en.htm>
- Leach, M., Stirling, A. C., & Scoones, I. (2010). *Dynamic sustainabilities: Technology, environment, social justice*. Routledge.
- Lefebbo, N., Haji, J., Geta, E., & Zemedu, L. (2016). Determinants of status and extent of market participation among bulla producers in Hadiya Zone, Southern Ethiopia. *Journal of Biology, Agriculture and Healthcare*, 6(7), 84–92.
- Liddell, C. (2012). Fuel poverty comes of age: Commemorating 21 years of research and policy. *Energy Policy*, 49, 2–5.
- Lipton, M. (1983). Poverty, undernutrition, and hunger. World Bank Staff Working Papers 573. <https://documents.worldbank.org/pt/publication/documents-reports/documentdetail/892041468766760990/poverty-undernutrition-and-hunger>
- Little, T. D., Schnabel, K. U., & Baumert, J. (2000). *Modeling longitudinal and multilevel data: Practical issues, applied approaches, and specific examples*. Lawrence Erlbaum Associates.
- Lobo, J., Lockhart, D. M., & Gonçalves da Costa, M. (1640/1984). *The itinerário of Jerónimo Lobo* (2nd ser., no. 162). Hakluyt Society.
- Lowder, S. K., Sánchez, M. V., & Bertini, R. (2019). *Farms, family farms, farmland distribution and farm labour: What do we know today?* (FAO Agricultural Development Economics Working Paper 19-08). Rome, FAO. <http://www.fao.org/3/ca7036en/ca7036en.pdf>

- Lowder, S. K., Scoet, J., & Raney, T. (2016). The number, size, and distribution of farms, smallholder farms, and family farms worldwide. *World Development*, 87, 16–29.
- Lybbert, T. J., Barrett, C. B., Desta, S., & Layne Coppock, D. (2004). Stochastic wealth dynamics and risk management among a poor population. *The Economic Journal*, 114(498), 750–777.
- Malhi, Y. (2018). Ancient deforestation in the green heart of Africa. *Proceedings of the National Academy of Sciences*, 115(13), 3202–3204. <https://doi.org/10.1073/pnas.1802172115>
- Malthus, TR. (1798). *An essay on the principle of population*. <http://www.esp.org/books/malthus/population/malthus.pdf>
- Mamo, G., Sjaastad, E., & Vedeld, P. (2007). Economic dependence on forest resources: A case from Dendi District, Ethiopia. *Forest Policy and Economics*, 9(8), 916–927. <https://doi.org/10.1016/j.forpol.2006.08.001>
- Marsh, G. P. (1864/2013). *Man and nature* (David Lowenthal, Ed.). University of Washington Press.
- Marsh, G. P. (1874). *The earth as modified by human action: A new edition of man and nature*. Scribner, Armstrong & Company.
- Marx, K. (2013). *Das Kapital*. Wordsworth Editions. (Original work published 1887)
- Masera, O. R., Saatkamp, B. D., & Kammen, D. M. (2000). From linear fuel switching to multiple cooking strategies: A critique and alternative to the energy ladder model. *World Development*, 28, 2083–2103. [https://doi.org/10.1016/S0305-750X\(00\)00076-0](https://doi.org/10.1016/S0305-750X(00)00076-0)
- Matul, M., McCord, M. J., Phily, C., & Harms, J. (2010). *The landscape of microinsurance in Africa*. ILO.
- Mayaux, P., & Lambin, E. F. (1995). Estimation of tropical forest area from coarse spatial resolution data: A two-step correction function for proportional errors due to spatial aggregation. *Remote Sensing of Environment*, 53(1), 1–15. [https://doi.org/10.1016/0034-4257\(95\)00038-3](https://doi.org/10.1016/0034-4257(95)00038-3)
- Mbow, C., Van Noordwijk, M., Prabhu, R., & Simons, T. (2014). Knowledge gaps and research needs concerning agroforestry’s contribution to sustainable development goals in Africa. *Current Opinion in Environmental Sustainability*, 6, 162–170. <https://doi.org/10.1016/j.cosust.2013.11.030>
- McDowell, C., & De Haan, A. (1997). *Migration and sustainable livelihoods: A critical review of the literature*. Institute of Development Studies.
- McKean, M., & Ostrom, E. (1995). Common property regimes in the forest: Just a relic from the past. *Unasylva*, 46, 3–15.

- McNeil, C. L., Burney, D. A., & Burney, L. P. (2010). Evidence disputing deforestation as the cause for the collapse of the ancient Maya polity of Copan, Honduras. *Proceedings of the National Academy of Sciences*, *107*(3), 1017–1022. <https://doi.org/10.1073/pnas.0904760107>
- Meadows, D. H. (2008). *Thinking in systems: A primer*. Chelsea Green Publishing.
- Mekonnen, A., & Köhlin, G. (2009). *Determinants of household fuel choice in major cities in Ethiopia* (Working Papers in Economics No. 399). University of Gothenburg.
- Mekonnen, D., Bryan, E., Alemu, T., & Ringler, C. (2017). Food versus fuel: Examining tradeoffs in the allocation of biomass energy sources to domestic and productive uses in Ethiopia. *Agricultural Economics*, *48*, 25–35. <https://doi.org/10.1111/agec.12344>
- Mekonnen, Z., Kassa, H., Lemenh, M., & Campbell, B. (2007). The role and management of Eucalyptus in Lode Hetosa district, central Ethiopia. *Forests, Trees and Livelihoods*, *17*(4), 309–323. <https://doi.org/10.1080/14728028.2007.9752606>
- Mendum, R., & Njenga, M. (2018). Integrating wood fuels into agriculture and food security agendas and research in sub-Saharan Africa. *FACETS*, *3*, 1–11. <https://doi.org/10.1139/facets-2017-0032>
- Michelson, H., Muñiz, M., & DeRosa, K. (2013). Measuring socio-economic status in the millennium Villages: The role of asset index choice. *The Journal of Development Studies*, *49*(7), 917–935.
- Miller, D. C., Muñoz-Mora, J. C., & Christiaensen, L. (2018). *Do trees on farms matter in African agriculture*. The World Bank.
- Miller, D. C., Muñoz-Mora, J. C., Zezza, A., Durazo, J. (2019). *Trees on farms: measuring their contribution to household welfare. A guidebook for designing household surveys*. The World Bank. http://surveys.worldbank.org/sites/default/files/publications/7_Guidebook_final%20web2.pdf
- Miller, D. C., Muñoz-Mora, J. C., Rasmussen, L. V., & Zezza, A. (2020). Do trees on farms improve household well-being? Evidence from national panel data in Uganda. *Frontiers in Forests and Global Change*, *3*, 101. <https://doi.org/10.3389/ffgc.2020.00101>
- Ministry of Environment Ethiopia. (2018). *National REDD+ Strategy (2018-2020) Federak Democratic Republic of Ethiopia Ministry of Environment, Forest and Climate Change National REDD+ Secretariat*. https://www.forestcarbonpartnership.org/system/files/documents/Ethiopia%20REDD%20Strategy_June%2025%20%202018_0.pdf

- Mohammed, B., Gabel, M., & Karlsson, L.M. (2013). Nutritive values of the drought tolerant food and fodder crop enset. *African Journal of Agricultural Research*, 8, 2326–2333. <https://doi.org/10.5897/AJAR12.1296>
- Mondal, M. A., Bryan, E., Ringler, C., & Rosegrant, M. (2016). Ethiopian power sector development: Renewable based universal electricity access and export strategies. *Renewable and Sustainable Energy Reviews*, 75, 11–20. <https://doi.org/10.1016/j.rser.2016.10.041>
- Morrow, N., Salvati, L., Colantoni, A., & Mock, N. (2018). Rooting the future; on-farm trees' contribution to household energy security and asset creation as a resilient development pathway—Evidence from a 20-year panel in rural Ethiopia. *Sustainability*, 10(12), 4716. <https://doi.org/10.3390/su10124716>
- Moser, C., & Dani, A. A. (Eds.). (2008). *Assets, livelihoods, and social policy*. The World Bank. <https://doi.org/10.1596/978-0-8213-6995-1>
- Musumba, M., Grabowski, P., Palm, C., & Snapp, S. S. (2017). *Guide for the sustainable intensification assessment framework*. Kansas State University.
- Naschold, F. (2012). The poor stay poor: Household asset poverty traps in rural semi-arid India. *World Development*, 40(10), 2033–2043.
- Naschold, F. (2013). Welfare dynamics in Pakistan and Ethiopia—Does the estimation method matter? *The Journal of Development Studies*, 49(7), 936–954.
- Ending hunger: Science must stop neglecting smallholder farmers. (2020). *Nature Research Journals*, 586(7829), 336–336. <https://doi.org/10.1038/d41586-020-02849-6>
- Negash, A., & Niehof, A. (2004). The significance of enset culture and biodiversity for rural household food and livelihood security in Southwestern Ethiopia. *Agriculture and Human Values*, 21(1), 61–71.
- Negash, M., Starr, M., & Kanninen, M. (2013). Allometric equations for biomass estimation of Enset (*Ensete ventricosum*) grown in indigenous agroforestry systems in the Rift Valley escarpment of southern-eastern Ethiopia. *Agroforestry Systems*, 87(3), 571–581. <https://doi.org/10.1007/s10457-012-9577-6>
- Newcombe, K. (1987). An economic justification for rural afforestation: The case of Ethiopia. *The Annals of Regional Science*, 21, 80–99. <https://doi.org/10.1007/BF01287284>
- Olango, T., Tesfaye, B., Catellani, M., & Enrico Pè, M. (2014). Indigenous knowledge, use and on-farm management of enset (*Ensete Ventricosum* (Welw.) Cheesman) Diversity in Wolaita, Southern Ethiopia. *Journal of Ethnobiology and Ethnomedicine*, 10(1), 1-18. <https://doi.org/10.1186/1746-4269-10-41>

- Organisation for Economic Cooperation and Development, & African Union Commission. (2018). *Africa's development dynamics 2018: Growth, jobs and inequalities*. OECD.
- Ostrom, E. (2009). A general framework for analyzing sustainability of social-ecological systems. *Science*, 325(5939), 419–422.
- Pachauri, S., & Spreng, D. (2003). Energy use and energy access in relation to poverty. *Economic Political Weekly.*, 17, 271–278.
<https://doi.org/10.2307/4414526>
- Parr, T. W., Sier, A. R. J., Battarbee, R. W. Mackay, A. & Burgess, J. (2003). Detecting environmental change: Science and society—perspectives on long-term research and monitoring in the 21st Century. *Science of the Total Environment*, 310(1-3), 1–8. [https://doi.org/10.1016/S0048-9697\(03\)00257-2](https://doi.org/10.1016/S0048-9697(03)00257-2)
- Patton, M. Q. (2010). *Developmental evaluation: Applying complexity concepts to enhance innovation and use*. Guilford Press.
- Pironon, S., Papuga, G., Villellas, J., Angert, A. L., García, M. B., & Thompson, J. D. (2017). Geographic variation in genetic and demographic performance: New insights from an old biogeographical paradigm: The centre-periphery hypothesis. *Biological Reviews*, 92(4), 1877–1909.
<https://doi.org/10.1111/brv.12313>
- Place, F., Garrity, D., Mohan, S., & Agostini, P. (2016). *Tree-based production systems for Africa's drylands*. The World Bank. <https://doi.org/10.1596/978-1-4648-0828-9>
- Potapov, P. V., Turubanova, S. A., Hansen, M. C., Adusei, B., Broich, M., Altstatt, A., Mane, L., & Justice, C. O. (2012). Quantifying forest cover loss in Democratic Republic of the Congo, 2000–2010, with Landsat ETM+ data. *Remote Sensing of Environment*, 122, 106–116.
<https://doi.org/10.1016/j.rse.2011.08.027>
- Powell, B., Hall, J., & Johns, T. (2011). Forest cover, use and dietary intake in the East Usambara Mountains, Tanzania. *International Forestry Review*, 13, 305–317.
- Powell, J. M., Pearson, R. A., & Hiernaux, P. H. (2004). Crop–livestock interactions in the West African drylands. *Agronomy Journal*, 96(2), 469–483.
- Pukkala, T., & Pohjonen, V. (1990). Yield models for eucalyptus globulus fuelwood plantations in Ethiopia. *Biomass*, 21, 129–143. [https://doi.org/10.1016/0144-4565\(90\)90054-N](https://doi.org/10.1016/0144-4565(90)90054-N)
- Quinlan, R. J., Quinlan, M. B., Dira, S., Caudell, M., Sooge, A., & Assoma, A. A. (2015). Vulnerability and resilience of sidama enset and maize farms in Southwestern Ethiopia. *Journal of Ethnobiology*, 35(2), 314–336.

- Quisumbing, A. R., & Baulch, B. (2013). Assets and poverty traps in rural Bangladesh. *The Journal of Development Studies*, 49(7), 898–916.
- Rabe-Hesketh, S., & Skrondal, A. (2008). *Multilevel and longitudinal modeling using Stata*. STATA Press.
- Rasmussen, L. V., Bierbaum, R., Oldekop, J. A., & Agrawal, A. (2017). Bridging the practitioner-researcher divide: Indicators to track environmental, economic, and sociocultural sustainability of agricultural commodity production. *Glob. Environ. Chang.*, 42, 33–46. <https://doi.org/10.1016/j.gloenvcha.2016.12.001>
- Rasmussen, L. V., Fagan, M. E., Ickowitz, A., Wood, S. L. R., Kennedy, G., Powell, B., Baudron, F., Gergel, S., Jung, S., Smithwick, E. A. H., Sunderland, T., Wood, S., & Rhemtulla, J. M. (2020). Forest pattern, not just amount, influences dietary quality in five African countries. *Global Food Security*, 25, 100331. <https://doi.org/10.1016/j.gfs.2019.100331>
- Ravindran, D., & Thomas, T. (2000). Trees on farms, stores of wealth and rural livelihoods—insights and evidence from Karnataka, India. *The International Forestry Review*, 2(3), 182–190.
- Reardon, T., & Vosti, S. A. (1995). Links between rural poverty and the environment in developing countries: Asset categories and investment poverty. *World Development*, 23(9), 1495–1506.
- Reddy, S., & Chakravarty, S. (1999). Forest dependence and income distribution in a subsistence economy: Evidence from India. *World Development*, 27, 1141–1149. [https://doi.org/10.1016/S0305-750X\(99\)00057-1](https://doi.org/10.1016/S0305-750X(99)00057-1)
- Reed, J., van Vianen, J., Foli, S., Clendenning, J., Yang, K., MacDonald, M., Petrokofsky, G., Padoch, C., & Sunderland, T. (2017). Trees for life: The ecosystem service contribution of trees to food production and livelihoods in the tropics. *Forest Policy and Economics*, 84, 62–71. <https://doi.org/10.1016/j.forpol.2017.01.012>
- Richards, A. I., & Land, L. (1939). Diet in northern Rhodesia. *An Economic Study of the Bemba Tribe*, London, New York and Toronto, 96.
- Rockström, J., Steffen, W., Noone, K., Persson, Å., Chapin III, F. S., Lambin, E., Lenton, T. M., Scheffer, M., Folke, C., & Schellnhuber, H. J. (2009). Planetary boundaries: Exploring the safe operating space for humanity. *Ecology and Society*, 14(2). <https://doi.org/10.5751/ES-03180-140232>
- Rockström, J., Williams, J., Daily, G., Noble, A., Matthews, N., Gordon, L., Wetterstrand, H., DeClerck, F., Shah, M., & Steduto, P. (2017). Sustainable intensification of agriculture for human prosperity and global sustainability. *Ambio*, 46(1), 4–17.

- Roberts, N., Fyfe, R. M., Woodbridge, J., Gaillard, M.-J., Davis, B. A. S., Kaplan, J. O., Marquer, L., Mazier, F., Nielsen, A. B., Sugita, S., Trondman, A.-K., & Leydet, M. (2018). Europe's lost forests: A pollen-based synthesis for the last 11,000 years. *Scientific Reports*, 8(1), 716. <https://doi.org/10.1038/s41598-017-18646-7>
- Rogg, C. (2006). *Asset portfolios in Africa: Evidence from Rural Ethiopia*. Research Paper, UNU-WIDER; United Nations University (UNU): Tokyo, Japan.
- Rowland, D., Ickowitz, A., Powell, B., Nasi, R., & Sunderland, T. (2017). Forest foods and healthy diets: Quantifying the contributions. *Environmental Conservation*, 44(2), 102–114.
- Royston, P., & Lambert, P. C. (2011). *Flexible parametric survival analysis using stata: Beyond the Cox model*. Stata Press.
- Ruiz-Mercado, I., & Masera, O. (2015). Patterns of stove use in the context of fuel-device stacking: Rationale and implications, *EcoHealth*, 12, 42–56.
- Sachs, J. D. (2006). *The end of poverty: Economic possibilities for our time*. Penguin.
- Sachs, J., McArthur, J. W., Schmidt-Traub, G., Kruk, M., Bahadur, C., Faye, M., & McCord, G. (2004). Ending Africa's poverty trap. *Brookings Papers on Economic Activity*, 2004(1), 117–240.
- Morris, X. (1989). Indigenous versus introduced solutions to food stress in Africa. In D. E. Sahn (Ed.), *Seasonal variability in third world agriculture: The consequences for food security* (pp. 209–234). The Johns Hopkins University Press.
- Salvati, L., & Serra, P. (2016). Estimating rapidity of change in complex urban systems: A multidimensional, localscale approach. *Geographical Analysis*, 48, 132–156. <https://doi.org/10.1111/gean.12093>
- Scheffer, M., & Carpenter, S. R. (2003). Catastrophic regime shifts in ecosystems: Linking theory to observation. *Trends in Ecology & Evolution*, 18(12), 648–656.
- Scherr, S. J. (1991). On-farm research: The challenges of agroforestry. *Agroforestry Syst.*, 15, 95–110. <https://doi.org/10.1007/BF00120183>
- Scheurlen, E. (2015). *Time allocation to energy resource collection in rural Ethiopia: Gender-disaggregated household responses to changes in firewood availability* (IFPRI Discussion Paper No. 1419). International Food Policy Research Institute. <http://ebrary.ifpri.org/cdm/ref/collection/p15738coll2/id/128986>

- Schnell, S., Kleinn, C., & Ståhl, G. (2015). Monitoring trees outside forests: A review. *Environmental Monitoring and Assessment*, 187(9), 1–17. <https://doi.org/10.1007/s10661-015-4817-7>
- Scoones, I. (2010). *Dynamics and diversity: Soil fertility and farming livelihoods in Africa*. Routledge.
- Scoones, I. (2015). Transforming soils: Transdisciplinary perspectives and pathways to sustainability. *Current Opinion in Environmental Sustainability* 15, 20–24.
- Scott, L., & Mariotti, C. (2014). *A place for panel data in the “data revolution.”* Overseas Development Institute.
- Sen, A. K. (1966). Peasants and dualism with or without surplus labor. *Journal of Political Economy*, 74(5), 425–450.
- Sepahvand, M. (2009). *The analysis of rural poverty in Ethiopia: Regarding the three measurements of poverty* [Master’s thesis]. University of Uppsala.
- Shackleton, C., & Shackleton, S. (2004). The importance of non-timber forest products in rural livelihood security and as safety nets: A review of evidence from South Africa. *South African Journal of Science*, 100(11–12), 658–664.
- Shackleton, C. M., Shackleton, S. E., Buiten, E., & Bird, N. (2007). The importance of dry woodlands and forests in rural livelihoods and poverty alleviation in South Africa. *Forest Policy and Economics.*, 9, 558–577.
- Shepherd, K. (2015). Development goals should enable decision-making. *Nature*, 523, 152. <https://doi.org/10.1038/523152a>
- Shao, Y., Anhäuser, A., Ludwig, P., Schlüter, P., & Williams, E. (2018). Statistical reconstruction of global vegetation for the last glacial maximum. *Global and Planetary Change*, 168, 67–77.
- Shukla, P., Skea, J., Calvo Buendia, E., Masson-Delmotte, V., Pörtner, H., Roberts, D., Zhai, P., Slade, R., Connors, S., Van Diemen, R., & others. (2019). *IPCC, 2019: Climate Change and Land: An IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems*.
- Smeds, H. (1955). *The Ensete planting culture of Eastern Sidamo, Ethiopia: The role of the Ensete-Plantations in the local economy and their significance in the cultural geography of Ethiopia* (Vol. 20). Tilgmann.
- Snyder, K. A., Ludi, E., Cullen, B., Tucker, J., Zeleke, A. B., & Duncan, A. (2014). Participation and performance: Decentralised planning and implementation in Ethiopia. *Public Administration and Development*, 34(2), 83–95. <https://doi.org/10.1002/pad.1680>

- Sola, P., Ochieng, C., Yila, J., & Iiyama, M. (2016). Links between energy access and food security in sub Saharan Africa: An exploratory review. *Food Security*, 8, 635–642.
- Sorrenti, S. (2017). *Non-wood forest products in international statistical systems*; Non-Wood Forest Products 22; FAO: Rome, Italy, 2017.
- Stanley, S. (1966). Ensete in the Ethiopian economy. *Ethiopian Geographical Journal* 4(1), 30–37.
- StataCorp, L. (2017). Stata: Statistics/data analysis (Version 15: 1 IC edition). College Station, TX: StataCorp LLC.
- Stone, L., Olinky, R., & Huppert, A. (2007). Seasonal dynamics of recurrent epidemics. *Nature*, 446(7135), 533–536. <https://doi.org/10.1038/nature05638>
- The State of Food Security and Nutrition in the World 2020*. (2020). FAO, IFAD, UNICEF, WFP and WHO. <https://doi.org/10.4060/ca9692en>
- Stuart, E., & Samman, E. (2017). Defining ‘leave no one behind’. *ODI Briefing Note*. <https://www.odi.org/publications/10956-defining-leave-no-one-behind>
- Tallis, H., Mooney, H., Andelman, S., Balvanera, P., Cramer, W., Karp, D., Polasky, S., Reyers, B., Ricketts, T., Running, S., Thonicke, K., Tietjen, B., & Walz, A. (2012). A global system for monitoring ecosystem service change. *BioScience*, 62(11), 977–986. <https://doi.org/10.1525/bio.2012.62.11.7>
- Tefera, N. T., Desta, M. D., & Rashid, S. (2012, August 18–24). *Welfare impacts of rising food prices in rural Ethiopia: A quadratic almost ideal demand system approach* [Conference session]. International Association of Agricultural Economists Conference, Foz do Iguacu, Brazil.
- Tiffen, M., (1996). Chapter 10. Blind spots in the study of the ‘resource poor’ farmers. In Leach, M., & Mearns, R. (Eds.). *The lie of the land: Challenging received wisdom on the African environment*. International African Institute in association with James Curre ; Heinemann.
- Tittonell, P., & Giller, K.E. (2013). When yield gaps are poverty traps: The paradigm of ecological intensification in African smallholder agriculture. *Field Crops Research*, 143, 76–90. <https://doi.org/10.1016/j.fcr.2012.10.007>
- Tropek, R., Sedláček, O., Beck, J., Keil, P., Musilová, Z., Šimová, I., & Storch, D. (2014). Comment on “High-resolution global maps of 21st-century forest cover change.” *Science*, 344(6187), 981–981.
- Tsegaye, A., & Struik, P. C. (2001). Enset (*Ensete ventricosum* (Welw.) Cheesman) kocho yield under different crop establishment methods as compared to yields of other carbohydrate-rich food crops. *NJAS - Wageningen Journal of Life Sciences*, 49(1), 81–94. [https://doi.org/10.1016/S1573-5214\(01\)80017-8](https://doi.org/10.1016/S1573-5214(01)80017-8)

- Tsegaye, A., & Struik, P. C. (2002). Analysis of Enset (*Ensete Ventricosum*) indigenous production methods and farm-based biodiversity in major enset-growing regions of southern Ethiopia. *Experimental Agriculture*, 38(3), 291–315. <https://doi.org/10.1017/S0014479702003046>
- Turnbull, J. W., & Booth, T. H. (2002). Eucalyptus in cultivation: An overview. In J. W. John (Ed.), *Eucalyptus: The genus eucalyptus*. Taylor and Francis. https://doi.org/10.4324/9780203219430_chapter_3
- Turner, B. L. (Ed.). (1990). *The Earth as transformed by human action: Global and regional changes in the biosphere over the past 300 years*. Cambridge University Press with Clark University.
- Turner, B. L., & Ali, A. M. S. (1996). Induced intensification: Agricultural change in Bangladesh with implications for Malthus and Boserup. *Proceedings of the National Academy of Sciences*, 93(25), 14984–14991. <https://doi.org/10.1073/pnas.93.25.14984>
- Tur-Sinai, A., Fleishman, L., & Romanov, D. (2020). The accuracy of self-reported dwelling valuation. *Journal of Housing Economics*, 48, 101660. <https://doi.org/10.1016/j.jhe.2019.101660>
- Umer, M., Lamb, H. F., Bonnefille, R., Lézine, A.-M., Tiercelin, J.-J., Gibert, E., Cazet, J.-P., & Watrin, J. (2007). Late Pleistocene and Holocene vegetation history of the Bale Mountains, Ethiopia. *Quaternary Science Reviews*, 26(17–18), 2229–2246. <https://doi.org/10.1016/j.quascirev.2007.05.004>
- United Nations Framework Convention on Climate Change Reducing Emissions from Deforestation and Forest Degradation and the Role of conservation, Sustainable Management of Forests and Enhancement of Forest Carbon Stocks in Developing Countries (REDD+) (2014). *Decision 13/CP.19*. <https://unfccc.int/resource/docs/2013/cop19/eng/10a01.pdf#page=34>
- United Nations Framework Convention on Climate Change Secretariat. (2016). *Key decisions relevant for reducing emissions from deforestation and forest degradation in developing countries (REDD+)*. https://unfccc.int/files/land_use_and_climate_change/redd/application/pdf/compilation_redd_decision_booklet_v1.2.pdf
- United Nations Food and Agricultural Organization. (1986). *Highlands Reclamation Study Ethiopia, Ethiopia: Final Report Volume 1*. <http://www.fao.org/3/ar863e/ar863e.pdf>
- United Nations Food and Agricultural Organization. (1996). *World Food Summit: Rome Declaration on World Food Security and World Food Summit Plan of Action*. <http://www.fao.org/3/w3613e/w3613e00.htm>

- United Nations Food and Agricultural Organization. (2002). *Role of Planted Forests and Trees Outside Forests in Sustainable Forest Management*.
<http://www.fao.org/3/j5838e/J5838E08.htm>
- United Nations Food and Agricultural Organization. (2018). *Establishing a system for measuring and monitoring changes in Ethiopia's forests*.
<http://www.fao.org/3/ca4994en/CA4994EN.pdf>
- United Nations Food and Agricultural Organization. (2020a). *Annex 9—Glossary—State of Food Security and Nutrition in the World 2020*.
http://www.fao.org/3/ca9692en/online/ca9692en.html#chapter-9a_1
- United Nations Food and Agricultural Organization. (2020b). *Ethiopia Report; Global Forest Resources*. <http://www.fao.org/3/ca9991en/ca9991en.pdf>
- United Nations General Assembly. (2015). *Transforming our World: The 2030 agenda for sustainable development*. A/RES/70/1.
<https://sustainabledevelopment.un.org/content/documents/21252030%20Agenda%20for%20Sustainable%20Development%20web.pdf>
- United Nations General Assembly. (2017). *Work of the Statistical Commission pertaining to the 2030 Agenda for Sustainable Development*. A/RES/71/313.
<https://undocs.org/A/RES/71/313>
- United Nations Task Force on Financing for Development. (2020). *Financing for sustainable development 2020*. United Nations.
https://developmentfinance.un.org/sites/developmentfinance.un.org/files/FSD_R_2020.pdf
- UNICEF. (1990). *Strategy for improved nutrition of children and women in developing countries*. Author.
- Upton, J. B., Cissé, J. D., & Barrett, C. B. (2016). Food security as resilience: Reconciling definition and measurement. *Agricultural Economics*, 47(S1), 135–147.
- Vaitla, B., Devereux, S., & Swan, S. H. (2009). Seasonal hunger: A neglected problem with proven solutions. *PLoS Medicine*, 6(6), e1000101.
<https://doi.org/10.1371/journal.pmed.1000101>
- Valbuena, D., Erenstein, O., Homann-Kee Tui, S., Abdoulaye, T., Claessens, L., Duncan, A. J., Gérard, B., Rufino, M. C., Teufel, N., van Rooyen, A., & van Wijk, M. T. (2012). Conservation Agriculture in mixed crop–livestock systems: Scoping crop residue trade-offs in Sub-Saharan Africa and South Asia. *Field Crops Research*, 132, 175–184.
<https://doi.org/10.1016/j.fcr.2012.02.022>

- Vanlauwe, B., Coyne, D., Gockowski, J., Hauser, S., Huising, J., Masso, C., Nziguheba, G., Schut, M., & Van Asten, P. (2014). Sustainable intensification and the African smallholder farmer. *Current Opinion in Environmental Sustainability*, 8(0), 15–22.
- Vavilov, N. I. (2009). *Origin and geography of cultivated plants*. Translated by Doris Löve. Digitally printed version. Cambridge University Press.
- Vedeld, P., Angelsen, A., Bojö, J., Sjaastad, E., & Berg, G. K. (2007). Counting on the environment: Forest incomes and the rural poor. *Forest Policy Economics*, 9, 869–879. <https://doi.org/10.1016/j.forpol.2006.05.008>
- Verburg, P. H., Neumann, K., & Nol, L. (2011). Challenges in using land use and land cover data for global change studies. *Global Change Biology*, 17, 974–989, <https://doi.org/10.1111/j.1365-2486.2010.02307>
- Verma, D. P. S. (1990). Agroforestry practices of Gujarat State. *International Tree Crops Journal*, 6(1), 17–30. <https://doi.org/10.1080/01435698.1990.9752868>
- Vira, B., Agarwal, B., Jamnadass, R. H., Kleinschmit, D., McMullin, S., Mansourian, S., Neufeldt, H., Parrotta, J. A., Sunderland, T. C., & Wildburger, C. (2015). Forests, trees and landscapes for food security and nutrition. In B. Vira, C. Wildburger, & S. Mansourian (Eds.), *Forests and food: Addressing hunger and nutrition across sustainable landscapes* (pp. 14–23). Open Book Publishers.
- von Bertalanffy, L. (1950). An outline of general system theory. *The British Journal for the Philosophy of Science*, 1(2), 134–165.
- Wassie, A. (2017). Forest resources in Amhara: Brief description, distribution and status. In K. Stave, G. Goshu, & S. Aynalem (Eds.), *Social and ecological system dynamics* (pp. 231–243). Springer International Publishing. https://doi.org/10.1007/978-3-319-45755-0_15
- Watts, M. J. (2013). *Silent violence: Food, famine, and peasantry in Northern Nigeria* (Vol. 15). University of Georgia Press.
- Webb, P., Coates, J., Frongillo, E. A., Rogers, B. L., Swindale, A., & Bilinsky, P. (2006). Measuring household food insecurity: Why it's so important and yet so difficult to do. *The Journal of Nutrition*, 136(5), 1404S–1408S. <https://doi.org/10.1093/jn/136.5.1404S>
- Weir, S., & Knight, J. (2007). Production externalities of education: Evidence from rural Ethiopia. *Journal of African Economies*, 16, 134–165. <https://doi.org/10.1093/jae/ejl026>

- Wessels, K. J., Prince, S. D., Frost, P. E., & van Zyl, D. (2004). Assessing the effects of human-induced land degradation in the former homelands of Northern South Africa with a 1 Km AVHRR NDVI Time-Series. *Remote Sensing of Environment*, *91*(1), 47–67. <https://doi.org/10.1016/j.rse.2004.02.005>
- Westphal, E., & Stevels, J. M. C. (1975). *Agricultural systems in Ethiopia* (Vol. 826). Centre for Agricultural Publishing and Documentation Wageningen.
- Wilson, R., Bailey, L., Hales, J., Moles, D., & Watkins, A. (1980). The cultivation-cattle complex in Western Darfur. *Agricultural Systems*, *5*(2), 119–135. [https://doi.org/10.1016/0308-521X\(80\)90003-7](https://doi.org/10.1016/0308-521X(80)90003-7)
- Winchester, P. (2000). Cyclone mitigation, resource allocation and post-disaster reconstruction in South India: Lessons from two decades of research. *Disasters*, *24*(1), 18–37. <https://doi.org/10.1111/1467-7717.00129>
- Wittmack, L. (1867). *Musa Ensete: Ein Beitrag zur Kenntniss der Bananen. Gebauer-Schwetschkesche Buchdr.* Hamburg Germany.
- Wood, S. A., Tirfessa, D., & Baudron, F. (2018). Soil organic matter underlies crop nutritional quality and productivity in smallholder agriculture. *Agriculture, Ecosystems & Environment*, *266*, 100–108. <https://doi.org/10.1016/j.agee.2018.07.025>
- Worku, T., Tripathi, S. K., & Khare, D. (2018). Household level tree planting and its implication for environmental conservation in the Beressa Watershed of Ethiopia. *Environmentak. Systems Research*, *6*, 1–12, <https://doi.org/10.1186/s40068-017-0087-4>
- Wren-Lewis, L., Becerra-Valbuena, L., & Hounghbedji, K. (2020). Formalizing land rights can reduce forest loss: Experimental evidence from Benin. *Science Advances*, *6*(26), eabb6914. <https://doi.org/10.1126/sciadv.abb6914>
- Yergin, D. (2006). Ensuring energy security. *Foreign Affairs*, *1*, 69–82.
- Zeder, M. A. (2008). Domestication and early agriculture in the Mediterranean Basin: Origins, diffusion, and impact. *Proceedings of the National Academy of Sciences*, *105*(33), 11597–11604. <https://doi.org/10.1073/pnas.0801317105>
- Zewdie, S., Olsson, M., & Fetene, M. (2008). Effect of drought/irrigation on proximate composition and carbohydrate content of two enset [*Ensete ventricosum* (Welw.) Cheesman] clones. *SINET: Ethiopian Journal of Science*, *31*(2), 81–88.
- Zimmerman, F. J., & Carter, M. R. (2003). Asset smoothing, consumption smoothing and the reproduction of inequality under risk and subsistence constraints. *Journal of Development Economics*, *71*(2), 233–260.

- Zomer, R. J., Neufeldt, H., Xu, J., Ahrends, A., Bossio, D., Trabucco, A., Van Noordwijk, M., & Wang, M. (2016). Global tree cover and biomass carbon on agricultural land: The contribution of agroforestry to global and national carbon budgets. *Scientific Reports*, 6, 1–12. <https://doi.org/10.1038/srep29987>
- Zomer, R. J., Trabucco, A., Coe, R. & Place, F. (2009). Trees on farm: Analysis of global extent and geographical patterns of agroforestry. *ICRAF Working Paper-World Agroforestry Centre*, 89.
- Zomer, R. J., Trabucco, A., Coe, R., Place, F., Van Noordwijk, M., & Xu, J. (2014). Trees on farms: An update and reanalysis of agroforestry's global extent and socio-ecological characteristics. *World Agroforestry Center Working Paper*, 179.