

Article

Harnessing the Direct and Indirect Effects of Agriculture on Health and Nutrition to Accelerate Human Capital Development in Kenya: Evidence from Household Surveys

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Abstract

This paper estimates the direct and indirect effects of agriculture on health and nutrition using nationally representative survey data collected by the Kenya National Bureau of Statistics in 1994, 1997, 2005 and 2015. The models estimated serve as examples of general frameworks that can be used to measure the direct and indirect effects of agriculture on health and nutrition in Africa and elsewhere. The results indicate that substantial direct and indirect improvements in health and nutrition can be achieved via policies that increase agricultural productivity. Growth in household income is the main mechanism through which the effects are transmitted to household members. Exogenous variation in household holding of land and cattle is used to identify the effects we estimate. The idea underlying the identification strategy is that agricultural policies over which households have no control can be used by the government to vary farm assets, thus changing household income, *ceteris paribus*. Examples of such policies include interventions that improve land tenure systems and agricultural extension services at the farm level. The conclusion highlights the policy value of our findings.

Keywords: health; nutrition; direct and indirect effects; agricultural policies; land; livestock; Kenya

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1. Introduction

1.1. Background

Human capital is widely recognized as a determinant of economic growth and development. Health and nutrition are sources and drivers of human capital development (Strauss & Thomas, 1998). A healthy and well-nourished population is more productive, positively impacting economic growth (Bloom et al., 2004). The agricultural sector offers opportunities to support health and nutrition improvements (Fan & Pandya-Lorch, 2012; Ruel et al., 2018; Sharma et al., 2021; Duncan et al., 2022).

The effects of agriculture on health are of critical importance. The majority of the African population lives in rural areas, where the main source of livelihood is agriculture (Lam & Leibbrandt, 2023). The farm-based livelihoods of African households suggest that agriculture has a major effect on the health and nutrition of rural people in Africa. As the urban population on the continent relies heavily on food produced in rural areas, it

is a fair assumption that the health and nutrition outcomes of the African population are determined by agriculture. The global nutrition report ([Development Initiatives, 2018](#)) points out that agriculture enables households to produce food and generate income to purchase and consume better-quality foods. Consequently, it is critical to promote nutrition (health)-sensitive agriculture.

Despite the evident contribution of agriculture to the health and nutrition of the African population, a systematic analysis of this role has not been conducted in the previous literature. In particular, there are gaps regarding the effects of agriculture on health and nutrition outcomes; the channels through which different aspects of agriculture affect health and nutrition; the implications of feedback from health and nutrition to agriculture; and the contribution of agriculture to health capital accumulation. Filling these gaps is important because any efforts to leverage agriculture for health and nutrition improvements need to be backed by empirical evidence. For example, [Ruel et al.'s \(2018\)](#) review of the previous literature reports a consensus that agriculture can influence nutrition outcomes, but empirical evidence on this contribution is weak.

Despite the existence of elaborate conceptual models of the relationships between agriculture, health, and nutrition in the previous literature ([Strauss & Thomas, 1998, 2008](#)), estimates of the parameters of these models using African data are rare. The paper fills this gap using Kenyan data.

The overall framework discussed in the paper sheds light on channels through which African agriculture affects health and nutrition given the constraints under which the households operate. We use the empirical version of the framework to measure the direct and indirect nutrition and health effects of agricultural policies. We interpret the estimates using the conceptual version of the model. The main feature of the empirical model is exogeneity in all regressors, typically variables that households cannot influence when making resource allocation decisions, such as land tenure systems. The main feature of the conceptual model is that it contains a causal factor (household income) that directly influences the outcome variable of interest, nutrition. As nutrition is an aspect of overall health, the terms health and nutrition in this paper are mostly used interchangeably.

1.2. Research Objectives

The objectives of this study are to (i) develop a conceptual framework to guide measurements of the direct and indirect effects of agriculture on health and nutrition in African countries where appropriate datasets exist; (ii) estimate human capital production models, taking into account the potential endogeneity of household income, the main driver of human capital formation within a household; and (iii) simulate the effects of a portfolio of agricultural policies, particularly on health and nutrition, as these dimensions of human capital are a priori-sensitive to agricultural productivity.

1.3. Literature Review

Agriculture is the backbone of African economies. Apart from the income it provides, agriculture keeps people active, an important behavioral input into the production of health and nutrition. Agriculture provides income to purchase food and healthcare and is a major source of individual consumption. African agriculture is a source of labor and raw materials for industrial production. The bulk of consumption in low-income countries in sub-Saharan Africa is from agriculture. However, in a lot of economic analyses, consumption is not considered an investment. In this paper, we follow the argument that “much of what we call consumption constitutes investment in human capital” ([Schultz, 1961](#), p. 1). Consumption of agricultural products requires a key investment in human capital—nutrition, health and

education. Learning, for example, is not possible without sufficient investment in food production and consumption.

Improving the food environment is of critical importance to better health and nutrition outcomes. The [Global Panel on Agriculture and Food Systems for Nutrition \(2014\)](#) identified four components of the food environment: agricultural production (which determines both own-based and market-based consumption); markets and trade systems (which determine food supplies, crop sales, and farm incomes); consumer purchasing power (which determines households' intake of nutrients and healthcare); and food processing (which affects food preparation and nutrient quantities).

The food environment determines the quality of people's health and nutrition through its effects on diet diversity, adequacy, and safety. Therefore, the food policy issue in Africa and elsewhere is threefold. The first component is how to ensure adequate diet quality for everyone, as food availability is not the only constraint of good nutrition and good health ([Global Panel on Agriculture and Food Systems for Nutrition, 2014](#)). The second aspect of food policy is how to improve the intake of a diversified diet because such a diet is associated with a greater variety of nutrients. The final policy issue is how to correctly measure the impacts of agricultural policies on health and nutrition without bias.

A large body of literature exists on the connections between agriculture, health, and nutrition (for example, [UNICEF, 1990](#); [The World Bank, 2007](#); [Herforth et al., 2012](#); [Webb, 2013](#); [Herforth & Ballard, 2016](#); [Pandey et al., 2016](#)). These studies focus on various determinants of health and nutrition and the mechanisms through which the determinants produce their effects. Agricultural policies are some of the determinants of health and nutrition, the mechanisms of which are not well known.

We focus on the microeconomic literature that measures effects of household income on health and nutrition to support the conceptual framework used in the paper. The key assumption in this study is that the bulk of household income in African countries is affected by events in agriculture. Therefore, public policies that affect agricultural production should have substantial impacts on nutrition and health. We also review the macroeconomic literature linking agricultural policies to nutrition and growth.

According to the [African Union \(2017\)](#), poor nutrition can hold back national development. It follows that food security and nutrition should have the highest priority in the development agenda of African economies. The adoption of the Comprehensive Africa Agricultural Development Programme (CAADP) in 2003 in Maputo and, a decade later in June 2014, the adoption of the Malabo Declaration on Accelerated Agricultural Growth and Transformation in Equatorial Guinea ([African Union, 2017](#)) shows that African countries are taking food and nutrition issues seriously as drivers of development. The [African Union \(2017\)](#) Report shows that from 2003 to 2013, when CAADP was being implemented, African governments were concurrently designing policies to guide agricultural development and transformation in their countries. The 2003–2013 period of CAADP implementation facilitated the mobilization and alignment of multi-stakeholder partnerships and investments around National Agriculture and Food Security Investment Plans. The recognition of the substantial contribution of food and agriculture to national development led to the inclusion of food and agriculture in the United Nations' Sustainable Development Goals ([African Union, 2015](#)).

In a different vein, the [African Development Bank \(2016\)](#) shows that, globally, there has been progress in fighting hunger and malnutrition, as the prevalence of undernourishment fell from 14.7% to 10.6% between 2000 and 2015, while the number of undernourished people declined from 900 million to 777 million over the same period. In sub-Saharan Africa, the proportion of undernourished people declined from 28.1% in 2000 to 20.6% in 2010, as the number of undernourished individuals fell from 178 million to 171 million over

the same period. However, after 2010, the rate of undernourishment in Africa remained flat and then rose to 22.7% in 2016.

The previous literature has analyzed the relationship between agricultural policies and nutritional outcomes. Several reviews exist: [The World Bank \(2007\)](#) assessed a wide range of studies and concluded that the evidence of the contribution of agriculture to nutritional outcomes was at best mixed. Similarly, [Haddad and Meeker \(2013\)](#) did not find a definitive link between agriculture and nutrition in studies of food-insecure regions. [Berti et al. \(2004\)](#) found that agricultural interventions improved food production but not nutritional status. [Masset et al.'s \(2012\)](#) review of evidence on home garden interventions established that they increased production, consumption of food rich in protein and micronutrients, and absorption of vitamin A. However, there was no evidence pointing to an effect on absorption of iron, household income, and nutritional status among young children. [Webb and Kennedy \(2014\)](#) found weak and mixed empirical evidence for impacts of agricultural interventions on nutrition. [Kadiyala et al.'s \(2014\)](#) review of Indian studies pointed toward a consensus that agriculture influenced diets, controlling for income, and relative food prices. Studies of the South Asia region reviewed by [Pandey et al. \(2016\)](#) revealed mixed results. However, agricultural interventions aimed at nutrient-rich crops and diversification towards fruits, vegetables, and aquaculture support improvements in nutritional outcomes in the context of women empowerment.

The literature suggests that the linkage between growth, nutrition, and agricultural policies is still not well understood. Specifically, it is not clear how public policies on agriculture-related variables, such as land, livestock, and extension services, translate into better health and nutrition. This conclusion also emerged from subsequent studies reviewed by [Ruel et al. \(2018\)](#). While diversity in agricultural production and livestock ownership are positively associated with household and dietary diversity and intake of essential micronutrients, evidence of their effect on health and nutrition is limited. The review by [Sharma et al. \(2021\)](#) also concludes that there is limited evidence of the pathways through which agriculture influences nutritional status.

We argue that household income is the pathway through which public policies in agriculture affect health and nutrition ([Ruel et al., 2018](#)). In particular, public policies that improve land tenure systems, increase production or quality of the livestock, increase land productivity or farming skills, or address covariant or specific risks in agricultural households can have large impacts on health and nutrition through the income channel. An important emerging risk to African agriculture and to health capital accumulation is the covariant risk posed by climate change ([Frankhauser, 2017](#)). Mitigating the adverse effects of climate change requires cooperation among countries.

The [Global Panel on Agriculture and Food Systems for Nutrition \(2014\)](#) notes that governments around the world have increasingly focused on investing in the link between agriculture and nutrition, i.e., in transforming agriculture in the hope of improving nutrition. However, the mechanisms through which transformation of agriculture affects health and nutrition at the household level are rarely clarified. On this crucial point, the [Global Panel on Agriculture and Food Systems for Nutrition \(2014\)](#) concludes that there is no single agricultural policy on its own that can improve nutrition. Applying this fundamental observation at the household level, it can be concluded that no single commodity in the household consumption case can substantially improve nutrition or health on its own. It is the efficient and equitable allocation of total household income to a broad range of consumption goods that has the best chance of improving health and nutrition.

Returning to the fundamental observation of the [Global Panel on Agriculture and Food Systems for Nutrition \(2014\)](#), it is clear that a multisectoral approach to agricultural transformation is arguably the best strategy to use to improve health capital in Africa. As

many types of agricultural policies are at play in the agricultural sector, it is important to know how each affects household income, and the pathways through which each influences health and nutrition. Ideally, nutrition-enhancing policies should reinforce each other, within and outside agriculture. The income pathway in agrarian economies in Africa has not received much attention in the human capital formation literature. This paper provides an in-depth, statistical investigation of this issue using Kenyan data.

The remainder of the paper is organized as follows: Section 2 presents a discussion of the conceptual and empirical frameworks, describing the data and the Kenyan context informing the analysis, while Section 3 presents the results. A brief discussion is provided in Section 4. Section 5 concludes.

2. Methodology

2.1. Conceptual Framework and Measurement Models

In this paper, we examine the hypothesis that agriculture influences the health and nutritional status of individuals within farming households directly through the household income attributable to agriculture and indirectly through agricultural assets that influence household income. The household, our unit of analysis, is assumed to maximize the following health production function, subject to the usual budget constraint:

$$H = H(x, y; Z) \quad (1)$$

where H is a set of health and nutrition indicators; x is a set of inputs into health and nutrition; y is a set of non-health goods, such as housing, transportation, household durables, and social amenities; and Z is a vector of controls, such as demographics, area of residence and weather shocks. Briefly, x and y are all the goods and services that a household spends its income on, so that household total expenditure is equal to income. As is well known, the maximization of H subject to a budget constraint yields optimal quantities of x and y . The same consumption vector minimizes the household expenditure needed to achieve the utility level consistent with this vector (Deaton & Muellbauer, 1980).

Thus, H (in Equation (1)) can be thought of as a function of total per capita household expenditure (PCE), so that the estimable counterpart of Equation (1) can be written as follows:

$$H = H(PCE, Z) + e \quad (2)$$

Equation (2) is the natural tool to use to measure direct and indirect effects of agricultural policies on nutrition and health. Contrary to much of the nutrition literature that relates nutrition level or status to nutrients, and also in contrast to the health economics literature that causally links health levels to healthcare alone, Equation (2) asserts that the health and nutrition conditions of the population are determined by per capita household income, holding constant other factors that shift the health production technology. The central argument is that health and nutrition depend on the household's command over all the goods it consumes, not just on food or healthcare. A household that has all the nutrients it needs but has no control over the resources it can spend on healthcare or housing is worse off from a nutrition standpoint, relative to its counterpart that has the purchasing power to acquire the additional goods. To stretch this point to the limit, a child who consumes a balanced diet but lacks treatment for worms (or lacks decent housing) does not receive the full benefit of that intervention.

Briefly, the non-health goods consumed by the household are important complementary inputs into the production of nutrition. However, because of market failures, household income alone is not sufficient to improve nutrition. It is important to provide households with information on appropriate foods and healthcare, and to optimally sub-

sidize the consumption of such goods. In order to carry out the measurement without bias, the causal effect of household income on health and nutrition, the endogeneity of household income in Equation (2), must be addressed (Wooldridge, 2009). To that end, we first instrument *PCE* with household land and cattle (large livestock units that take time to accumulate). In Kenya and other African countries, land and cattle are the key determinants of agricultural production. The first-stage equation in linear form is

$$PCE = a_0 + \sigma L + a_2 C + a_3 Z + v \quad (3)$$

where *L* is landholding in acres and *C* is the stock of cattle herd (oxen, milk and beef cows). The coefficients on *L* and *C* are parameters to be estimated, and *v* is a disturbance term. We assume that the household takes *L* and *C* as given at the beginning of a cropping season and these are thus potential instruments for *PCE*. The land and cattle holdings are further assumed to be determined by prevailing land tenure systems and by land use policies. We assume current landholdings are outcomes of previous land adjudication and registration laws, including legislation governing the operations of land markets. Similarly, cattle herds in a cropping cycle are a result of land tenure systems, livestock policies, such as the rules governing farm extension services, or the functioning of livestock markets. In this set-up, a change in land tenure system affects the sizes of farms and cattle herds.

The structural equation (Heckman, 2001), where the coefficient on per capita household expenditure (*PCE*) is the main parameter of policy interest, becomes

$$H = \alpha + \beta_1 PCE_hat + \delta Z + e \quad (4)$$

where *PCE_hat* is the predicted household income based on Equation (3).

The parameters of the reduced-form nutrition production function are also of interest because they can be used to compute the indirect effects of agricultural policies. To illustrate how this effect is computed and interpreted, we assume exact identification, i.e., only one excluded instrument is used to predict *PCE*. Thus, for illustration purposes only, we drop *C* from Equation (3) and write the reduced-form version of Equation (4) as follows:

$$H = a + b_1 L + b_3 Z + u \quad (5)$$

where *L* is now the only instrument for *PCE* in Equation (3).

In Equation (3), the coefficient on *L* (i.e., σ) is the change in household income induced by a unit increase in landholding, e.g., one-acre increment. We interpret σ as the change in household income induced by the implementation of agricultural land policies that increase landholding exactly by one acre. Thus, in Equation (4), β_1 represents the number of units by which the nutrition level changes (e.g., increases) for every exogenous shilling increase in household income induced by agricultural policy. Thus, from Equations (3) and (4), it is easy to check (using the partial derivatives for the outcome variables in Equations (3)–(5), with respect to *L*, *PCE*, and *L*, respectively) that a unit increase in landholding improves nutrition by $\sigma \times \beta_1$, which is identically equal to b_1 , the coefficient of *L* in Equation (5), assuming exact identification. Due to its centrality in the understanding of direct and indirect effects, this calculation is worth illustrating.

From Equations (3)–(5), $dPCE/dL = \sigma$, $dH/dPCE_hat = \beta_1$, and $dH/dL = b_1$, respectively. Thus, in Equation (5), $b_1 = \sigma \times \beta_1$ because from Equation (3), when *L* increases by one unit, *PCE* changes by σ , so that for every additional unit of σ , *H* changes by β_1 (Equation (4)), demonstrating that we can calculate b_1 without estimating Equation (5). This effect is indirect because it happens through *PCE* in either Equation (2) or (4).

As already noted, Equations (3) and (4) facilitate computation of the indirect effect in a structural model of human capital production that encompasses only the health and nutrition dimensions of human capital. Conceptually, without the intervention of the household in Equation (4), the coefficient of L in Equation (5) would be zero. In other words, it is the allocation of income by the household on nutrients and healthcare that makes it possible for agricultural policies to improve the dimensions of human capital that are of policy interest here, i.e., health and nutrition.

As the indirect effect, b_1 (reduced-form coefficient), is equal to $\sigma \times \beta_1$, we see that the direct effect, β_1 , is equal to b_1/σ , i.e., the number of natural units by which nutrition or health is increased by a shilling increase in household income attributable to agriculture. Moreover, as this quantity is a ratio, the monetization of b_1 (the marginal product of land in the nutrition sector) transforms β_1 into a financial return. Stated differently, σ is the increase in household income attributable to agriculture that is invested in nutrition, while the monetary value of b_1 (say, b_s) is the financial return on that investment. Thus, b_s/σ shows the amount of shillings earned per shilling invested in health or nutrition. If the ratio is 0.2, for example, the investment has a financial rate of return of 20%. The expression shows that technical progress within households (in the production of nutrients) and efficiency in resource allocation within agriculture (in the targeting of agricultural policies to the most productive farm activities) are key to improving health and nutrition.

To further illustrate this point, consider the ratio $(b_1/\beta_1) = \sigma$. As before, b_1 is the indirect effect on nutrition of a unit increase in household land size due, for example, to a public policy favorable to agriculture, and β_1 is the direct effect on nutrition of a shilling increase in household income attributable to any exogenous source. The expression shows that the ability of a household to improve the nutrition and health of its members critically depends on the productivity of the resources invested in agriculture.

Moreover, as σ is the change in total household income (irrespective of source), agricultural policies that increase productivity in off-farm activities also enhance health and nutrition. Furthermore, an improvement in efficiency within a household (i.e., an increase in β_1) improves nutrition. Efficiency as measured by the size of β_1 per unit of σ can be increased via better nutrition information and by reducing food wastage or by increasing food quality. Thus, β_1 is bounded by the level of efficiency in the production of human capital within the household. In contrast, b_1 is constrained by the size of σ (income from an additional unit of land) and by the efficiency of the use of that land to produce σ , as well as by the efficiency of the use of σ to enhance health or nutrition (see Equations (3) and (5)).

The foregoing discussion assumes exact identification of the structural model. In the case of over-identification, the indirect effect, b_1 , cannot be obtained using the expression $b_1 = \sigma \times \beta_1$. We use this expression only to approximate the indirect effect of agricultural policies on health and nutrition. Although the direct effects are precisely estimated, caution is needed in interpreting indirect effects because they are precise only in the case of exact identification. It is worth noting that the indirect effects measured in this paper are driven by observed exogenous factors, such as acreage and oxen. The indirect effects of unobserved and/or unmeasured covariates (such as weather, genetics, or epidemics) are not considered in this paper but are fully analyzed by [Baye et al. \(2020\)](#).

It is tempting to incorrectly view the indirect effect ($b_1 = \sigma \times \beta_1$) as mixed, i.e., as a mixture of direct and indirect effects, but this is not the case. The change in health or nutrition (b_1) is indirect because it is felt by household members only through higher household income, rather than via an increment in land acreage, the origin of the causal change (see Equations (3) and (4)). Since a one-unit increment in acreage, which raises income by σ in Equation (3), is induced by agricultural policy, that increment is outside the control of the household. Thus, the change in acreage that enhances income is not

attributable to the household. However, the household can use the extra income arising from more land to improve the human capital of its members (Equation (4)). Thus, the expression ($b_1 = \sigma \times \beta_1$) is the indirect effect of an extra acre on health or nutrition, which is transmitted to household members through extra income, σ . Furthermore, the magnitude of the effect transmitted is equal to $\sigma \times \beta_1$, where β_1 is the direct effect on health or nutrition for every additional Kenyan shilling earned. The direct and indirect effects converge when either both coefficients σ and β_1 are equal to one or when σ is equal to one. The indirect effects discussed above are due to observed exogenous covariates. As already noted, the indirect effects stemming from unobservable or omitted covariates can be measured using the control function approach; see, e.g., [Baye et al. \(2020\)](#). It should be noted that both the direct and indirect effects are measured at the margin of the change in household income.

2.2. Data and Policy Context

The data are from nationally representative surveys conducted in 1994, 1997, 2005, and 2015 by the Kenya National Bureau of Statistics. The surveys are population-based and use the same sampling frame. The details of the surveys are available in the bureau's reports ([Kenya National Bureau of Statistics, 1996, 1998, 2006, 2016](#)). Similar analyses can be conducted using survey data from other African countries, where available. In this paper, we estimate the direct and indirect effects of agricultural policies on health and nutrition using all of the above datasets after selecting observations containing data on variables used in the study.

In Kenya, at the time of the 2015/16 household survey, agriculture contributed 33% to the gross domestic product (GDP), while services and industry contributed 47% and 20%, respectively ([Republic of Kenya, 2019](#)). Moreover, about 62% of Kenya's total employable population derive their livelihood from agriculture. In rural areas, it is over 70%. Consequently, land is a critical factor of production in Kenya and the most controversial issue, with roots of land conflicts going back to the pre-independence era.

Since independence in 1963, the government has instituted a number of land policies aimed at improving equity in land ownership and efficiency in its use. The Kenyan land reforms have their origin in the Swynnerton agricultural plan of the 1950s ([Heyer et al., 1976](#)). Recent agricultural land policies and legislation include Sessional Paper No. 10 of 1965; Sessional Paper No. 1 of 1986; the Land Planning Act (Cap 303); the Town Planning Act (Cap 134); the Land Control Act (Cap 302); the Agriculture Act (Cap 318); the Environmental Management and Coordination Act (EMCA), 1999; the Physical Planning Act (Cap 286); and the National Development Plans, 2002–2008 ([Republic of Kenya, 2009](#)). Although these policies and legislation have affected the functioning of the agricultural sector in various ways, the effects they have had on health and nutrition have not been assessed previously.

Kenya has not yet adopted a national land policy that meets the standards of the 2010 Constitution, which devolved the country's administrative system to the local level. However, Kenya Vision 2030 and Sessional No.3 of 2009 made progress on this issue. The two documents contain policies to promote investments in land, support agriculture-based livelihoods, protect the environment, and develop the livestock sector. In particular, Kenya Vision 2030 aims at transforming agriculture from an initiative of subsistence to an innovative and modern enterprise.

Other legal frameworks designed to modernize agriculture and livestock farming include the Strategy for Revitalizing Agriculture (SRA), 2004–2014 ([Republic of Kenya, 2004](#)), and the Agriculture Sector Development Strategy (ASDS), 2010–2020 ([Republic of Kenya, 2010](#)). However, the policies to improve the livestock sector have not received as much attention, despite its central role in people's livelihoods in semi-arid lands.

Livestock, especially cattle, are an important agricultural asset in Kenya. According to the [Kenya Ministry of Agriculture \(2008\)](#), livestock production accounts for nearly 95 percent of family income in arid and semi-arid lands (ASALs). The livestock sector contributes 12% to Kenya's GDP and 42% to agricultural GDP ([Republic of Kenya, 2008](#)). However, despite its relatively large contribution to agricultural GDP, the livestock sector is underfunded. Additional investments in the sector can play an important role in improving health and nutrition, especially in arid and semi-arid lands.

3. Results

3.1. Effect of Agricultural Assets on Household Income

Table 1 shows the associations between household income and agricultural assets—land and cattle—which we use as instruments for household income. The results in Table 1 show that between 1994 and 2015, a percentage change in landholding was associated with a 3–14% increase in household income. Thus, the marginal contribution of agriculture to household income has been rising, on average. Another notable finding is that the return to traditional cattle is negative—a finding consistent with previous studies ([Gehrke & Grimm, 2014](#)). Rural households have lower incomes than their urban counterparts and there is nuanced evidence that adverse weather shocks reduce household incomes. In 2005, for example, households that experienced adverse weather shocks had incomes that were 8% lower than unaffected households. However, in 2015, households that experienced droughts had higher incomes. A drought makes farmers who are net sellers better off by raising the prices of their produce, while reducing the purchasing power of the net buyers. Thus, the overall impact of a drought depends on the relative proportions of net buyers and sellers.

Table 1. First-stage estimates: contributions of exogenous variation in farm assets (assumed to be induced by agricultural policies) to change in household incomes, 1994–2015.

Variables	Log of Total per Capita Adult Equivalent Household Income (Absolute <i>t</i> -Statistics in Parentheses)			
	1994	1997	2005	2015
<i>Instruments</i>				
Log household landholding, acres	0.036 (3.12)	0.027 (1.60)	0.028 (2.02)	0.144 (22.9)
Log of number of cattle (all breeds)	0.099 (10.4)	0.161 (11.1)	0.021 (1.31)	-
Log of local cattle	-	-	-	−0.023 (4.77)
Exotic milk cows	-	-	-	0.028 (14.5)
Exotic beef cattle	-	-	-	0.069 (10.5)
<i>Controls</i>				
Residence (1 = rural)	−0.395 (13.4)	−0.590 (14.2)	−0.474 (16.0)	−0.191 (21.8)
Adverse weather shocks? (1 = yes over past five years)	-	-	−0.085 (2.90)	0.018 (2.77)
Education? (yes)	Yes	Yes	Yes	Yes
Age? (yes)	Yes	Yes	Yes	Yes

Table 1. *Cont.*

Variables	Log of Total per Capita Adult Equivalent Household Income (Absolute <i>t</i> -Statistics in Parentheses)			
	1994	1997	2005	2015
Constant term	8.91 (84.8)	9.28 (56.1)	6.96 (85.4)	8.73 (273.9)
R-Squared	0.189	0.225	0.114	0.089
Observations	6742	4413	5009	26,221

Note: Critical *t*-values: 1% (2.58); 5% (1.96); 10% (1.645).

3.2. Direct Effect of Predicted Household Income on Health and Nutrition

Tables 2–5 report the impacts of predicted household income on health and nutrition. The impacts are identified by exogenous variation in household income induced by agricultural policies. Changes in landholding and livestock herds are assumed to emanate from such policies.

The first two columns of Table 2 show a positive relationship between predicted household income and indicators of child nutrition. In particular, a percentage increase in household income is associated with a 0.53 increase in standardized weight-for-age, and a nearly 0.4 increase in the height-for-age z-scores. However, the negative effect of income on child mortality is statistically insignificant in contrast to its effect on immunization.

Table 2. Second-stage estimates: direct effects of household income on health and nutrition, 1994 (absolute *t*-statistics in parentheses).

Variables	Nutrition		Health	
	Weight-for-Age z-Scores	Height-for-Age z-Scores	Log Child Deaths (4 Weeks Prior to Survey)	Child Vaccinated? (1 = Yes)
Log of per capita household income	0.531 (4.0)	0.369 (2.43)	−0.018 (0.33)	−0.220 (4.43)
Controls				
Residence (rural = 1)	0.112 (1.89)	−0.046 (0.74)	−0.015 (0.69)	−0.033 (1.80)
Weather shocks (=1)	No	No	No	No
Gender?	Yes	Yes	Yes	Yes
Age?	Yes	Yes	Yes	Yes
Education?	Yes	Yes	Yes	Yes
Constant	−5.218 (4.36)	−3.35 (2.51)	3.04 (2.38)	2.59 (5.80)
<i>F</i> -statistic [<i>p</i> -value]	24.2 [0.000]	7.19 [0.000]	89.2 [0.000]	26.1 [0.000]
Observations	6742	6742	6712	6608

Note: Critical *t*-values: 1% (2.58); 5% (1.96); 10% (1.645).

Table 3 shows a pattern of results similar to those reported in Table 2. However, the coefficient on income is positive for vaccination and statistically significant. One reason for this finding is that the vaccination variable is measured differently. The first dose of a polio vaccine is typically given before a newborn baby leaves a health institution. The coefficient therefore suggests that a large proportion of women from high-income households delivered at health facilities.

Table 3. Second-stage estimates: direct effects of predicted household income on health and nutrition, 1997 (absolute *t*-statistics in parentheses).

Variables	Nutrition		Health	
	Weight-for-Age z-Scores	Height-for-Age z-Scores	Body-Mass-Index z-Score, Children	Polio Vaccination? (1 = Yes)
Log of per capita household income	0.240 (2.38)	0.445 (3.99)	0.069 (0.64)	0.109 (3.03)
Controls				
Residence (Rural = 1)	−0.044 (0.62)	0.116 (1.57)	−0.094 (1.27)	0.042 (1.76)
Weather shocks (=1)	No	No	No	No
Gender?	Yes	Yes	Yes	Yes
Age?	Yes	Yes	Yes	Yes
Education?	Yes	Yes	Yes	Yes
Constant	−2.187 (2.29)	−4.02 (3.81)	−0.666 (0.65)	−0.206 (0.61)
<i>F</i> -statistic [<i>p</i> -value]	17.9 [0.000]	8.72 [0.000]	12.2 [0.000]	23.6 [0.000]
Observations	4413	4413	4413	4746

Note: Critical *t*-values: 1% (2.58); 5% (1.96); 10% (1.645).

Table 4 reports the results from the same analysis for 2005, nearly a decade after the estimates for the 1990s that appear in Tables 2 and 3. Here, the effect of income on child weight is statistically insignificant. On the health side, the coefficient on income for both sickness reporting and immunization is negative and statistically significant. Thus, the association between income and health in 2005 is ambiguous. The column for nutrition shows that income had no effect on child nutrition. Sickness reporting was positively correlated with adverse weather conditions in 2005, and rural residents reported sickness less frequently than urban populations.

Table 4. Second-stage estimates: direct effects of predicted household income on health and nutrition, 2005 (absolute *t*-statistics in parentheses).

Variables	Nutrition		Health	
	Weight-for-Age z-Scores	Height-for-Age z-Scores	Sick 4 Weeks Prior to Interview (1 = Yes)	Child Vaccinated? (1 = Yes)
Log of per capita household income	0.118 (0.06)	5.90 (1.41)	−0.377 (8.27)	−0.259 (2.21)
Controls				
Residence (Rural = 1)	−0.567 (0.59)	1.79 (0.92)	−0.221 (9.25)	−0.168 (2.64)
Weather shocks (=1)	−0.133 (0.58)	0.489 (1.04)	0.057 (7.16)	−0.021 (0.85)
Gender?	Yes	Yes	Yes	Yes
Age?	Yes	Yes	Yes	Yes
Education?	Yes	Yes	Yes	Yes
Constant	−2.49 (0.17)	−44.3 (1.51)	3.03 (9.83)	2.28 (2.86)

Table 4. *Cont.*

Variables	Nutrition		Health	
	Weight-for-Age z-Scores	Height-for-Age z-Scores	Sick 4 Weeks Prior to Interview (1 = Yes)	Child Vaccinated? (1 = Yes)
<i>F</i> -statistic [<i>p</i> -value]	467.1 [0.000]	308 [0.000]	136.2 [0.000]	17.9 [0.000]
Observations	5009	5009	42,839	2411

Note: Critical *t*-values: 1% (2.58); 5% (1.96); 10% (1.645).

Table 5 reports the results for 2015, a decade later. In that year, income is positively associated with child weight, and negatively with sickness reporting (as in 2005), but its correlation with vaccination is insignificant. Adverse weather shocks continue to be positively correlated with sickness reporting. The coefficients on log of income indicate that the income effects (increases in *z*-scores) decline with income, suggesting that children with poor nutrition could also be residing in high-income households.

Table 5. Second-stage estimates: Direct effects of predicted household income on health and nutrition, 2015 (absolute *t*-statistics in parentheses).

Variables	Nutrition		Health	
	Weight-for-Age z-Scores	Height-for-Age z-Scores	Sick 4 Weeks Prior to Survey (1 = yes)	Vaccinated? (1 = yes)
Log of per capita household income	0.378 (2.00)	0.107 (0.37)	−0.065 (3.68)	0.043 (0.75)
Controls				
Residence (Rural = 1)	−0.135 (2.11)	−0.010 (0.11)	−0.014 (2.10)	−0.028 (1.50)
Adverse Weather Shocks? (1 = yes)	−0.027 (0.59)	−0.048 (0.71)	0.059 (12.3)	0.016 (0.94)
Gender?	Yes	Yes	Yes	Yes
Age?	Yes	Yes	Yes	Yes
Education?	Yes	Yes	Yes	Yes
Constant	−2.85 (1.78)	−0.891 (0.36)	1.12 (7.20)	−0.253 (0.52)
<i>F</i> -statistic [<i>p</i> -value]	22.8 [0.000]	24.3 [0.000]	127.3 [0.000]	34.6 [0.000]
Observations	3145	3138	32314	1465

Note: Critical *t*-values: 1% (2.58); 5% (1.96); 10% (1.645).

3.3. Indirect Effects of Agriculture on Health and Nutrition

Table 6 reports the indirect effects of agriculture on health and nutrition. The results are obtained using estimates from the first-stage and second-stage regressions (not from Equation (5), which also yields directly the same estimate for b_1). As already explained, the direct effects of agriculture on health and nutrition are computed using the expression $b_1 = \sigma \times \beta_1$ (see Equations (3) and (4)). The period averages for indirect effects (last row of Table 6) suggest strong positive correlations between the accumulation of agricultural assets and indicators of improvements in health and nutrition over the study period. It

is worth noting that adverse weather shocks increase sickness reporting while growth in household income reduces it.

Table 6. Reduced-form estimates: indirect effects of a percentage increase in household landholding (e.g., due to agricultural policies) on health and nutrition, and approximations from first-stage and second-stage regressions, 1994–2015.

Survey Year	Nutrition			Health	
	Weight-for-Age z-Scores	Height-for-Age z-Scores	Sickness (1 = Sick)	Body Mass Index z-Scores	Vaccination Status (1 = Vaccinated)
1994	0.0192	0.0133	-	0.0179	−0.008
1997	0.0065	0.0120	-	0.0019	0.0029
2005	0.0033	0.0165	−0.0106	-	−0.0073
2015	0.0544	0.0154	−0.0094	-	0.0148
Period means	0.0208	0.0143	−0.0100	0.0198	0.0027
N (various subsamples)	5009–6742	5009–6742	32,314–42,839	5009–6742	1465–26,221

Note: Critical *t*-values: 1% (2.58); 5% (1.96); 10% (1.645).

The indirect effects reported in Table 6 show that increases in farm assets (land and cattle) are negatively correlated with sickness rates. They are computed by multiplying the coefficients of log land (first-stage regression) with the coefficient of the log of household income (second-stage regression). For example, the indirect effect (0.0192) for 1994 in column (1) above is obtained from the calculation (0.036×0.531) , where (.) is taken from the first columns of Tables 1 and 2, respectively. Looking at the period means (Table 6), we see that a percentage increase in household income attributable to agriculture is associated with a 1% reduction in sickness reporting. Similarly, a 1% increase in income is associated with a 0.0208 improvement in weight-for-age z-scores, roughly a 0.021 increase in standard deviation above the average for normalized weights. Other period means can be given similar interpretations.

3.4. The Link Between Direct and Indirect Effects

Table 7 presents period averages (1994–2015) of the direct effects. The direct effects, β_1 s, are derived from Tables 2–5. Notice that the b_1 s (indirect effects of agriculture in Table 6) and the β_1 s (the direct effects of household income), which represent level changes in health and nutrition, are expressed in the same units, and are assumed to be emanating from agricultural policies that increase households' land acreage and therefore income.

Table 7. Period averages for direct effects of income on nutrition and health, 1994–2015 (effects are in natural units for a percentage increase in household income).

Nutrition and Health Indicators, Period Means	Period Means (Annual Changes)
Weight-for-age z-score	0.3168
Height-for-age z-score	1.705
Proportion of population reporting sickness or injury	−0.111
Proportion of immunized children	−0.0818

Table 7 presents averages of the direct effects for four measures of human capital. The direct effect of income on nutrition occurs when there is no intermediation between income

and nutrition before the income effect is felt by household members. Any effects measured prior to the causal link between income and nutrition are indirect. For example, an effect is indirect if it is measured (using a known value for β_1) at the point where an increase in acreage raises income (Equation (3)).

Table 7 shows that a percentage increase in household income increases the z-score for children's weight directly by 0.3168. Remarkably, the indirect effect of a 1% increase in land acreage that raises household income by 1% has the same size effect, 0.3168, i.e., (1×0.3168) , as $(b_1 = \sigma \times \beta_1)$ where σ (expressed in %) = 1. More generally, the indirect effect on health or nutrition per unit of household income exogenously induced by agricultural policy is b_1/σ , the magnitude of which depends on the value of sigma (σ), where sigma is driven by farm level efficiency. The indirect effects for all units of income induced by policy is b_1 , which depends on the magnitude of the direct effect, β_1 , which is determined by the efficiency in human capital production within the household. The land effect on human capital (Equation (5)) is indirect because the income change, σ (in Equation (3)), induced by land policy requires a household's intervention to influence nutrition. Notice that consumption at the individual level is the channel through which household income affects health or nutrition directly. Therefore, a causal effect is direct or indirect depending on the point on the causation chain where that effect is measured. The direct effect is on the last node of a finite causal chain, whereas an indirect effect is on an earlier point, but its magnitude is computed using a direct effect value, e.g., β_1 in this case. A causal effect is of course undefined in an infinite causation process. In our analysis, the first cause that induces direct and indirect correlations between agriculture and human capital formation over a defined time period is an agricultural policy implemented by the government in a previous period. There is need to mention that the discussion of the precise link between direct and indirect relationships between human capital formation and agriculture is based on the assumption that the estimated structural model is exactly identified using household landholding. Assuming that the foregoing assumption does not hold, the results from structural models (Tables 2–5) should be interpreted as associations rather than as causal effects.

4. Discussion

The results of this study support the hypothesis that there is a significant effect of agricultural assets amenable to agricultural policy, and that these affect the health and nutritional status of individuals in the household directly and indirectly.

The related literature (see reviews by [Ruel et al., 2018](#), and [Sharma et al., 2021](#)) finds that the empirical evidence on the contribution of agriculture to nutrition is not strong. Moreover, the focus has mainly been on the effect of agriculture on measures of nutrition such as dietary diversity and consumption of specific crop and animal products. In contrast, our study looks at the effects of agriculture on anthropometric nutrition indicators and on health status indicators. We show that public policies on some facets of agriculture, such as landholding and livestock ownership, can translate into better health and nutrition outcomes.

The results from the overall analysis suggest that the implementation of policies to increase farm productivity would significantly improve health and nutrition. However, interpretation of the evidence outside the Kenyan context should be undertaken with care. Agricultural policies that are potentially beneficial to human capital formation include adoption of high-yielding seeds, implementation of agricultural input subsidies, and introduction of land tenure systems that encourage expansion of cultivable and grazing land.

However, it must be noted that it is the household decision to allocate income on healthcare and nutrients that enables agricultural policies to improve health and nutrition, the dimensions of human capital that are of policy interest in this paper. Therefore, the

efficient and equitable allocation of income within the household is important for human capital development. For example, in Kenya, woman empowerment in Northern Kenya has been shown to be positively correlated with nutritional outcomes. Empowering women economically can help address inequality in the distribution of health and nutritional inputs within the household (Lentz et al., 2025). In Ghana, internal migration worsens food insecurity for children left behind; targeted income transfers can help address this problem (Gosselin-Pali, 2025).

5. Conclusions

In this paper, we measured direct and indirect associations between agriculture and human capital accumulation, with a focus on health and nutrition using data from Kenyan household surveys. The findings show that agriculture contributes significantly to better health and nutrition. The increase in household income attributable to agriculture is associated with large improvements in two dimensions of human capital, namely, health and nutrition. Our study has addressed a lacuna identified by the [Global Panel on Agriculture and Food Systems for Nutrition \(2014\)](#) by clarifying the mechanisms through which transformation of agriculture can affect health and nutrition at the household level. The study points to investment routes for transforming agriculture in ways that could boost economic growth and human capital in Africa.

The paper has presented methods and concepts for measuring and interpreting direct and indirect correlations between agriculture, health, and nutrition in Kenya over the period 1994–2015. Future studies could refine the general approach employed here to estimate effects of agricultural policies on health and nutrition in other African countries, especially where panel or experimental datasets exist.

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