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ORIGINAL PAPER

Urbanization, market development and malnutrition in farm households: evidence from the Demographic and Health Surveys, 1986–2011

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Abstract A principal effect of agricultural productivity growth is to accelerate urbanization by supplying food, labor and other resources to urban services and industry. Towns and cities may also grow for their own reasons, pulling food and resources out of rural areas. Whether pushed or pulled, the development of markets creates new opportunities for agricultural households. This study tests whether, on balance, proximity to older towns and cities has improved or worsened malnutrition among farm households in 43,850 survey clusters in 46 developing countries between 1986 and 2011, using 83 Demographic and Health Surveys (DHS) combined with other geographic and historical data. Controlling for national income, we find that regions with a longer history of urbanization have children with higher weight-for-height and height-for-age z-scores at a wide range of national income levels. We also find a higher prevalence of overweight among mothers living near older cities. These results suggest that, on average, access to urban markets has reduced rural child stunting and wasting in the surveyed countries, but also increased the risks of overweight for children and adult women. These results motivate the need to guide agricultural market development in ways that promote improved nutrition while limiting the rise of diet-related disease.

Keywords Structural transformation · Nutrition transition · Agriculture · Double burden · Commercialization

Special section series Strengthening the links between nutrition and health outcomes and agricultural research.

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Introduction and motivation

This paper is concerned with the market linkages between urbanization and rural farm households. Many studies have investigated nutritional, health, and socioeconomic differences between urban and rural residents, as well as changes in these populations over time. Here, we merge spatial data on urbanization with household survey data on nutritional outcomes to test whether the past and ongoing development of nearby urban markets has been associated with better or worse nutritional status among those remaining in agriculture.

Our goal is to help inform agricultural production, agricultural research, and market development: if nearby urbanization is generally associated with improved nutrition, then policies and programs that strengthen farmers' access to nearby towns and cities are likely to be helpful. If nearby urbanization is also associated with increased risk of overweight or diet related disease, this would indicate that there is an opportunity to limit harms by improving access to beneficial agriculture and nutrition linkages. Either way, understanding how rural health outcomes are affected by the development of nearby towns and cities will reveal the influence of off-farm factors on rural nutrition, which could be leveraged to improve those outcomes in the future.

There is abundant evidence that living in an urban area is attractive for those who migrate, driving the historical movement of rural people into towns and cities around the world towards new employment opportunities. However, there is

also growing evidence that living in an urban area can be detrimental to health and nutrition, for example, due to sanitation challenges or higher population density facilitating the transmission of disease. Thus, the overall health effects of living in urban areas are yet unclear. These effects likely depend on the specific health or nutrition outcome in question, as well as on many individual-level factors such as household wealth, immune function, occupation, and other risk factors.

Urbanization's influence is also unclear for those who remain living in nearby rural areas, working in agriculture. These effects are important to consider because, in many areas, rural population density is still increasing and extreme rural poverty persists. Once urbanization begins to occur, rural population growth – and the accompanying reduction in land per farm worker – persists until cities are large enough for their annual growth to absorb all of each year's increase in total population (Masters et al. 2013; Jedwab et al. 2014). This study is concerned with what is happening to rural nutrition and health as urbanization progresses nearby, and estimates the associations for a large sample of children and their mothers.

Factors which could modify the relationships between markets and malnutrition

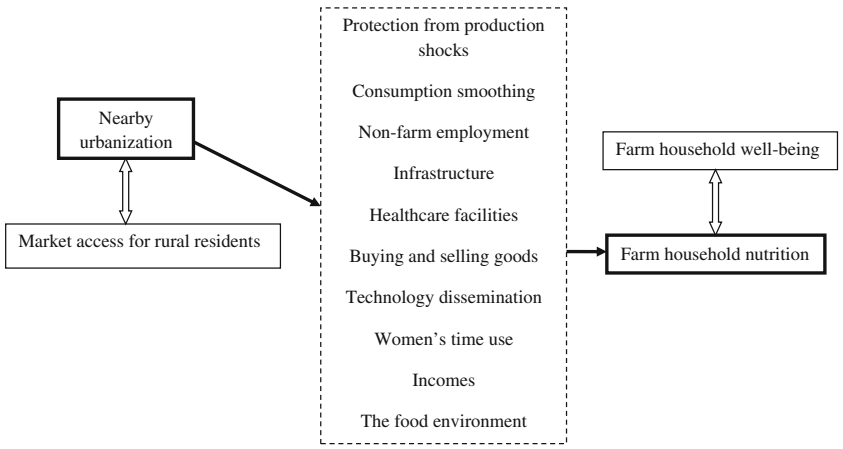
The conceptual framework in Chart 1 illustrates our goals for this study. Here, we examine the global associations between the bolded boxes: urbanization and farm household nutrition. The diagram emphasizes that nearby urbanization could have a wide range of effects on rural farm households. In this study our goal is just to establish the average relationship, if any. If the relationship is significant, future studies could address possible mechanisms, for example to distinguish the role of access to food markets from other factors. For now, we focus on the net association between the two, and as any effect is likely to be felt gradually over time, our explanatory variable is the number of years (in duration before the year 2000) that a given survey cluster had at least 10 % of nearby residents living in urban areas.

As shown in the diagram, there are many factors which could influence the observed relationships between urbanization and rural malnutrition. This paper will first review the economic theory behind why markets have the potential to improve farm household well-being in the short- and long-term. The theory we discuss in this section could encompass many of the modifiers and causal mechanisms outlined in the diagram. Next, we will briefly review the literature on selected key factors shown in the diagram, including how urbanization may affect overall farm household well-being, which is highly linked with farm household nutrition. Then, our main goal is to examine the associations between market access for rural residents and rural household nutritional status, while controlling for national incomes. If there is a significant association, deeper investigation into causal mechanisms and effect modifiers would be warranted. For an in-depth look at some of the food environment factors which could drive the associations between urbanization and nutrition, see Herforth and Ahmed in this special section of the journal (Herforth and Ahmed 2015). Lastly, we conclude with policy implications and suggest directions for further investigation of the relationships found.

How could markets improve farm household well-being?

Market access has the potential to improve farm household well-being in the short term through facilitating the exchange of goods, and in the long term through facilitating the dissemination of productivity gains. In the short-term, buying and selling goods or services could allow farm household members to overcome decreasing returns to additional input use on their own farms, and also help them to diversify and smooth consumption relative to what they can produce on the farm. Opportunities for diversification of income, assets, and activities may become increasingly available with market

Chart. 1 Conceptual framework



development, and allow for risk reduction among farm families (Barrett et al. 2001). Public services may also become increasingly available. Reducing risk and smoothing consumption are key factors which can protect child nutrition, as well as overall farm household well-being (Alderman et al. 2006; Foster 1995; Jensen 2000; Hoddinott and Kinsey 2001; Morduch 1995). Over time, access to increasingly mature urban markets may facilitate the farm household's adoption of new technologies which can further improve their productivity. Productivity gains are a core goal of agricultural research and development activities, but dissemination of those gains requires that households can find out about, learn how to use, purchase complementary goods for, and troubleshoot the new technologies.

Purpose of the study

This study estimates the magnitude of association between market development and farm household health, and the extent of variation around those central tendencies. Our goal is to capture the effects of nearby urbanization on those who remain in rural areas and working in agricultural occupations. Our units of analysis are individual children and their mothers, as well as survey cluster-level aggregates of malnutrition indicators. The survey cluster locations vary widely in the institutions and infrastructure that give rise to urbanization and shape the development of markets, providing a rich dataset to analyze.

We focus on just the most visible aspects of malnutrition, namely the heights and weights of children and their mothers. We also focus on just the most visible aspect of rural markets, namely the growth of nearby towns and cities. This study offers one initial perspective on the links between agricultural markets and health, by testing the associations between farm households' current nutritional status and their region's past urbanization, while controlling for national income. This study contributes to the rich and growing body of literature on agriculture-nutrition linkages, offering an analysis of a large new database and a new perspective on the determinants of maternal and child nutrition in rural farm households.

Terms and definitions

We use the term 'malnutrition' to encompass both undernutrition (measured by child height-for-age and stunting prevalence, as well as weight-for-height and wasting prevalence) and overconsumption (measured by the prevalence of overweight for children and for adult women). Including problems on both ends of the dietary spectrum recognizes the global double burden of insufficiencies alongside excesses, as the consequences of nutritional shortfalls such as stunting are observed together with the consequences of too much intake, such as obesity (Popkin 2001). The double burden is becoming more evident over time, and may appear within a given region, a particular household, or even a specific individual (FAO and WFP 2014; Lee et al. 2012). The phenomenon is closely linked with the nutrition transition from lower to higher cost diets, which may close some nutritional deficits while overshooting on total calories and other dietary risk factors for chronic disease (Popkin et al. 2012).

An examination of both over- and under-nutrition is necessary for our purposes due to the growing double burden of malnutrition in low and middle-income countries, where the prevalence of obesity and metabolic syndrome is increasing (Misra and Khurana 2008). While childhood underweight is still the leading contributor to global disability-adjusted life years (DALYs) and the vast majority of that occurs in low-income countries, total deaths worldwide attributed to high blood pressure, high blood glucose, and physical inactivity are relatively evenly divided between low-, middle-, and high-income countries (WHO 2009). There may also be significant understanding to be gained by conceptualizing changes in all types of malnutrition as stemming from the same root causes associated with economic growth and market development.

Literature review

Urbanization and urban health

There has been remarkably fast and extensive urbanization in low- and middle-income countries in recent decades, and urban areas are growing faster in low-income countries today than they did in now high-income countries during the 19th century (Jedwab et al. 2014). Numerous epidemiological studies have demonstrated that people living in urban areas are often healthier than people living in rural areas, but that may be because they have higher incomes and better access to a wide range of goods and services. There are a few examples of studies which specifically take advantage of the rich global DHS data to examine health differences between urban and rural women and children at comparable levels of income. One study utilizing the DHS surveys of 47 countries investigated the disparities and found that rural children have systematically worse health indicators than urban children, including for stunting and mortality risk, but that poor urban children are worse off than rural children (Van de Poel et al. 2007). Another study using DHS data from 36 countries addresses the potential mechanisms, namely, caring practices, through which living in an urban area can reduce the risk of malnutrition (Smith et al. 2005). The determinants of nutrition in urban areas may differ from those in rural areas in terms of their importance and associations

with other factors (Smith et al. 2005; Ruel 2000). For example, urban households do not necessarily rely as heavily on uncertain natural resources and phenomena for their livelihoods as rural farmers do. Urban areas may also provide more employment opportunities for men and women, including opportunities in food service and retail (Neven et al. 2009).

Potential drawbacks of urbanization for urban residents

Urban residence may have adverse consequences for population health when controlling for real income, as evidenced by lower child weight-for-height and higher child mortality in many urban areas compared with rural areas, especially for the urban poor and those living in urban slums (Smith et al. 2005; Ruel 2001; Haddad et al. 1999; Garenne 2010). Over time, rapid in-migration has led to increasing rates of poverty, food insecurity, and malnutrition in some urban areas (Haddad et al. 1999; Crush et al. 2012). It's possible that sanitation emerges as a problem with the increased population density which accompanies urbanization, increasing the risk of child malnutrition and exposure to diseases which thrive with poor sanitation (Spears 2013), most notably in the largest and fastest-growing slums (Kimani-Murage et al. 2014). Urban areas may also have particularly high rates of double-burden coexistence of stunting and child overweight (Groeneveld et al. 2007). Some studies have found that there are significant inequalities among the health and nutritional status of urban women and children, suggesting that urban averages hide extremes (Matthews et al. 2010; Menon et al. 2000). In this study, we isolate the role of urbanization on maternal and child health by looking outside the city, at how it affects rural neighbors at each level of income.

Urbanization and rural health

This paper focuses on the most visible aspect of market development: the growth of towns and cities. Urban areas provide public services which can directly and indirectly affect rural nutrition, such as health facilities, and also markets for private trade in goods and services through which rural farm households can improve their living standards. Virtually every dimension of rural life is potentially affected by the presence of urban neighbors, from farmers' employment opportunities to the availability of all kinds of goods and services, including healthcare (Liu et al. 2003), all of which can help offer an escape path from being trapped in purely subsistence agriculture (Gollin 2010).

One major indirect pathway through which urbanization could improve nutrition is through income growth. Income growth in turn can improve the proximal determinants of nutrition status: food intake, health status, sanitation, and caring practices. The services available in urban areas can also directly affect the proximal determinants of nutrition, such as by providing treatment for a child with diarrhea, or pre-natal care for a pregnant woman. A substantial body of literature has demonstrated that proximity to urban areas can increase farmer incomes. A study in Kenya showed that farmers who live closer to urban areas sell a larger proportion of their harvest than those who live farther from urban areas (Omiti et al. 2009). Other studies of Kenyan farmers showed that participation in formal markets was associated with improved household food security and incomes (Kirimi et al. 2013: Rao and Qaim 2011). Several studies have demonstrated that smallholder farmers who make steps towards market participation have higher incomes as a result (von Braun 1995: Bouis and Haddad 1990).

A few key studies have investigated the linkages between access to services and infant or child mortality. One earlier study which helps motivate the present paper found that the main observable factors associated with infant mortality were community-level infrastructure and access to health facilities (Van de Poel et al. 2009). Another study of healthcare access in Burkina Faso demonstrated the importance of living close to a health facility, as child mortality was 50 % higher for those households which did not have access to health facilities (Schoeps et al. 2011). Another important study investigated the differences in child mortality rates based on their mother's migration status, finding that actual type of place of residence – urban or rural – has less of an influence on child mortality when controlling for observable factors, whereas access to services seems to be the key determinant instead (Bocquier et al. 2011). A key study of the expansion of transportation infrastructure in India demonstrated the importance of access to markets and trade for reducing mortality (Burgess and Donaldson 2010).

Turning to nutrition outcomes, a working paper by Darrouzet-Nardi et al. (2014) in the Democratic Republic of the Congo found that the heights of children living in households located closer to major towns were protected from the adverse consequences of being born during the less healthy season, highlighting the potential role of access to urban goods and services. In a study of child nutrition in Malawi, children in households which participated in markets for cash crops such as tobacco had better heights and weights (Howard et al. 2011). Supermarkets, which are spatially associated with urban areas, may provide new opportunities and risks for nutrition. For example, evidence from Kenya suggests that supermarkets can improve farm household nutrition outcomes (Qaim et al. 2014). Turning to dietary outcomes, access costs and infrastructure were another key factor determining dietary diversity in urban and rural China (Liu et al. 2013). Production diversity by rural farm households in Bolivia is positively associated with an index of child feeding quality, and the strength of this association increases with the altitude of farm

household location, again suggesting the importance of access to markets, as higher elevations are likely to be more isolated (Jones 2014).

Potential drawbacks of urbanization for rural residents

The evidence described above about the beneficial effects of market access on farm household well-being is substantial. However, access to markets doesn't necessarily offer clear-cut gains to farm households, just as living in an urban area doesn't offer clear-cut benefits for urban residents. Opportunities to work in non-farm activities will leave more land and other natural resources available per farmer, but could also alter the composition of farm labor – perhaps imposing additional tasks on women and children, which could harm their nutritional status. Similarly, opportunities to buy and sell agricultural products could raise farm incomes, but also change relative prices – perhaps making nutritious foods even less accessible for the poorest farm households. On average, the presence of a nearby town may improve farm household nutrition through increases in income and employment opportunities. Despite the potential benefits of urbanization, an explicit focus on *agricultural* development may be necessary to achieve poverty reduction (Dorosh and Thurlow 2014). And at a given national income level, nearby urbanization could lead to better rural nutrition through improved access to a wider range of goods and services, including public services such as health care and nutrient-dense foods such as fruits, vegetables and animal products. But market access and commercialization may also bring more caloric, less nutrient-dense foods more readily accessible without facilitating the exchange of goods produced by rural farm households (Gómez and Ricketts 2013). The study by Qaim et al. (2014), mentioned above, also finds that supermarkets may increase the prevalence of overweight for urban children. Thus, there is evidence that urbanization can have beneficial and deleterious health effects for urban residents and rural residents, for a mixed overall effect on nutrition. Our goal in this paper is to uncover its average impact on those who remain on farms in nearby rural areas.

Methods

Database construction and cleaning

The data are individual observations of women and children from 83 Demographic and Health Surveys (DHS) across 43,850 survey clusters in 46 countries conducted between 1986 and 2011 (ICF International 2014), merged with historical data on each survey cluster's nearby historical urbanization rates (Motamed et al. 2014) and the country's per-capita national income at the time of the DHS survey (Heston et al. 2012). Merging the individual-level survey data with cluster-level urbanization data permits us to address variation within each country's rural population's access to urban markets, while controlling for the overall level of socioeconomic development. Due to differences in the number of survey clusters per country, as well as the country sizes and number of available surveys per country, a majority (74%) of the observations are in Africa, while 9.5% are in the Americas, and 16.5% are in Asia. The sample is not globally representative, as country inclusion depended on the availability of spatially geocoded DHS survey clusters, but it is representative at the national level.

In each country, the DHS are nationally representative surveys of households with at least one woman of childbearing age, typically defined as between 15 and 49 years old. As the DHS has consistent survey methodology across and within countries, one can think of the DHS as offering repeated cross-sections of all 46 countries at semi-regular intervals. We begin with N=657,138 births of children in the underlying collection of DHS data, which consists of 83 surveys, geocoded by cluster, appended together using Stata M/P (StataCorp 2012). There were N=604,549 children alive at the time of each survey (92%). Observations flagged by DHS as incorrect were omitted, typically due to biologically implausible Z scores greater than 6 or less than −5 for either children's height-for-age (HAZ, N=36,883 observations omitted), children's weight-for-age (WAZ, N=32,503 observations omitted), children's weight-for-height (WHZ, N=32,117 observations omitted). Of the children who were alive at the time of the survey, N=407,419 of them have measured heights and weights within plausible ranges, and approximately N=164,799 of the children with plausible height and weight measurements lived in rural households with at least one parent engaged in agricultural activities. Observations of mother's height and weight were omitted if her calculated body mass index (kg/m^2) was greater than 40 (N=8947 observations omitted) or less than 15 (N=1050 observations omitted). We have two main sub-samples of interest: children with biologically plausible height and weight measurements living in rural areas with at least one parent engaged in agricultural activities, and mothers with biologically plausible height and weight measurements who were engaged in agricultural activities.

The births data are geocoded by clusters, of which there are 43,850 across the 83 DHS surveys included. In order to merge the DHS data with urbanization and national income data, we spatially joined the DHS survey clusters with grid-cell measurement of geographic and urbanization variables using ArcGIS 10.2 (ESRI 2011). The underlying geographic and urbanization data are a 0.5 degree by 0.5 degree global grid from Motamed et al. (2014), a study of how each location's agroecological conditions and access to transportation influenced their timing of urbanization, as measured using

historical data on rural and urban population densities from Klein-Goldewijk et al. (2010). Here, we use those same data to provide a historical measure of market development, defined as the duration in years before 2000 that each grid-cell containing each DHS survey cluster reached 10 % of its population living in towns and cities. We log-transform this variable using the natural logarithm function in order to obtain a less-skewed distribution. Urbanization in this sense began at different times and increased at different rates, but is almost never reversed. As a result, the number of years since a region became 10 % urbanized provides a simple, internationally comparable measure of a region's market development. Each measurement of the urbanization variable may correspond to multiple cities within a grid-cell, and are not weighted by overall population within the grid-cell (Motamed et al. 2014). Despite this potential complication, we expect that the indicator will provide a useful proxy of whether farmers in each survey cluster have had access to urban goods and services earlier or later, especially given the relatively fine spatial resolution of the cluster-level observations.

After spatially joining the DHS clusters with the Motamed et al. (2014) global grid, we merged the resulting database with the Penn World Tables 7.1 (PWT), and dropped the observations which didn't correspond to any of the included DHS countries and survey years (Heston et al. 2012). Using the PWT allows us to incorporate internationally comparable measures of real Gross Domestic Product, national-level population, and other macroeconomic factors of interest. After merging the DHS and urbanization data with the PWT, we constructed an aggregated nutrition indicator database containing the prevalences of stunting, wasting, child overweight, and maternal overweight by DHS survey cluster, household location (urban/rural) and occupation (agricultural/nonagricultural), weighted by the inverse sampling probability provided by the DHS surveys. We used these population-level indicators to complement the individual-level height and weight data. With the inclusion of the PWT data, the collection of individual DHS surveys was transformed into a repeat-cross sectional database on geography, urbanization, national incomes, and nutrition with global coverage.

Analysis

To explore the relationships between urbanization and rural household nutrition in a visually informative manner, we use non-parametric regressions to draw means and confidence intervals for each nutritional outcome as a continuous smoothed function of urbanization and national income. This approach is adapted to relationships whose functional form is unknown, as each mean and confidence interval uses only observations in the immediate neighborhood of that value of the explanatory variable, which in this case is the country's income level at the time of the survey (measured as the natural logarithm of its gross national product per capita, in purchasing power parity terms). The outcome variables on the y-axis are the child height-for-age Z-scores, child weight-for-height Z-scores, the prevalence of stunting by survey cluster, the prevalence of wasting by survey cluster, and the prevalences of child and maternal overweight by survey cluster.

To test the association between nutritional outcomes and historical urbanization at each level of national income, we constructed a binary indicator for early urbanization and market development, equal to one for sub-national regions that had reached 10 % urbanization before 1980, and the remainder that reached the threshold later (or that hadn't reached the threshold by the year 2000). These thresholds were chosen to divide the sample into two equal halves, so as to compare the mean nutritional outcomes for the higher and lower levels of market development (urbanization) at each level of national income. To compare outcomes across national incomes and different levels of urbanization, we used Epanechnikov kernel-weighted local polynomial smoothing of degree zero, with 95% confidence intervals, and bandwidths ranging between 0.75 and 1. The resulting non-parametric regressions are useful as a diagnostic for further analysis using parametric methods, and are also useful in themselves for visual clues about structural patterns.

Results

Table 1 presents summary statistics of key variables, split into type of place of residence and occupation groups. The DHS categorizes survey clusters as urban or rural based on population. Large cities, small cities with population over 50,000, and towns are designated as urban areas, and survey clusters located in the countryside are designated as rural areas (ICF International 2014). Two-thirds of children in the sample live in a rural survey cluster, and approximately half children in the original sample come from agricultural households. Children living in rural farm households have the lowest mean height and weight Z-scores of the four groupings. We confirmed these patterns using paired t-tests for equality of means across household locations, to establish that rural farm households indeed have the worst nutrition indicators for children (results not shown). Mean maternal BMI is systematically lower in farm households, and especially in rural farm households. The highest stunting and wasting prevalence can also be found among rural farm households, and the highest maternal overweight prevalence can be found in urban clusters. This brief summary motivates the attention paid to the well-being of rural farm households as a group due to the relative severity of the malnutrition situation in those areas, and also motivates the stratification into groups by location and occupation for clarity of analysis.

Table 1 Summary statistics

Location: Occupation	Rural Ag *N*=280, 292 children	Rural NonAg *N*= 153,547 children	Urban *N*=223, 299 children	All Observations *N*=657, 138 children
Nutrition status outcomes				
HAZ	−1.52 (*1.51*)	−1.17 (*1.51*)	−0.89 (*1.47*)	−1.21 (*1.52*)
WHZ	−0.37 (*1.24*)	−0.25 (*1.30*)	−0.13 (*1.27*)	−0.25 (*1.27*)
Mother's BMI (kg/m^2)	21.81 (*3.28*)	23.15 (*4.30*)	24.48 (*4.68*)	22.95 (*4.17*)
Stunting (%)	34.5%	28.0%	18.6%	26.75%
Wasting (%)	7.3%	6.8%	5.1%	6.37%
Child overweight (%)	0.12%	0.12%	0.17%	0.14%
Mother overweight (%)	1.2%	1.6%	2.4%	1.7%
Urbanization and national accounts				
GDP per capita ($2005 PPP)	$1614.0 (*1449.1*)	$2454.5 (*2510.3*)	$1911 (*1776.1*)	$2131.9 (*2078.5*)
Years since urbanization at 10% level (years)	45.62 (*82.68*)	63.83 (*92.57*)	75.96 (*106.09*)	60.2 (*94.45*)

The summary statistics for urbanization timing are presented in the last section of Table 1. As would be expected, grid-cells that urbanized earlier are more likely to have urban survey clusters. We confirmed this pattern using t-tests for equality of means as well (results not shown), and further investigated the distribution of urbanization timing with histograms as in Fig. 1, which is drawn by omitting the survey clusters that were located in grid-cells that had not yet reach 10 % urbanization by the year 2000. We can investigate this key urbanization variable further by looking at a histogram of its distribution. At the time of measurement, 38.47 % of children were living in clusters where the 10 % urbanization threshold still had not been reached by the year 2000. The earliest year of at least 10 % urbanization for half of all children in the sample was 1980, and Fig. 1 shows that there is great variation in exposure to towns and cities around that median.

Figures 2, 3, 4 and 5 provide the principal hypothesis tests, comparing height-for-age (and stunting prevalence) and weight-for-height (and wasting prevalence) of children in rural farm households in regions with earlier urbanization, with children in rural farm households in regions with later urbanization, at each level of national per-capita income. The only observations included in these nonparametric charts are the rural farm households, as this is our main population of interest. The solid lines represent children who live in areas where urbanization started later, and the dashed lines represent children who live in areas where urbanization started earlier, and hence had a longer duration of exposure to its effects.

From Fig. 2, with HAZ scores on the y-axis, one can see that the earlier urbanized regions' head start on market development is associated with significantly taller rural farm children at the whole range of national income levels shown on

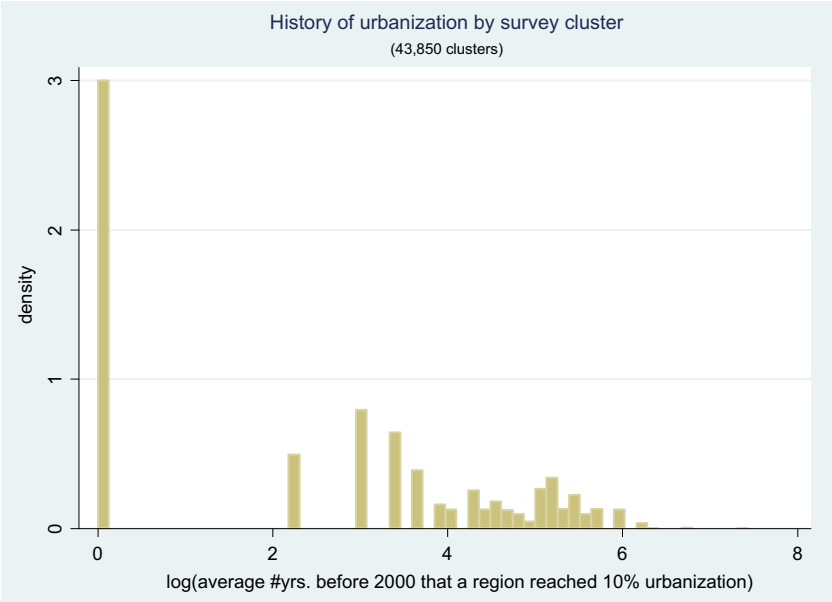


Fig. 1 Timing of urbanization histogram

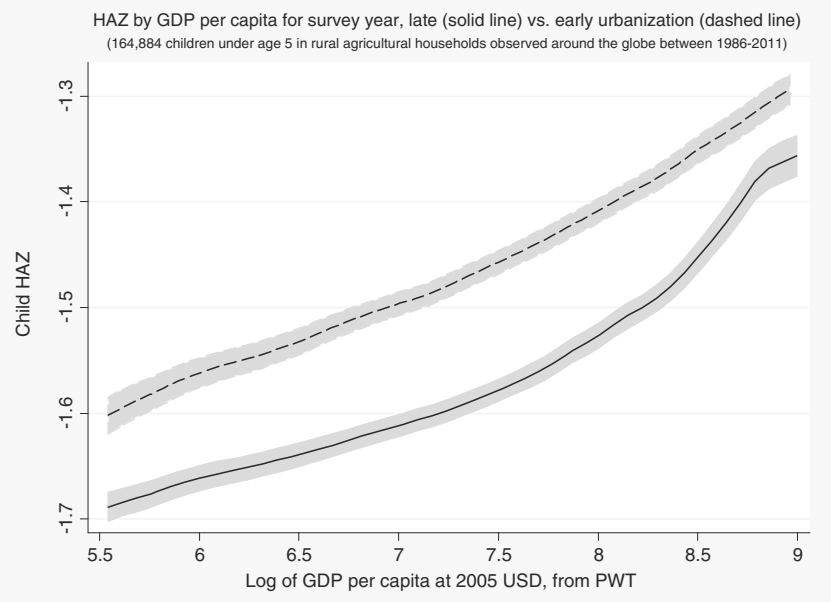


Fig. 2 Height-for-age Z-scores by gross national income for survey year and urbanization

the graph, which range from about $244 ($2005 PPP per capita) to $8103 ($2005 PPP per capita). The relationship between national incomes and child heights is even slightly convex for those survey clusters which experienced later urbanization. The relationship is flatter and more linear for the clusters where urbanization has been taking place for longer relative periods of time. This chart indicates that nearby urbanization may protect children's heights in rural farm households. A similar pattern can also be seen at the cluster-level displayed in Fig. 3. In Fig. 3, the prevalence of stunting among rural farm children declines with national income, as expected. However, clusters which urbanized earlier have systematically lower prevalences of stunting across the spectrum of national incomes.

From Fig. 4, with WHZ scores on the y-axis, one can see that the mean weight-for-height of farm children in regions that urbanized earlier is healthier for a wide range of national income levels, between about $665 and $5000 per capita. Rural children living in areas which urbanized later are lagging behind in terms of their heights and weights. At very low levels of national income, for example less than about $665 ($2005 PPP per capita) per year, child weights are similar regardless of historical urbanization at the cluster level. Only when national incomes start to grow do the spatial disparities appear. This chart indicates that nearby urbanization may protect child weights, especially as national incomes grow from the lowest levels. This pattern can also be seen in Fig. 5 at the cluster-level for the prevalence of wasting among rural farm

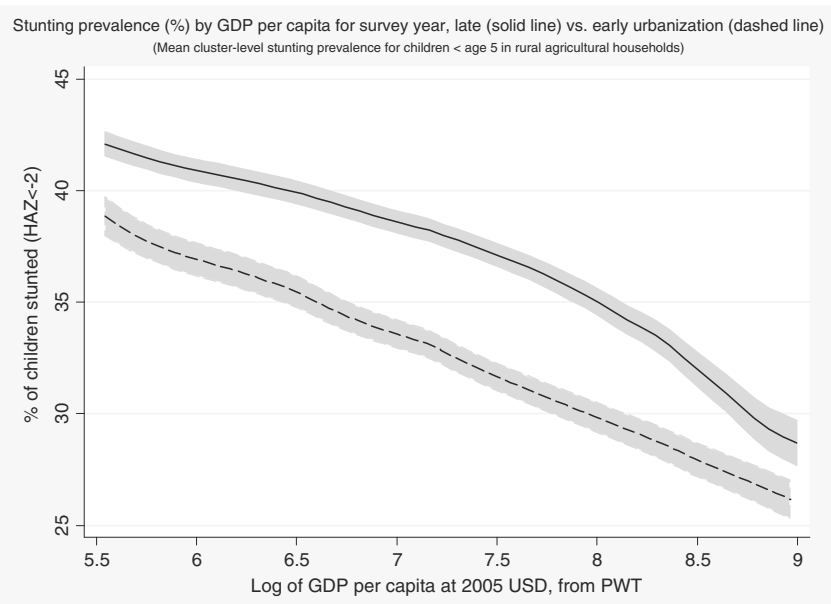


Fig. 3 Prevalence of stunting by GDP per capita and urbanization history

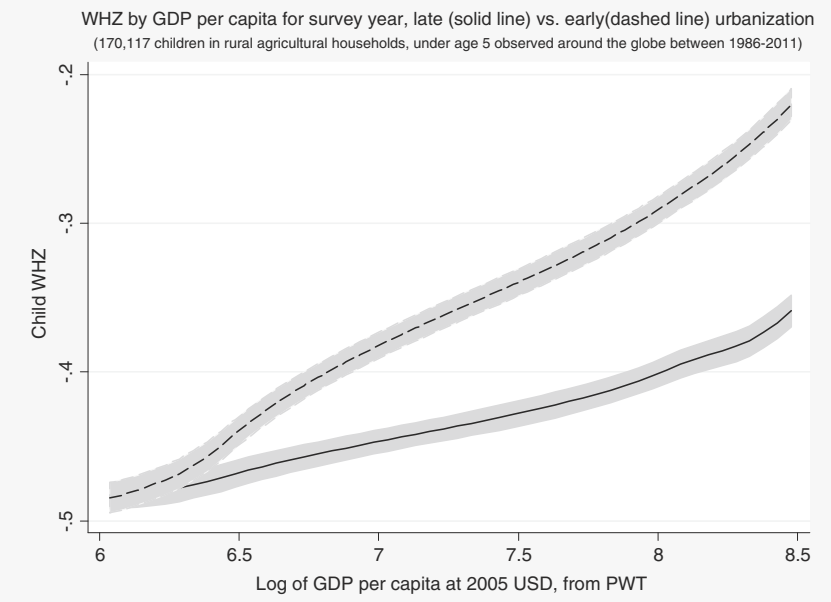


Fig. 4 Weight-for-height Z-scores by GDP per capita and nearby urbanization

children. The prevalence of wasting among rural farm children declines with national incomes, as would be expected. When national incomes are very low, the prevalence of wasting is similar across different levels of urbanization, similar to the pattern seen for mean WHZ scores. As national incomes grow, a divergence emerges between the prevalence of wasting in earlier and later urbanized areas, where children living in clusters which urbanized earlier appear protected.

Figure 6 shows that the prevalence of child overweight increases with national incomes, as expected, and that this relationship holds even for rural farm children. Overall, the prevalence of child overweight in rural farm households is very low compared with other populations, but these patterns suggest the emergence of an important phenomenon: the influence of nearby markets. This finding suggests that the growing double burden of malnutrition phenomena is not limited to urban areas or middle-income countries, and that even children whose families remain in agriculture are affected by nearby market development. Investigating the nature of the dietary changes that lead to increased overweight prevalence among children in rural farm households could shed light on the causal pathways.

Figure 7 shows the effects of urbanization on mother's risk of overweight. For mothers in areas which urbanized earlier, there is a positive association between national incomes and the risk of overweight. The relationship is concave for survey clusters which urbanized earlier, and convex for survey

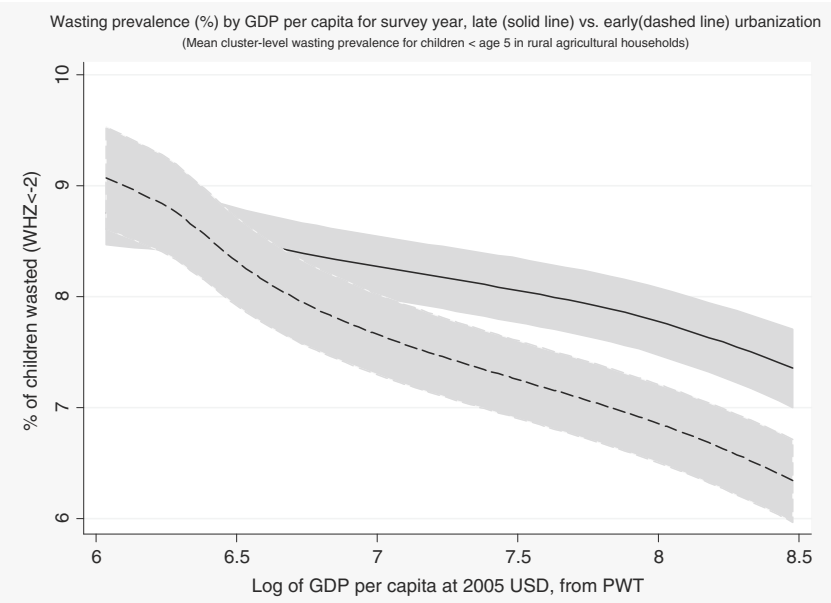


Fig. 5 Prevalence of wasting by GDP per capita and urbanization history

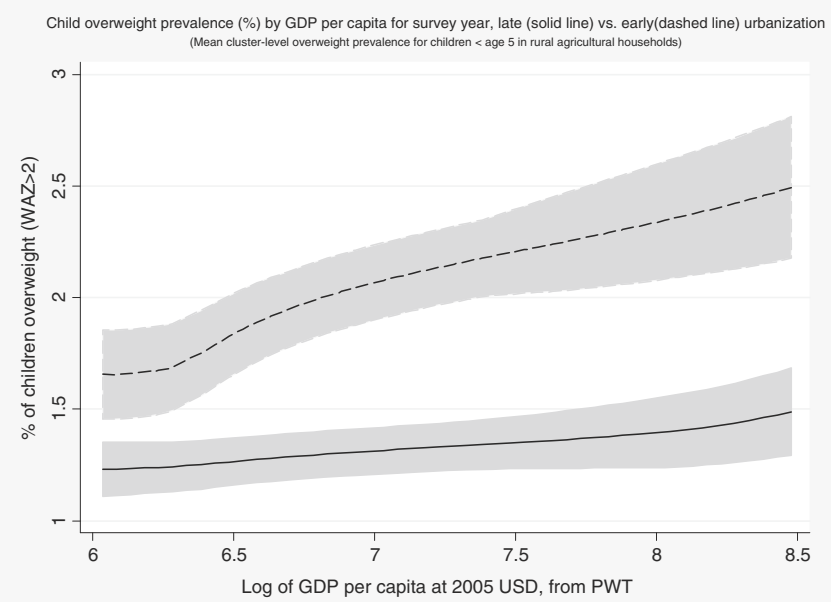


Fig. 6 Child overweight prevalence by GDP per capita and urbanization history

clusters which urbanized later. The slopes across both urbanization groups are similar, except that the prevalence of maternal overweight is systematically lower for those in clusters which urbanized later. For a given level of national income per capita, mothers in rural farm households living in areas which urbanized earlier have higher risk of overweight than mothers in areas which urbanized later. This finding is distinct in that it examines the effects of nearby urbanization on rural agricultural women as opposed to the effects on weight or health of actually living in a rural or urban area. Maternal overweight prevalence appears to be increasing at a greater rate than national incomes in those survey clusters which urbanized later, providing evidence for another dimension of the double burden of malnutrition.

Study limitations

This study has several limitations. First, the frequency and density of DHS surveys is higher in Africa than in other regions, and our method controls for national income but not individual household expenditure or wealth. These constraints reflect the limitations of the available data, and could be remedied only to the extent that international agencies choose to invest in more globally-representative surveys that measure household income, household agricultural production, and nutritional status. Second, we estimate only the association between farm household malnutrition and nearby urbanization. Having found evidence for both beneficial effects in less frequent undernutrition and also potentially harmful effects in

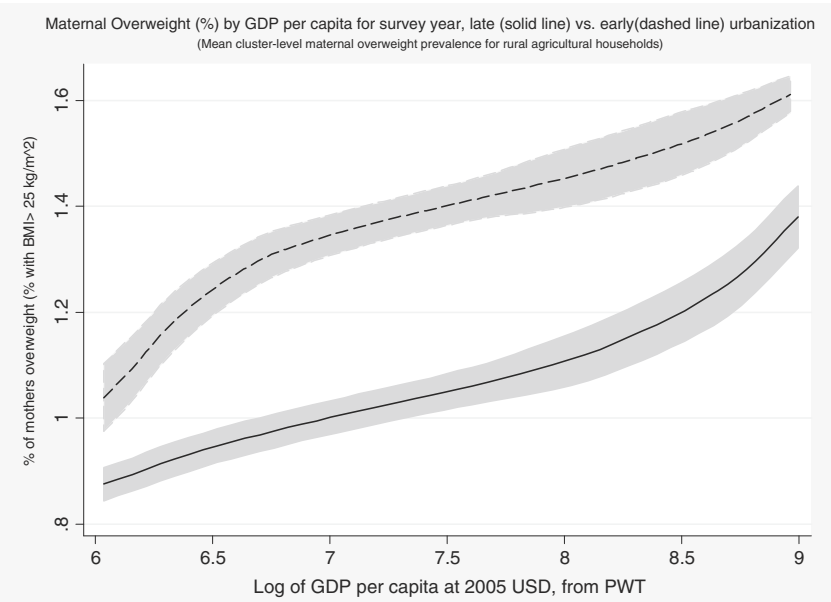


Fig. 7 Maternal overweight prevalence by GDP per capita and urbanization history

more frequent overweight, future studies could attempt to isolate specific mechanisms such as dietary differences. Finally, household location and urbanization history cannot be assigned experimentally, so there is room for omitted variables and reverse causality to confound our result. For example, more successful farmers may migrate to areas closer to towns and cities, and urbanization may occur earlier where rural people are better nourished for other reasons. Again, having established the association, further investigation would be required to test causal mechanisms. Lastly, we focus on nutrition indicators which, depending on the context, may have stronger or weaker linkages with food security, dietary quality, and food availability. An analysis of the mechanisms by which urbanization could affect rural malnutrition might use other kinds of nutrition outcomes such as diet quality, as well as other kinds of geographic data such as travel cost to food markets, health clinics, and other specific amenities.

Conclusion

Combining 83 nationally representative Demographic and Health Surveys with other data on historical urbanization and national per-capita income allows us to investigate the links between the development of nearby urban markets and malnutrition among rural farm households. The central finding is that rural children in farm households have higher height-for-age and weight-for-height z-scores in survey clusters which have a longer history of urbanization, when controlling for national income. There is also a lower prevalence of stunting and wasting among children and a higher prevalence of child and maternal overweight in regions with longer histories of urbanization. These patterns are consistent with the hypothesis that the development of nearby markets contributes to a gradual shift from undernutrition to overconsumption as the principal diet-related health risks, at each level of national income. The results appear across a global dataset spanning over 400,000 measured children and their mothers living in 43,850 survey clusters. The data are not globally representative, as the majority of these surveys were conducted in Sub-Saharan Africa and the inclusion of a household survey in this study required the availability of geo-coded survey data. But the relationships seen here could be of considerable significance for policies and programs to reduce rural malnutrition, and merit detailed scrutiny in future research.

Most importantly, the results suggest that farm households' access to towns and cities has the potential to improve their nutrition outcomes, particularly for children. Policies and programs that take account of these linkages could leverage the presence of towns and cities, helping farmers to improve their use of urban amenities for nutritional improvement. One possible way to do this would be to invest in rural transportation infrastructure. This study demonstrates that the benefits and risks of urbanization extend to rural farm households, as community-level changes in socioeconomic and agricultural conditions affect maternal and child nutrition. Urbanization matters not only for those who actually obtain off-farm employment, but also for those who remain in agriculture. Further work can explore these relationships in more detail, identifying potentially causal mechanisms using a variety of statistical techniques and additional data.

An example of possible future work in this area could be to develop indices and formal definitions of market accessibility based on various factors such as transportation infrastructure, size, diversity of services and products offered, and ease of participation. Next, agricultural interventions with phased implementation design or case–control studies could perhaps be used to test some kinds of specific interventions in particular locations designed to improve market access. Turning to broad policy implications, these structural patterns strongly suggest that investment in rural infrastructure is a necessary condition for leveraging the market linkages between agriculture and nutrition. The results also suggest that agricultural research and development activities should encompass detailed dissemination plans which account for varying levels of market access and geographic isolation of the households they intend to target with newly developed technologies or interventions. Finally, at the global level, the broad, structural patterns documented here can be helpful in themselves, showing both the average relationships that held in the past and the variance that can be exploited to improve outcomes for all kinds of farm households.

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Conflicts of interest The authors declare no conflicts of interest.

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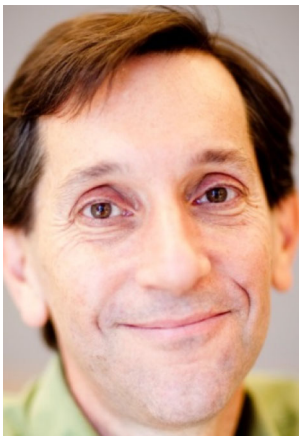

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