An Economic Analysis of Dietary Diversification in the Developing World

By

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THESIS

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Abstract

Child undernutrition, including micronutrient deficiency, is widespread in many parts of the developing world. Low dietary diversity is a major source of this problem. This occurs where diets are predominantly based on starchy staples with few fruits, vegetables and animal-sourced foods. Improving children's diets is therefore an important step towards solving the nutrition problem in low-income settings and reducing its debilitating symptoms such as stunting.

Despite the importance that nutritionists attach to early childhood dietary diversification, very little research has focused on the key question of how dietary diversification can be accelerated. Chapter 1 reviews an extensive multi-disciplinary literature on dietary diversification that nevertheless fails to systematically address the multidimensional drivers of diversification, particularly in low-income settings. This thesis aims to fill this knowledge gap by investigating factors that drive dietary diversification at a national level (Chapter 2) and at an individual child level (Chapter 3). Chapter 4 sheds light on the nutritional impacts of dietary diversification specifically in the context of dairy, a food group widely perceived to be especially critical for child growth (Chapter 4).

Chapter 2 of the thesis investigates the economic, social and agro-ecological indicators that drive dietary diversification of national food supplies (DFS) over time across countries and regions. The traditional economic view, stemming from Bennett (1944), is that economic growth is the major driver of the diversification of food supplies, but meso- and micro-level work point to many other drivers, and to potential agro-ecological constraints to diversification. This chapter addresses those questions through a cross-country analysis linking a simple measure of diversity of food supply (the share of calories supplied by non-staple foods) with various economic, social

and agro-ecological indicators. Using panel regression models, the analysis shows that while economic growth and other indicators of structural transformation (urbanisation and demographic change) explain changes in DFS within countries, time-invariant agro-ecological indicators also are significantly associated with DFS. In short, broader structural transformation processes do appear to drive diversification, but some countries face retarded diversification because of specific agro-ecological constraints as well.

In contrast to the global view on diversification in Chapter 2, Chapter 3 investigates the determinants of child dietary diversity specifically among pre-school children. Pre-schoolers are a crucial demographic, because most growth faltering occurs between 6 and 23 months of age. This chapter tests the various hypotheses emerging from the economics and nutrition literature by linking Demographic and Health Survey (DHS) data on child dietary diversity to household socioeconomic characteristics with community level indicators of climate and infrastructure. Using non-parametric and parametric regression models, the findings uncover strong support for linear effects of household wealth (again, in keeping with Bennett's Law) but also large and nonlinear associations with parental education, access to health services, infrastructure and climate, and modest associations with an indicator of women's empowerment.

Chapter 4 tests the importance of cow ownership for child growth in rural Bangladesh. Bangladesh is a country with unusually low levels of milk consumption by international standards and very high rates of undernutrition. Unlike previous papers in the literature, this chapter introduces a novel placebo test by distinguishing between lactating dairy cows that have produced milk over the past 12 months and those that have not. Using a rich nationally representative rural household survey, the results show a robust positive association between ownership of lactating cows and child growth among young children (6-23 months). The empirical analysis also reveals an unusual positive association between ownership of lactating cows and wasting, and some evidence that household dairy production is associated with reduced rates of breastfeeding in the first 12 months of life. In short, the apparent linear growth benefits of increased household milk availability are qualified by adverse breastfeeding outcomes and a disconcerting association with child wasting. Efforts to promote increased dairy consumption arguably should be accompanied by interventions to improve nutritional knowledge and emphasize exclusive breastfeeding in early life.

The findings of this thesis have important implications for food and nutrition strategies that aspire to accelerate dietary diversification. Chapter 5 points to the results providing evidence that the impact of economic growth on dietary diversification is moderately strong; growth alone would yield only modest diversification without accompanying improvements in parental education, health infrastructure, physical infrastructure and broader demographic transformations. Reassuringly for the nutritionists, the results often suggest that nutritional knowledge may indeed be a critical determinant of dietary diversity, and one partly shaped by exposure to formal education and basic health services. However, more research is needed to determine how best to improve nutritional knowledge cost-effectively, and at scale. The demonstrated importance of agro-climatic and infrastructural constraints also provides support for the separability hypothesis. Resolving the problem of poor diets, especially in rural areas, will likely require significant investments in making markets more effective in delivering a diverse and affordable array of foods. More research is needed to determine how much more of such specific investments are needed to improve rural diets in particular settings.

Key words: Dietary diversity; Undernutrition; Child diets; Agriculture; Livestock; Dairy production; Animal-sourced foods

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Dedication

To my late mother, Samina Farhad Chowdhury

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Certification:	This paper reports on original research I conducted during the period of my Higher Degree by Research candidature and is not subject to any obligations or contractual agreements with a third party that would constrain its inclusion in this thesis. I am the primary author of this paper.		
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Chapter 1: Introduction

Globally, child undernutrition is increasingly acknowledged as a major constraint to the economic development of individuals and nations. More than 3 million child deaths annually are associated with child undernutrition, and nutritionists estimate that almost 165 million children under the age of five are stunted and 52 million are wasted in low and middle-income countries (Black et al. 2013). The prevalence of stunting in Asia has fallen dramatically, from 49% in 1990 to 28% in 2010, almost halving the number of stunted children from 190 million to 100 million. For instance, countries such as Cambodia have been successful in reducing child stunting over the period 2000 to 2014 (Zanello, Srinivasan and Shankar 2017). This suggests the problem is solvable. Nonetheless, the majority of the world's malnourished and stunted children are still found in Asia. Meanwhile in Africa, the stunting prevalence has stagnated at around 40% since 1990, representing the second largest area of stunting (de Onis et al. 2010).

Child malnutrition has severe short and long-term health consequences. Evidence demonstrates that malnutrition is associated with impaired cognitive development in early childhood (Walker et al. 2011; Grantham et al. 2007). A sizeable literature in economics links malnutrition in early childhood to reduced educational achievement and lower economic productivity and adult wages (Shekar et al. 2006). Furthermore, nutritionists have increasingly highlighted that the first 1000 days of childhood growth – in utero and the first 24 months after birth – is critical (Shrimpton et al. 2001; Victora et al. 2010): child growth retardation can begin from conception (especially in South Asia), and undernourished children continue to experience linear growth retardation until aged two. Thereafter, child stunting seems substantively irreversible, suggesting that there are potentially very high economic returns to reducing early childhood malnutrition through a focus on the diets facing infants and young children.

This ever-growing body of evidence has catalysed development agencies, NGOs and many developing country governments. Since the first *Lancet* nutrition series (Bhutta et al. 2008), a policy document on undernutrition has been published by nearly every development agency. Overseas development assistance for nutrition has gone up from US $259 million in 2008 to $418 million in 2011 – an increase of more than 60% (Di Ciommo 2013). G-8 countries increased their bilateral spending towards nutrition-specific and nutrition-sensitive programmes by nearly 50% between 2009 and 2011 (G-8 2012). The Scaling Up Nutrition (SUN) movement that began in September 2010 is the main icon of the increased interest in nutrition (United Nations 2011). By mid-May 2013, the movement was made up of 35 countries who are committed to the scaling-up of direct nutrition programmes.

Addressing the challenge of malnutrition is made difficult by the multidimensional nature of the problem. The widely used UNICEF (1990) framework emphasises that nutrition outcomes are the product of both food and non-food factors. The latter include disease burdens that affect the utilization of nutrients. Perhaps surprisingly, however, the question of how to improve diets through food systems has been relatively neglected (Pinstrup-Andersen 2012). Many nutrition-specific interventions focus on non-dietary factors or on nutrient fortification and supplementation interventions. However, the 2013 *Lancet* Nutrition Series estimated that these nutrition-specific interventions alone would address only about 20% of the global malnutrition burden, implying that various nutrition-sensitive sectors may be the main drivers of nutritional improvements (Black et al. 2013). These sectors will partly need to address the problem of low-quality and low-quantity diets, which is one of the most important challenges to solving the nutrition problem in developing countries.

This thesis will extend the limited literature on the importance of dietary diversity for child nutrition, with a view to informing the challenging question of how dietary diversity can be accelerated in poor countries. In the developing world, low dietary diversity is a major problem among the poorest populations, where diets are heavily based on starchy staples and often include few animal-sourced foods, fruits and vegetables. Yet despite growing acknowledgement of this problem, there is limited evidence on how to accelerate dietary diversification, and whether specific foods are particularly important for child growth. This thesis analyses the economic, social and agroecological determinants of dietary diversification at an individual (child) level as well as at a national level, using different types of data (nutrition surveys, household surveys and cross-country panel data) and different econometric techniques: Chapter 2 focuses on the diversification of national food supplies over time using panel econometric techniques; Chapter 3 focuses on dietary diversification among young children (6-23 months of age) in a broad swathe of developing countries; and Chapter 4 examines the consumption of dairy products in rural Bangladesh, an area where dairy intake is very limited.

1.1 Literature Review

This section first reviews the non-economics literature on the importance of dietary diversity with sub-sections on dietary diversity metrics, evidence on dietary diversity indicators, nutritional benefits of animal-sourced foods, and dietary interventions. It then summarises the economics literature on dietary decision-making, with a focus on the separability hypothesis and unitary versus non-unitary household models.

1.1.1 Non-economics literature on the importance of dietary diversity

Dietary diversity metrics

A healthy human diet regularly needs at least 51 known nutrients in sufficient amounts (Graham and Tetroe 2007). Furthermore, it is possible that there are many synergies between nutrients, making dietary diversity an important concept by itself. Dietary diversity, assessed as the number of foods consumed across and within food groups over a reference period, is widely regarded as a potential proxy for diet quality (Kennedy et al. 2011; Ruel 2003). Nutritionists have generated an extensive range of dietary diversity indicators that vary from detailed weighing of individual food intake to very simple recalls of broadly defined food groups. The gold standard of dietary diversity is the 24-hour recall method of food intake measured at the individual level as compared to household levels (FAO 2003). The 24-hour recall method is not widely implemented in large-scale surveys in developing countries because of the time and resources necessary to collect and analyse quantitative food intake data.

There are other alternative ways to collect and analyse food consumption information using indicators that are proxies for dietary quality (WFP 2008). For instance, Food Balance Sheet data report estimates of national food availability but to date have been limited to national level assessment and cannot be used to infer the distribution of adequacy of intakes for individuals within the population. Nevertheless, these dietary metrics are useful for monitoring nutritional diversity to design and evaluate food system policies that prioritize the nutritional needs of a healthy population (Story et al. 2008; Hawkes 2012).

Evidence on dietary diversity indicators

Dietary diversity indicators have been shown to be strong predictors of adequate nutrient intake (Hatløy, Torheim and Oshaug 1998; Shimbo et al. 1994; Foote et al. 2004; Steyn et al. 2006; Moursi et al. 2008) and are therefore key elements of dietary quality (Randall et al. 1985; Krebs Smith et al. 1987; Kant 1996; Drewnowski et al. 1997). Moreover, dietary diversity indicators are strongly associated with health and nutrition outcomes (Arimond and Ruel 2004; Kant et al. 1993; Slattery et al. 1997; Levi et al. 1999). Evidence shows that dietary diversity has a positive association with nutritional status at the individual level (Kennedy et al. 2011; Arimond et al. 2010); and the available studies have generally supported the association between dietary diversity and anthropometric measurements in children (Hatløy et al. 2000; Onyango, Koshi and Tucker 1998; Tarini, Bakari and Delisle 1999). For instance, Onyango, Koshi and Tucker (1998) measure diversity by the number of individual foods consumed in 24 hours and demonstrate a significant relationship with five nutritional status indicators (height-for-age, weight-for-age, weight-for-height, triceps skinfolds and mid-upper arm circumference) among children aged 12-36 months. Their findings highlight the importance of diversity in complementary foods, particularly for those children who are no longer breastfed and depend solely on complementary foods for their nutrient intakes. Other food group diversity measures that used either a 24-hour or seven-day recall also correlate positively with children's height-for-age Z-scores (HAZ) (Arimond and Ruel 2002).

Nutritional benefits of animal-sourced foods

Inclusion of animal-sourced foods (ASFs, namely meat, poultry, fish, eggs and milk) in the diet has been cited as important for nutritional status (McLean et al. 2007; Neumann et al. 2013;

Neumann et al. 2007; Neumann et al. 2002) especially in the first 1000 days, during which good nutrition and healthy growth have long-term implications throughout life (Black et al. 2013). This is because ASFs contain richer sources of particular micronutrients such as iron, zinc, riboflavin, vitamin A, vitamin B12 and calcium than plant-based foods (Murphy and Allen 2003). In general, red meat contains a higher content of zinc and iron compared to poultry and fish. Milk, eggs and fish are inherently rich sources of preformed vitamin A, and fish and milk contain calcium and phosphorous (Hansen et al. 1998). Vitamin B12 is supplied by meat and milk (Watanabe 2007). Milk and meat are also rich sources of high-quality and readily digested protein, providing all the essential amino acids (Williamson et al. 2005). In particular, milk has been highlighted as important for growth and development of children older than 12 months, providing several critical micronutrients as well as insulin-like growth factor-1 (IGF-1) (Iannotti, Muehlhoff and Mcmahon 2013; Dror and Allen 2011; Wiley 2009; Sadler and Catley 2009; Hoppe et al. 2006).

Dietary interventions

The importance of ASF consumption for child nutrition has been cited in observational settings, and recently in intervention studies (Azzarri et al. 2015; Neumann et al. 2014). A recent Kenyan study shows causal evidence that including a modest amount of meat to the diet among school-aged children improves growth, micronutrient status, cognitive function and school performance (Neumann 2007). Another comprehensive systematic review reports that six of 24 studies have a causal link between milk interventions and nutrition outcomes (Iannotti, Muehlhoff and Mcmahon 2013). Additionally, Hoppe et al.'s (2006) review of observational and intervention studies in developing countries finds robust evidence that cow's milk stimulates linear growth.

Another quasi-experimental community-based dietary intervention in Malawi, promoting dietary diversification with an increase in fish utilization, has shown improvements in the lean body mass of stunted children after 12 months (Yeudall et al. 2002). Overall, outcomes from several nutrition interventions promoting ASF production and consumption have demonstrated positive impacts on nutritional outcomes (Leroy et al. 2007).

Recent literature on child nutrition and health outcomes

There are some studies that have focused on the effects of environmental risk factors and climate change on child nutritional status (Johnson and Brown 2014; Johnson, Jacob and Brown 2013). Johnson and Brown (2014) observe the relationship between a climate-related environmental indicator (vegetation index – NDVI) and child nutrition using Demographic and Health Surveys (DHS) data from four West African countries (Mali, Burkina Faso, Guinea and Benin), linked with NASA's satellite remote sensing data. Their findings show that NDVI is positively associated with child nutrition outcomes, specifically with wasting instead of stunting, in countries with a broad distribution of NDVI values. Their research identifies the importance of environmental factors for child nutrition outcomes in particular settings. Similarly, Johnson, Jacob and Brown (2013) examine the relationship between forest cover and child nutrition outcomes using the 2010 Malawi Demographic and Health Survey and satellite remote sensing data. They find that forest cover contributes to improvements in child nutritional status. In particular, children who resided in areas with net forest cover loss during the period 2000-2010 are 19 percent less likely to consume a diversified diet and 29 percent less likely to have vitamin A-rich foods compared to children residing in areas with no net change in forest cover. Children residing in areas with greater shares of forest cover are more inclined to have not only vitamin A-rich foods but also a lower probability of experiencing diarrhoea. Their analyses pose concerns regarding the possible long- and short-term effects of ongoing deforestation and ecosystem degradation on community health in Malawi, and highlight the importance of preventing forest loss and sustaining ecosystem services of forests to improve nutrition outcomes.

In another recent study, Grace, Brown and McNally (2014) investigate the association between food prices and food insecurity by employing a multi-level analysis of maize price and birthweight in Kenya. The price of maize, a major food staple in Kenya, acts as an indicator of food accessibility, while low birth weight characterizes household food insecurity. Using the most recent Kenyan Demographic and Health Surveys (DHS), they construct various regression models to estimate the effect of maize prices and estimates of crop production on infant low birth weight. They find that increases in pre-pregnancy maize prices are associated with low infant birth weight. The results of the models reveal the importance of including community crop production to estimate impacts of maize prices on low birth weight outcomes.

1.1.2 The economic literature on dietary decisionmaking

Economists typically explain diets in a utility maximizing framework where demand for particular foods is a function of incomes and relative prices. The focus has therefore been on estimating income elasticities, own-price elasticities and cross-price elasticities. However, the conventional literature has limitations, particularly from a nutritional perspective in which dietary diversity as a whole is often emphasised. The following theoretical framework, which adapts the agricultural household model under complete and missing markets, is useful for understanding the key determinants of dietary choices.

Separability hypothesis

The agricultural household model emphasises underdevelopment of markets that can alter food markets in ways that inhibit dietary diversification. Following the works of Behrman and Deolalikar (1988) and Strauss and Thomas (1995), we adapt the standard agricultural household utility model to examine intake of foods and children's nutritional status under complete and missing markets.

We maximize the household utility function

$$\mathbf{U= U\ (\boldsymbol{N_i, F_i, X_i, l_i}),\ i= 1, \ldots\ I} \tag{1}$$

where parents are concerned about their child's nutritional status N_i and nutrient intakes F_i. Other possible arguments are aggregated in the household utility function such as X_i (consumption of all other goods by child and other household members) and l_i (leisure of child and other household members). This household utility function is maximised subject to production functions for child's nutritional status N_i, income Y_i, time T and budget constraints, leading to demand functions as represented by equation (2) under the assumption of complete markets. Child's nutritional status N_i is produced by combining nutrient intakes F_i with time spent by the primary care giver looking after the child and is the outcome of a set of inputs, including good care practices toward the child (C_i), genetic endowments (η_i), health status and the household environment H_i (such as the prevalence of disease and access to information about good child care practices), exogenous wage *w* earned by other household members engaged in off-farm labour, prices of nutrients P^N, exogenous prices of agricultural goods produced by the household P^A, prices of all other goods P^X , and total income Y^T.

$$\mathbf{V=v}\ (\boldsymbol{C_i}, \boldsymbol{\eta_i}, \boldsymbol{H_{i,}}\ \mathbf{w}, \boldsymbol{P^N}, \boldsymbol{P^A}, \boldsymbol{P^X}, \boldsymbol{Y^T}) \tag{2}$$

where $\mathbf{V}=(\boldsymbol{N_{i,}}\boldsymbol{F_i}), \mathbf{i}= \mathbf{1}, \ldots \mathbf{I}$

Singh, Squire and Strauss (1986) emphasise that, based on the strong assumptions of complete markets and exogenous prices, the level of income influences demands for nutrient intake and nutrition outcomes. Under separability, we assume that household production decisions are not affected by the consumption-leisure decisions and the household behaves as a pure profit-maximizing producer (de Janvry, Fafchamps and Sadoulet 1991). However, due to the nature of imperfect rural markets, these assumptions may break down. For instance, most rural households may consume food from their own farm production. They also face multiple market imperfections, which affect household behaviour. High transaction costs related to poor infrastructure or poor processing and storage technologies usually raise the costs of purchasing and selling food products in local markets, in the process making self-sufficiency of food consumption more attractive (de Janvry, Fafchamps and Sadoulet 1991). This would be particularly true of perishable products such as fresh milk, eggs and many fruits and vegetables. We assume that under non-separability, household production and consumption decisions are jointly determined (Bardhan and Udry 1999; LaFave and Thomas 2014; Strauss 1984). In this situation, factors that have an impact on consumption decisions (wealth, prices of consumer goods, household characteristics and preferences that affect consumption) also affect production decisions.

Unitary versus non-unitary household models

Traditional economic models of household decision-making assume a single household utility function. These "unitary models" (Hoddinott, Haddad and Alderman 1997) assume that tastes and preferences of all household members are the same. In other words, husbands and wives make household production and consumption decisions jointly.

When we take into account the likely differences in the preferences and tastes of the household members – particularly husbands and wives –we can no longer treat the family as a single decision-making unit (Behrman 1997). In such instances, the utility maximization is reliant on a collective decision making and bargaining process. These models are known as collective, non-unitary models or intra-household bargaining models where each household member is taken as a separate unit who controls his/her own income (Haddad, Hoddinott and Alderman 1994). These models assume that husbands and wives do not necessarily share the same preferences and try to pursue, at least partly, their own objectives.

The allocation of available household resources is centered on a process of bargaining where the outcome is determined by the bargaining power of household members. Duflo and Udry (2004) and Banerjee and Duflo (2007) claim that household spending on their chosen variety of goods arises from individual specific 'mental accounts'; for instance, women are inclined to spend more on their children, whereas men often prefer spending on commodities such as alcohol and tobacco. Quisumbing and Maluccio (2003) use data from many developing countries and their findings show a positive correlation between indicators of female bargaining power and expenses on food and education. Related research has often suggested that women's education and empowerment tends to be more important for nutrition (Block 2004; Block 2007; Haddad 1999). Recently, Alderman and Headey (2017) assessed the impacts of parental education on child nutrition for 56 countries using the Demographic and Health Surveys (DHS) and find that the estimated nutritional returns are larger for mothers and larger for secondary education than primary. However, some economists have questioned the importance of women's status for child health, since rigorous experimental evidence is often difficult to generate; moreover, quasi-experimental evidence sometimes suggests little or no advantages of women's education or empowerment in influencing child health outcomes (Duflo 2012).

1.1.3 Knowledge gaps

Gap 1: Economists have emphasised the role of income and economic growth in driving the diversification of diets (that is, estimating Bennett's Law). The underlying microeconomic explanation of this association is that as incomes rise, consumers begin to consume more expensive calories (Subramanian and Deaton 1996; Skoufias 2003; Yu and Abler 2009; Jensen and Miller 2010; Logan 2006; Yu, Gao and Zeng 2014; Timmer, Falcon and Pearson 1983). But, microeconomic studies also reveal that households in least developed countries may consume food from their own farm production due to imperfect markets (de Janvry, Fafchamps and Sadoulet 1991; Singh, Squire and Strauss 1986). In contrast, meso-analyses find that factors such as infrastructure, urbanisation and demographic change influence dietary diversification. Yet, no study has attempted to integrate these different factors into a single empirical framework.

Gap 2: Nutritionists have validated the predictive power of dietary diversity indicators in explaining child undernutrition, including stunting and key micronutrient deficiencies.

The economics literature has focused on consumers' income-elastic demand for non-staple foods while nutritionists have explained child dietary diversity empirically but with no real theoretical framework and focused their interventions on improving nutritional knowledge, with little emphasis on economic constraints. Therefore, a much more extensive theoretical analysis is required to understand the determinants of children's diets in developing countries.

Gap 3: Benefits of dietary diversification for child growth are still debated and there is not enough evidence informed by experimental approaches. Several studies conducted in least developed countries have linked child growth to dairy cow ownership, but the findings are confined to East Africa and they suffer from significant methodological caveats. Fortuitously, the incompleteness of markets that create separability conditions also provides opportunities for economists to utilize observational or quasi-experimental analyses to explore the consequences of dairy production for child growth in less developed country settings.

1.2 Research questions

Given the nutritional importance of dietary diversification and mounting interest in understanding the drivers of diversification, this thesis proposes three research questions:

1. What economic, social and agroecological factors drive the diversification of national food supplies (DFS) over time and across countries and regions? (Chapter 2);
2. What household socioeconomic characteristics and community level indicators of climate and infrastructure determine dietary diversity among pre-school children according to the Demographic and Health Survey (DHS) data? (Chapter 3); and
3. What are the impacts of dairy production on child nutrition outcomes in rural Bangladesh? (Chapter 4).

1.3 Thesis outline

The three core chapters in this thesis contain are stand-alone pieces (albeit linked by common themes), with self-contained references, tables and figures.

Chapter 2 of this thesis investigates which economic, social and agroecological factors drive the diversification of national food supplies (DFS) over time across countries and regions, and conversely which factors may constrain diversification. In addition, this chapter observes stylized trends and patterns in dietary diversification. Using panel regression models, we find that in addition to per capita consumption expenditure, various indicators of structural transformation (urbanisation and demographic change) also are strong predictors of changes in DFS within countries. However, time-invariant agro-ecological factors are significantly associated with DFS too, supporting the separability hypothesis described above.

In contrast to the global view of diversification in Chapter 2, Chapter 3 focuses on a more micro approach to examine specifically child dietary diversity among pre-school children (who are a crucial demographic, given that most growth faltering occurs between 6 and 23 months of age). This chapter observes which household socio-economic and community level geographical factors are linked to child dietary diversity. The results show strong support for linear effects of household wealth but also large and nonlinear effects of parental education, access to health services, infrastructure and climate, and modest associations with an indicator of women's empowerment. These results provide considerable indirect support for the separability hypothesis and non-unitary household models outlined in the previous sections. Chapters 2 and 3 also challenge the income-centric view of nutritional change that economists are often accused of, and the knowledge-centric view that nutritionists might be accused of. Income, knowledge, empowerment, agricultural and infrastructural conditions all appear to play important roles in shaping children's diets.

Chapter 4 highlights the consequences of cow ownership for child growth in rural Bangladesh, a country where milk consumption is unusually low by international standards and which has one of the highest rates of undernutrition. Unlike previous papers in this literature, we introduce a novel placebo test by distinguishing between cows that have and have not produced milk in the last 12 months. The findings show a robust positive association between ownership of lactating cows and child growth among young children (6-23 months). We also find an unusual positive association between ownership of lactating cows and wasting, and that in the first 12 months of life, dairy supply may substitute for breast milk. This chapter also clearly supports the separability hypothesis described above, despite the stark differences in population density and access to markets between Bangladesh and East African settings.

The thesis concludes in Chapter 5 by summarizing the main results and suggesting areas for further research.

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Chapter 2:

What drives Diversification of National Food Supplies?

A Cross-Country Analysis

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Abstract

While most economic studies of diet diversification tend to focus on the determinants of calorie consumption, little previous research has explored what economic, social and agroecological factors drive the diversification of national food supply (DFS) over time across countries and regions. We first review the theory and evidence of diet diversification, focusing mainly on economic growth and several processes of structural transformation (urbanisation, demographic transitions, expansions in education) as well as microeconomic models of farm household behaviour in the presence of market underdevelopment, such as high transport costs. We then create and analyse a cross-country panel data set, linking a simple measure of diversity of food supply (the share of calories supplied by non-staple foods) with various economic, social, infrastructural and agroecological indicators. Using fixed effects and correlated random effects models, we find that in addition to per capita consumption expenditure, various indicators of structural transformation (urbanisation and demographic change) are strong predictors of changes in DFS within countries, yet time-invariant agroecological factors are also significantly associated with DFS. We conclude the paper with a discussion of the implications of this research for food and nutrition strategies.

Key words: Dietary diversity; Diversification of food supplies; Nutrition; Food systems; Economic transformation.

2.1 Introduction

A widely used UNICEF framework emphasises that nutrition outcomes are the product of both food intake and non-food factors. However, diets alone are complexly determined by a wide range of deeper factors, such as cultural norms of child feeding and care practices, incomes, education and nutritional knowledge, and relative food prices (UNICEF 1990). Addressing the problem of low-quality and low-quantity diets remains one of the most important challenges to solving the nutrition problem in developing countries. Diversity of food supply has long been acknowledged as significant for ensuring adequate nutrient intake (Foote et al. 2004; Hatløy, Torheim and Oshaug 1998; Moursi et al. 2008; Shimbo et al. 1994; Steyn et al. 2006) and human health (Arimond and Ruel 2004; Kant et al. 1993; Levi et al. 1999; Slattery et al. 1997); yet, diversity of food supply has not been widely studied relative to calories. This is despite new interest in diversity of food supply as a useful proxy for dietary quality and a powerful predictor of nutrition outcomes (Ruel 2003).

Poor diversity of food supply is a major contributor to micronutrient deficiencies in particular (Bouis 2000), which inhibit both physical and cognitive development. Although these micronutrient deficiencies are widely recognised by the health sector, there is very little economic research on why diversity of food supply is low in some countries, and why it has persisted in other countries despite rising incomes and significant poverty reduction. Bennett's Law hypothesises that people diversify away from starchy staples as their incomes rise. Microeconomic analysis confirms that starchy staples typically have low income elasticities of demand compared to more nutrient-dense foods, such as animal-sourced foods, fruits and vegetables (Melo et al. 2015). For example, Pingali (2007) suggests that as incomes have risen in Asian countries, consumers have diversified their diets away from rice towards fruits, vegetables and animal-sourced foods, in accordance with Bennett's Law. This trend towards diet diversification has already been observed across many poor and middle-income countries in Asia (Huang and Bouis 2001; Pingali 2007), though it is also notable that some countries continue to exhibit low levels of diversity of food supply. For example, data from the Food and Agricultural Organization (FAO) of the United Nations suggest that more than 70% of calories in Bangladesh are supplied via starchy staples, mainly rice. More generally, there is wide variation in the diversity of food supply around any given income level. This suggests that other factors need to be taken into account. For example, the separability hypothesis predicts that in the presence of market underdevelopment – such as very high transport costs – rural households will tend to make consumption and production decisions jointly. Of particular relevance here is the fact that many nutrient-dense foods are highly perishable, and therefore costly to trade internationally and even intra-nationally. In such environments, dietary diversity is also heavily influenced by agroecological constraints on production diversity.

To answer these questions, we use cross-country regression analysis to explore the linkages between the DFS, shown to be a good proxy for dietary diversity, and various potential drivers of diversification. In this paper, we address two questions. First, is DFS a useful metric for monitoring dietary diversity? Second, what drives nutritionally meaningful dietary diversification over the course of a country's economic development? Is income growth the main driver of diversity (as per Bennett's Law) or do other multiple dimensions of structural transformation matter, such as rapid increase in levels of education, agricultural transformation, urbanisation, and the demographic transition from older to younger populations?

Yet, despite growing interest in dietary diversity at the individual or household level, there is very little research on DFS. After many years of focusing solely on calorie supply, the FAO recently added a simple DFS measure – the share of calories supplied by non-staple foods – to its expanded suite of food security indicators (FAO 2016). Headey (2013) shows that this indicator has stronger correlations with maternal and child undernutrition outcomes than the FAO estimates of total calories per capita, despite both indicators being derived from the same set of food balance sheets. Remans et al. (2014) likewise find that this indicator – along with other DFS indicators – is negatively correlated with national estimates of stunting, wasting and underweight prevalence (but not overweight prevalence). Thus, as with individual and household measures of the diversity of diets, DFS is negatively associated with indicators of the prevalence of undernutrition and may be regarded as a useful metric for monitoring diets.

In this paper, we adopt a novel methodological approach. Most economic studies analyse diets (usually calories) in national-level, often cross-sectional surveys. This approach can produce well-known biases (Bouis and Haddad 1992). Of particular concern in these regressions is that the dependent variable (usually calories) and the right-hand side measure (household income or expenditure) are derived from the same survey module, and hence suffer from common measurement errors, leading to biased coefficient. A second possible source of bias is the exclusion of fixed effects from these models, which are likely to be highly correlated with household income or expenditure. In this paper, we instead adopt a multi-country panel (economics) approach that addresses these two concerns. Our dependent variable is derived from FAO food balance sheets, while most of our independent indicators are derived from alternative sources (such as the World Bank), such that measurement error is more likely to be random, without leading to bias. Moreover, by using the correlated-random-effects (CRE) model (Wooldridge 2010) we are able to estimate the effects of time-invariant variables (e.g. agroecological factors) whilst still controlling for other unobserved time-invariant effects, as well as time-fixed effects. However, for time-varying factors – such as per capita incomes or education levels – we are able to estimate coefficients of the within-country (difference-in-difference) estimator. This is a significant advantage over the cross-sectional approaches commonly observed in the microeconomic literature on this subject.

The remainder of this paper is structured as follows: Section 2.2 provides a literature review. It focuses on the economics of food demand systems; non-income drivers of food demand associated with structural transformation (urbanisation, demographic transitions, expansions in education); dietary diversity indicators; microeconomic models of farm household behaviour in the presence of market underdevelopment; and a more macroeconomic literature on the market and government imperfections that inhibit international trade in food. Section 2.3 outlines the data and the empirical models we use to conduct our analysis. Section 2.4 presents descriptive statistics. Section 2.5 includes our results, before turning to some important sensitivity tests reported in Section 2.6. Section 2.7 concludes.

2.2 Literature review

This section outlines some key literature on the drivers of dietary diversification. First, we review some of the theory and evidence on the economic analysis of demand systems, particularly as they pertain to Engel's Law and Bennett's Law, which highlight the role of household income in determining the demand for aggregate calories (Engel's law) or for calories from different types of food (Bennett's law). Second, we provide linkages between several processes of structural transformation and dietary diversification. Third, we review nutritional literature on the importance of dietary diversity indicators. Fourth, we review microeconomic household models to examine the scope for non-income factors to influence food demand. We briefly review the literature on agricultural household models that emphasise underdevelopment of markets, which can alter food markets in ways that inhibit dietary diversification. Fifth, we explore the macroeconomic analogue to the microeconomic literature on distortions by examining the role that institutions, infrastructure and government policies play in influencing DFS.

2.2.1 The effect of income on food demand – Engel's Law and Bennett's Law

Traditionally, the World Bank and other development institutions shared the conventional wisdom that malnutrition can be alleviated by income growth (Behrman and Deolalikar 1987). This optimistic view of income growth was driven by the argument in early nutritional studies that a lack of calories is one of the main constraints to improved nutrition, and the assumption that calorie intake rises with incomes. Although some empirical work supported strong linkages between calories and incomes or expenditure, estimating Engel's Law (Abdulai and Aubert 2004; Subramanian and Deaton 1996; Tian and Yu 2013), other papers in this area found weak linkages between income and calories or income and nutrition outcomes (Behrman and Deolalikar 1987; Behrman and Wolfe 1984; Wolfe and Behrman 1983). The literature as a whole has uncovered calorie–income elasticities that are quite heterogeneous, ranging from almost zero (Behrman and Deolalikar 1987; Behrman and Wolfe 1984; Bouis 1994) to near one (Behrman, Foster and Rosenzweig 1997; Pitt 1983; Strauss 1984). One explanation may be methodological. Bouis and Haddad (1992) identify that most cross-sectional estimates of the effect of income on calories will be biased upwards because random errors in measuring food purchases are transmitted (by construction) both to calorie availability and total expenditures, and because the residual difference between family calorie intake and household calorie availability will often increase with income. They claim that the most plausible estimates suggest calorie–income elasticities are low (0.08–0.14), adding to the growing evidence that they are significantly lower than previously thought. In addition, they reject the previous policy conclusion that increasing income alone could improve calorie intakes (Behrman and Deolalikar 1987) and instead recommend that direct government intervention would be crucial to improving nutrition in the short-to-medium run.

Another explanation may be that even if income increases, poor households are more likely to spend additional income on purchasing more expensive calories rather than additional cheap calories from staple foods (Jensen and Miller 2010; Logan 2006; Skoufias 2003; Subramanian and Deaton 1996; Tian and Yu 2013; Yu and Abler 2009; Yu, Gao and Zeng 2014). An analogue to Engel's Law is Bennett's Law, that as income rises, people consume less starchy staples in favour of more expensive, nutrient-rich foods such as animal-sourced foods, fruits and vegetables (Timmer, Falcon and Pearson 1983). Generally, calorie consumption patterns with respect to income do vary according to income groups. For instance, the low-income group mainly purchase starchy staples, which are the cheapest available source of calories. But, as their incomes increase, they start to have a strong preference for better quality nutritious food (meat, fish) instead of merely increasing their calorie intake (Behrman and Deolalikar 1987; Jensen and Miller 2010, 2011).

A few studies have identified the role of income in influencing dietary diversification. Theil and Finke (1983), using cross-sectional data for 30 countries, document that the diversity of food supplies increases as income per capita rises. Estimation of cross-country Engel curves suggests that the number of foods consumed increases and the concentration of expenditure decreases with rising income per capita (Falkinger and Zweimüller 1996). Similarly, Pollack (2001) and Regmi (2001) find that consumption of fruits and vegetables increases with income. In economics, this increased demand for high-value nutrient-rich foods is reflected in income elasticities. Using cross-country data from the International Comparison Program, Seale, Regmi and Bernstein (2003) and Muhammad et al. (2011) confirm that staple foods indeed have smaller income elasticities compared to non-staple foods such as meat and dairy, and that those differences tend to rise with income. For instance, Seale, Regmi and Bernstein (2003) estimate that the income elasticity for staples varies from 0.62 in Tanzania to just 0.05 in the United States.

Country-level studies also reveal diverse results, though there are consistent patterns of high income elasticities for animal-sourced foods, moderate elasticities for fruits, vegetables, pulses, legumes and nuts, and low income elasticities for cereals. Using household level data for India, Kumar et al. (2011) find income elasticities are highest for milk (1.64), followed by vegetables and fruits (0.82) and pulses (0.72), with a much lower income elasticity for rice (0.19). Average income elasticities derived from of a meta-analysis of studies from Sub-Saharan Africa by Melo et al. (2015) show that cereal, legumes and nuts, and roots and tubers have low income elasticities, generally below 0.5. Interestingly, elasticities for fruits and vegetables are also relatively low (0.56 on average), but elasticities for animal products are much higher (0.90 on average). These results suggest that, at low-income levels at least, income gains will translate into more diversified diets, although diversification into fruit and vegetable consumption may be relatively slow. Thus, clearly there is a strong empirical support for an important role for income in driving dietary diversification.

2.2.2 Urbanisation

Another dimension of structural transformation related to diversification of diets is the transition from rural agrarian livelihoods to urban non-farm livelihoods, that is, urbanisation. Economic growth is accompanied by urbanisation (Henderson 2003). Rising incomes and intensified urbanisation will not only increase the demand for food but also transform diets. This has already been observed in Asian and Latin American countries characterised by rapid economic growth (Pingali 2007). In addition, lifestyle changes emerging from urbanisation raise the opportunity costs of women's time, resulting in change in the composition of food demand (Reardon and Timmer 2014).

Rapid urbanisation affects the structure of diets (Popkin 1999). Diets of urban residents are distinctly different from those of rural residents: they tend to consume foods with higher fat content, animal-sourced foods and more processed foods (Popkin 1998), moving away from staple cereal-based diets (Mendez and Popkin 2004). Though urban residents have lower food budget shares than rural residents, they have sufficiently higher incomes, which allows for greater consumption of nutrient-rich foods such as meat or fish. For instance, according to the China Health and Nutrition Survey, consumption of animal-sourced foods is more prevalent among urban residents compared to those residing in rural areas (Zhai et al. 2014).

Agricultural transformation also emerges as countries start to urbanise. Once countries develop larger urban markets with greater proportions of high-income consumers, then more sophisticated value chains for nutrient-rich foods begin to develop (Reardon and Timmer 2012). In many instances, such value chains will result in better logistics and transport, more focus on access to finance and other essential services, and the transition from small-scale informal food retail markets to supermarkets (Pingali 2007; Reardon and Timmer 2012). Likewise, the development of these value chains can put transformative feedback effects on the agricultural sector, mainly in agricultural areas with better access to urban centres that enable them to focus production on higher value commodities. But though this dietary transition can also result in harmful impacts on diets and obesity rates (Popkin 1994, 2001), urbanisation is likely to be associated with reductions in undernutrition (Ruel et al. 2010), possibly because of improved access to nutrient-rich foods. For example, many Latin American and some Asian and African nations with predominantly urbanised populations have been able to sustain long-term trends of reductions in infant and child mortality rates and rising average life expectancies, which also imply improvements in nutrition levels (Satterthwaite, McGranahan and Tacoli 2010).

2.2.3 Demographic transition

Another structural transformation that is of potential relevance is the demographic transition from high to low age dependency ratios. Overall, the key demographic phenomenon that the world is currently experiencing is that the rate of growth of the global population is reducing rapidly. There is emerging evidence showing large increase in investments on children's health and education due to reductions in fertility (Joshi and Schultz 2007). Moreover, such demographic transitions have shown major impacts on savings, and on consumption of goods and services. Consequently, this can affect the types of food consumed (Blandford 1984). For instance, Bloom and Williamson (1998) find that increased disposable income and savings are associated with a decrease in the proportion of children in a given population. But a potential secondary effect of this is that parents are being able to devote more resources to a child when there are fewer children in aggregate to take care of (Becker and Lewis 1974). It is plausible that having fewer children leads parents to demand higher quality, nutrient-rich foods.

2.2.4 Expansions in education

Numerous studies (Frongillo, de Onis and Hanson 1997; Smith and Haddad 2000) have identified strong associations between maternal education and child nutrition. This appears to be consistent across household analyses, although only secondary and tertiary schooling tend to be linked to better nutrition outcomes (Behrman and Wolfe 1984). The shift towards higher levels of education, which might be accompanied by improved nutritional knowledge, may increase the demand for more nutrient-rich foods (Alderman and Headey 2014; Block 2004; Webb and Block 2004).

Only a limited number of studies have examined whether, or how, nutritional knowledge interacts with education. One exception is research conducted in Nicaragua (Lamontagne, Engle and Zeitlin 1998), which concludes that maternal education and certain categories of nutritional knowledge are significantly but independently related to child outcomes. Another study by Thomas, Strauss and Henriques (1990) in Brazil establishes that the strong association between maternal knowledge and child height can be a result of mothers' access to media messages, formal schooling and messages received from community health services. Likewise, Blaylock et al. (1999) find that maternal schooling in the United States has a positive influence on children's diets.

In addition, a study by Alderman and Headey (2014) observes the linkage between parental education and child nutrition outcomes for children from countries with the highest burdens of undernutrition. Their results confirm the widely held view that increasing the level of maternal education will lead to reductions in malnutrition. Moreover, they find that robust and sizeable nutritional returns to education are shown at the secondary level, although the returns appear to be consistently larger for maternal education compared to those for paternal education. Likewise, using cross-country panel regressions, Headey (2013) finds that only secondary education for mothers has a significant impact in lowering the prevalence of stunting in Bangladesh. A supplementary paper on complementary feeding practices in South Asian countries (Bangladesh, India, Nepal, Sri Lanka) using recent national survey data also shares similar findings that one of the key determinants of children's lack of dietary diversity is low maternal education (Senarath and Dibley 2012).

2.2.5 Nutritional review on dietary diversity indicators

Dietary diversity is a useful indicator in measuring nutrient adequacy in developing countries (Ruel 2003; Steyn et al. 2006). Evidence shows positive associations between dietary diversity and anthropometric measurements in children (Hatløy et al. 2000; Onyango, Koski and Tucker 1998; Tarini, Bakari and Delisle 1999). Onyango, Koski and Tucker (1998) measure diversity by the number of individual foods consumed in 24 hours and find that this is significantly associated with five nutritional status indicators (height-for-age, weight-for-age, weight-for-height, triceps skinfolds, and mid-upper arm circumference) among 12–36 month old children. Their result addresses the significance of diversity in complementary foods, especially for those children who are no longer breastfed and rely on complementary foods for their nutrient intakes. Likewise, findings from the Ethiopia 2000 Demographic and Health Survey indicate a strong and statistically significant relationship between food group diversity measures (that used either a 24-hour or seven-day recall) and children's height-for-age Z-scores (HAZ) (Arimond and Ruel 2002). They find a positive and linear trend in mean HAZ when there is an increase in food group diversity over the past seven days.

However, findings from a recent study by Hoddinott and Yohannes (2002) have some important implications. They explore a multi-country analysis of data using ten countries (India, the Philippines, Mozambique, Mexico, Bangladesh, Egypt, Mali, Malawi, Ghana, and Kenya) to validate whether there is a relationship between household dietary diversity and household per capita consumption (a proxy for household income) and energy availability. Their findings illustrate that, on average, a 1% increase in dietary diversity leads to a 1% increase in per capita consumption/expenditure and 0.7% increase in total per capita energy availability. Further, a 1% increase in household dietary diversity is associated with a 0.5% increase in household energy availability from staples and a 1.4% increase in energy availability from non-staples. This is an example of a study confirming that when households diversify their diets, they tend to increase their consumption of non-staple foods rather than increase the variety of staple foods consumed. Overall, the literature establishes that because dietary diversity is associated with improved nutritional status (Arimond and Ruel 2002; Onyango, Koski and Tucker 1998; Taren and Chen 1993), diversity may actually indicate higher dietary quality as well as increased likelihood of meeting nutrient requirements on a daily basis.

2.2.6 Microeconomic models of household behaviour for nutrition and agriculture

The motivation behind agricultural household models comes from Gary Becker's model of the family economy (Becker 1965), which is based on utility-maximising behaviour with multiple constraints (financial, temporal). Kuroda and Yotopoulos (1978) were the first to apply this model to a developed country setting, namely, the supply response of rice among small farmers in Japan. These authors discovered an empirical puzzle, that increases in the price of a staple do not significantly raise the market supply. They explained this result by the integration of production and consumption decisions: by also being a consumer, the supplier of the staple in Japan may distribute more of their increased production towards their own consumption. In this case, an agricultural household is a worker, a producer and a consumer aiming to maximise utility.

Singh, Squire and Strauss (1986) book *Agricultural household models: extensions, applications, and policy* developed the complete agricultural modelling framework, covering the model specification, applications in empirical estimation and policy analysis. Subsequently, Sadoulet and De Janvry (1995) extend the agricultural modelling framework to investigate market failures arising from sizeable transaction costs and their empirical implications.

Most rural households in poor settings may consume food from their own farm production, in part because of multiple market failures due to both demand and supply constraints. On the demand side, low income levels and population dispersion relate to a lack of demand for more nutrient-rich foods. On the supply side, agricultural markets in poor countries face very high transaction costs (De Janvry, Fafchamps and Sadoulet 1991; Singh, Squire and Strauss 1986) related to poor infrastructure or poor processing and storage technologies, which raise the costs of purchasing and selling food products in local markets, in the process making self-sufficiency of food consumption more attractive. While these transactions costs might also hinder cereal markets (Minten, Stifel and Tamru 2014), cereals are much less perishable than most fruits, vegetables and animal-sourced foods (e.g. dairy, eggs). This allows some trade in cereals but also permits poor farmers to store cereals during lean seasons, making them attractive as a means of ensuring basic food security. In contrast, many nutrient-rich foods are consumed only if they can be locally produced, which means that agroecological conditions can substantially determine consumption patterns in poor areas.

The agricultural household model suggests that in the presence of an underdeveloped market, households may not simply maximise production/income first and then make separate decisions on consumption (De Janvry, Fafchamps and Sadoulet 1991; Singh, Squire and Strauss 1986). Rather, their production decisions factor in the market conditions that might prevent them from maximising utility. This is referred to as the separability hypothesis. In this situation, factors that have an impact on consumption decisions (wealth, prices of consumer goods, tastes, and other household characteristics that affect consumption, e.g. demographic structure and nutritional knowledge) can also affect production decisions.

Agricultural household models have been applied in various settings. Farm price policy analyses constitute one of the earliest applications. Such studies of price policies have been observed in Japan (Kuroda and Yotopoulos 1978); Taiwan (Lau et al. 1981); Korea (Ahn, Singh and Squire 1981); and Sierra Leone (Strauss 1984). The findings from these studies indicate positive own-price elasticity of consumption as well low supply response to price increases, which are consistent with the agricultural household model in the presence of underdeveloped markets. In addition, labour supply issues (Goodwin and Holt 2002) and consumption and related nutritional policy issues (Strauss 1984) are also addressed using these models. More recently, Hoddinott, Headey and Dereje (2015) invoke high transaction costs to explain the strong associations between cow ownership and milk consumption in rural Ethiopia; a relationship that diminishes with better market access.

2.2.7 Infrastructure, institutions and transport costs

The recent literature on trade (using gravity models) suggests that better institutions can promote trade. Levchenko (2007) finds that differences in institutions across countries determine trade patterns. Anderson and Marcouiller (2002) argue that bilateral trade volumes have a positive association with the institutional quality of the trading countries with the use of a gravity model. Similarly, Depken II and Sonora (2005) assess the impacts of economic freedom on US consumer exports and imports for the years 1999 and 2000. Their findings show that institutional quality of the import country positively affects the amount of exports from the United States to that country. Helble (2007) focuses on trade of countries in the Asia-Pacific region and demonstrates that higher transparency of the trading environment affects trade costs.

There is also widespread evidence on the impact of infrastructure on trade. Limao and Venables (2001) find that levels of infrastructure are important as determinants of transport costs. They show that being landlocked increases transport costs by about 50%. Also, poor infrastructure is responsible for 40% of predicted transport costs for coastal countries. Using Sub-Saharan African trade as an example, they estimate that poor infrastructure accounts for their poor trade performance. Employing a gravity model, Bougheas, Demetriades and Morgenroth (1999) link infrastructure to transport costs and therefore trade, using data from European countries, based on the assumption that transport costs depend inversely on the level of infrastructure. Wilson, Mann and Otsuki (2003) measure the impact of trade facilitation by looking at four different elements of trade facilitation effort (ports, customs, regulations, and ebusiness) and determine the increasing benefit of unilateral trade facilitation reforms. On the other hand, Brun et al. (2005) question the significance of the quality of physical infrastructure for trade. Nordås and Piermartini (2004) further analyse the quality of different infrastructure measures (rail, roads, telecommunications, ports, and airports) and find that among all measures, ports have the largest effect on trade. Regarding logistics, Behar, Manners and Nelson (2009) estimate that improving logistics by one standard deviation could result in raising exports by 46% for a developing country. Studies by Iwanow and Kirkpatrick (2007) and Portugal-Perez and Wilson (2012) conclude that trade facilitation measures positively influence export performance. A recent paper by Francois and Manchin (2013) investigates the overall impact of institutional and infrastructure indicators on trade flows between low- and high-income countries. Their results predict that variations in institution and infrastructure quality alone imply that trade volumes between low- and high-income countries are about 55% to 64% below trade volumes between high-income countries. Likewise, poor institutional and infrastructure quality in low-income countries increasingly restricts market access for exports from high-income to low-income markets. Concurrent with other studies, their results indicate that trade volumes as a whole depend on both access to well-developed transport and communications infrastructure, and institutional quality. Likewise, the importance of transportation infrastructure, in particular roads and bridges, for moderating price levels and price volatility in Nepal's food markets has been highlighted in a recent study (Shively and Thapa 2017).

Using FAO food balance sheet data, Remans et al. (2014) present evidence that as economies expand and become more intensive in both domestic and international trade in foods, the importance of agroecological conditions begins to lessen. In general, poor institution and infrastructure quality in low-income countries increasingly restricts market access for exports from high-income to low-income markets and is likely to be an important constraint on agricultural diversification, since staple foods tend to be much less perishable than non-staple foods. To our knowledge, however, no previous research has tested this hypothesis explicitly.

2.2.8 Government policies that encourage/discourage diversification

Beyond income constraints, some countries may also impose additional policy constraints on agricultural diversification. Over the past 50 years, developing countries experienced an extraordinary period of food crop productivity growth amidst increasing land scarcity. This was known as the Green Revolution period[1] (1966–1985), when governments and other international organisations were heavily biased towards the production of staple foods, such as rice, wheat and maize, with relatively few large-scale success stories in nutrient-rich non-staple foods. This took place for various reasons.

In the early 1960s, Southern Asia was characterised by rising poverty, heavy dependence on food aid, and population pressures. But rapid agricultural growth, by accelerating the production of staples, led to a doubling of rural income and accounted for the largest single poverty reduction in human history (Chen and Ravallion 2004; Fan, Gulati and Thorat 2008). Faster rice production growth has enabled countries such as India and China to experience increasing demand for industrial products and has stimulated the non-farm economy (Bezemer and Headey 2008; Haggblade, Hazell and Reardon 2007). Widespread adoption of Green Revolution technologies also resulted in a major shift in the food supply function, contributing to a reduction in real food

[1] Gollin, Hansen and Wingender (2016) examine the contribution of the Green Revolution to economic growth.

prices (Hayami and Herdt 1977; Scobie and Posada 1978) and avoiding the conversion of thousands of hectares of land into agricultural cultivation (Pingali 2012). Nevertheless, the nutritional gains of the Green Revolution are debated. Though calorie availability has increased, there is lack of diversity of food supply among the poor and micronutrient intake is still lagging (Hazell 2010). A recent study by Headey and Hoddinott (2016) tested more directly whether growth in yields of Bangladesh's main staple, rice, explains subnational trends in dietary diversification and nutrition outcomes for young children. They observe that rice productivity growth explains reductions in wasting but does not predict any improvement in the diversity of food supply among children, or stunting rates.

However, few countries have successfully accelerated the diversification of diets. There are a few exceptions, such as dairy interventions in India through Operation Flood (Cunningham 2009). India, historically a milk-consuming country, was heavily reliant on milk imports for decades and faced challenges in keeping up with domestic dairy demand. Operation Flood was a well-known smallholder dairy production initiative that invested in accelerating production and enhancing productivity to meet growing demands for dairy. This intervention transformed the policy environment and brought significant technological advancements into the rural milk sector. As a result, by 2007, India became the top milk producer in the world (buffalo, goat, cow) and the sixth largest producer of cows' milk, and milk was a bigger contributor to the country's GDP than rice.

Recently, there has been a growing interest in homestead gardening programs, but the extent of evidence is inconclusive. A systematic review (Masset et al. 2012) that includes 23 studies, mostly evaluating home garden interventions, finds that they are successful in promoting the consumption of nutrient-rich foods but the effect on the overall diet of poor people remains unclear. In contrast, Iannotti and colleagues (2009) evaluate homestead food production (HFP) programs introduced in Bangladesh by Hellen Keller International, and conclude that expectations of improvements in maternal and child micronutrient status have not been fully met. Despite clear evidence of HFP's positive impact on household production, diet quality and intake of micronutrient-rich foods, its effect on reducing the prevalence of deficiencies in vitamin A, iron or zinc is yet to be determined.

2.3 Data and methods

2.3.1 Data

In this paper, to examine the predictors of changes in DFS within countries, we use a cross-country panel data set that merges data from a variety of sources. Food balance sheets from the FAO, containing data on the supply of calories, proteins and fats from different food groups (e.g. cereals, vegetables) were used to create a very simple measure of diversity of food supply. Our outcome variable is calories supplied from non-staple foods, which excludes cereals and root crops. These data have well-known weaknesses. Conceptually, they do not measure the composition of diets per se, but only food supply, and much food may be wasted. Empirically, the underlying quality of national low-income country data sources that go into FAOSTAT is often poor. Nevertheless, these data remain the only comprehensive means of comparing the calorie content and diversity of food supplies across countries and over time. Moreover, while they may be measured with error (Del Gobbo et al. 2015), we show that the cross-country pattern for these indicators is indeed consistent with economic theory.

As the most suitable indicator of household purchasing power we use private consumption expenditure per capita, measured in international purchasing power parity (PPP) dollars from the World Bank (2016). In addition to purchasing power, education is often cited as a driver of demand for better diets, presumably through nutritional knowledge, and perhaps also through greater equality. We therefore use average years of schooling attained, constructed at five-year intervals, as our indicator for education (Barro and Lee 2010). We use share of urban population and the share of children aged 0–14 years in the population as indicators of urbanisation and the demographic transition (World Bank 2016). The World Bank (2009) also reports data on measures of topography (hills and mountains, lowland areas) that might influence production diversity. For example, hill areas are suitable for orchards and wet lowland areas tend to be less suitable for vegetable production. Likewise, rural population density can be considered a proxy for land constraints. Smaller farms may encourage households to diversify into higher value crops (Boserup [1965] 2005), or small farms may proxy for rural poverty and market underdevelopment (e.g. in rural land markets), which may constrain demand for more nutrient-rich foods. Likewise, land constraints typically result in livestock feed constraints, which limits the scope for livestock production in the absence of access to grazing commons. For infrastructure indicators, we include road density, international shipping costs, and electric power consumption. Though time-varying in principle, these indicators are only available for fixed points in time. Another set of time-invariant geographical characteristics (from WorldClim 2016 – a global climate database) contains data on average monthly rainfall and standard deviation. Cross-country average groundwater values have also been derived from the global groundwater database (Fan et al. 2013). Water availability could have complex relationships with production diversity. More rainfall, and more stability in rainfall, might reduce risk and encourage poor farmers to diversify production. On the other hand, too much water – especially groundwater – can lead to waterlogged soils that are poorly suited for vegetable production, leaving rice, in particular, as the only option for water-abundant lowland systems.

After integrating the data sets, we have an unbalanced panel data set of 51 countries (low-to-high–income countries) for the period 1965–2010, with a sample of 557 observations, observed every five years, although the actual sample size used varies according to the model specification (Table 2.9 in the Appendix lists the countries). Table 2.1 reports definitions of our dependent and independent variables and Table 2.2 reports descriptive statistics. About 52% of the population live in urban areas and 34% of the population are aged 0–14 years. More than half of the countries have hilly and mountainous areas and rural population density is relatively low on average. In addition, there is substantial variation in electric power consumption across countries. The sample covers ample variation in DFS and the main indicators of structural transformation, although we also test robustness to sample restrictions (Section 2.6).

Table 2.1 Definitions of variables

Variable	Definition
Diversity of food supply	
Calories supplied from non-staples	The share of calories not derived from starchy staples: cereals, roots, tubers, and plantains
Proteins from animal-sourced foods	Share of proteins supplied by any food of animal origin
Transformation indicators	
Consumption per capita	Household final consumption expenditure per capita is the market value of all goods and services purchased by households
Education (years)	Average years of schooling attained in five-year intervals

Urban population (% of total population)	Share of people living in urban areas
Population ages 0–14 (% of total)	Share of children in the population aged 0–14 years
Time-invariant geographical and infrastructural characteristics	
Rural population density	The population estimated to be rural, divided by agricultural land
Electricity consumption (kWh per capita)	The production of power plants less power plant use, transmission, distribution, and transformation losses, divided by midyear population
Road density (%)	Total length of the road network (includes the length of the paved and unpaved portions), divided by country land area
Shipping costs	Country ranking of international shipping costs
Groundwater depth (meters)	Average groundwater values in total land area
Hills and mountains (% of total land area)	The share of hill and mountain areas in total land area
Lowlands (% of total land area)	The share of lowland areas in total land area
Suitable land (%)	The share of land suitable in total land area
Rainfall (mm)	Average monthly rainfall, 1980–2000
Rainfall_std (mm)	Standard deviation of monthly rainfall over 1980–2000

Source: FAO (2016); World Bank (2009, 2016); Barro and Lee (2010); WorldClim (2016).
Note: kWh = kilowatt-hours.

Table 2.2 Descriptive statistics for key variables

Variable	Observations	Mean	Standard deviation	Min	Max
Share of calories supplied from non-staples (0–1)	557	0.49	0.16	0.14	0.78
Share of proteins from animal-sourced foods (0–1)	557	0.40	0.17	0.09	0.70
Consumption expenditure (constant PPP $)	557	5753.96	5906.03	144.33	27044.62
Education (years)	557	5.92	2.83	0.13	12.03
Urban population (% of total population)	557	51.59	20.96	3.58	92.49
Population ages 0–14 (% of total population)	557	34.11	10.32	13.29	49.97
Electric power consumption (kWh per capita)	557	27.20	25.40	0.03	99.32
Road density (roads per 1,000 sq. km)	557	74.59	90.72	3.60	372.20
Shipping costs (global rank)	557	70.31	46.68	2.00	169.00
Suitable land (%)	557	61.92	21.82	20.64	97.63
Population density (per 1,000 m^2)	557	111.82	164.52	0.39	1164.14
Hills and mountains (% of total land area)	557	0.52	0.30	0.00	1.00
Lowlands (% of total land area)	557	0.25	0.23	0.00	1.00
Groundwater (meters)	557	1.91	1.19	0.07	4.82
Average rainfall (mm)	557	90.85	49.53	27.60	227.00
Rainfall variation (mm)	557	51.39	39.95	6.40	169.50

Source: FAO (2016); World Bank (2009, 2016); Barro and Lee (2010); WorldClim (2016)
Note: PPP = international purchasing power parity; kWh = kilowatt-hour.

2.3.2 Methods

In terms of methods, we implement a variety of statistical techniques via Stata version 14.0. Graphically, we apply nonparametric techniques, specifically, the local polynomial smoother with 95% confidence intervals (the *lpolyci* command) to assess nonlinear relationships in key parameters of interest. To explore factors that might influence DFS, we first estimate FE models to assess the associations between *DFS* for a country *i* and time *t* and a vector of time-varying intermediate determinants (*X:* consumption, education, urbanisation and population ages 0–14 years), country fixed effects (μ_i) and trend effects represented by a vector of year dummy variables *(T).* The vector of coefficients (β) constitutes the set of parameters of principal interest. With the addition of an error term ($\varepsilon_{i,t}$), we represent the relationship by equation (1):

$$\boldsymbol{DFS_{i,t} = \alpha + \beta log X_{i,t} + T_t + \mu_i + \varepsilon_{i,t}} \quad (1)$$

But while FE models are useful for controlling for a range of time-invariant effects that might be correlated with time-varying factors such as mean consumption levels or education, a disadvantage of such models is that researchers are sometimes directly interested in the impacts of time-invariant factors, such as agroecological constraints and transport costs. We therefore utilise the CRE model, also called the Chamberlain-Mundlak device following Mundlak (1978) and Chamberlain (1984), allowing coefficients of time-invariant independent variables to be identified. In this model, fixed effects are effectively replaced with country averages of time-varying indicators as well as a vector of time-invariant indicators of interest (e.g. agroecological indicators). This model still therefore specifies within-country effects of time-varying indicators (e.g. growth in consumption per capita) but allows us to test associations between time-invariant factors and DFS. The key assumption is that the remaining unobserved heterogeneity is uncorrelated with the independent variables.

The CRE model therefore takes the form:

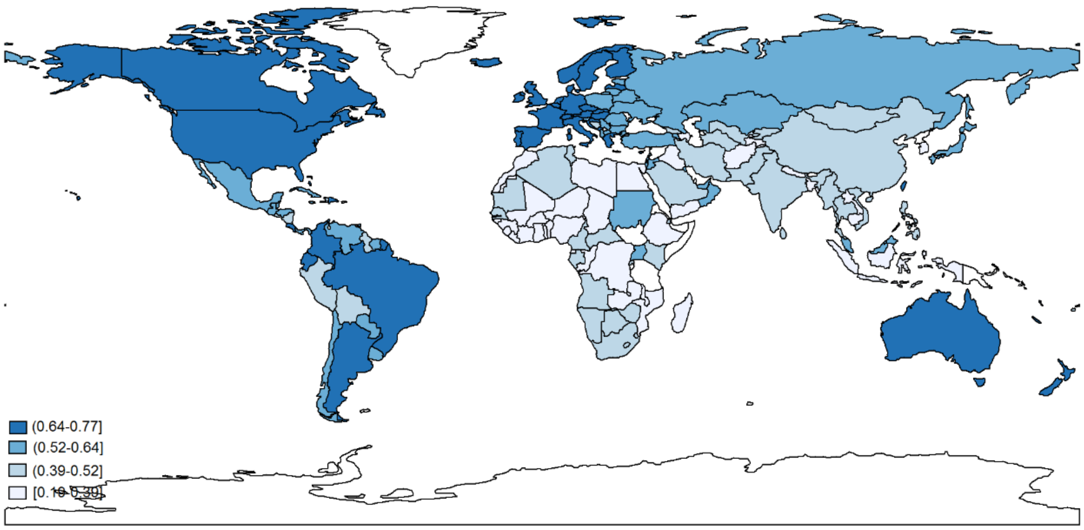
$$\boldsymbol{DFS_{it} = \alpha + \beta log\, X_{it} + \theta \overline{log\, X_i} + \gamma log\, z_i + T_t + \varepsilon_{it}} \quad (2)$$

to assess the associations between *DFS* for a country *i* and time *t* and a vector of time-varying determinants (*X:* consumption, education, urbanisation and population ages 0–14 years). *T* refers to time dummies; $\overline{X_i}$ includes time averages of all covariates; z_i is a vector of time-invariant variables related to geographical characteristics; and ε is an error term. β can be interpreted as the fixed-effects 'within-country' estimate of the predicted impact of changes over time in X on changes in *DFS*.

2.4 Descriptive results

How does DFS vary across regions and income levels? In this section, we assess patterns and trends in DFS to understand some basic stylised facts. Figure 2.1 presents a map of DFS across countries for 2010, with darker shades of blue representing greater DFS. The map provides several insights. Unsurprisingly, the map indicates that North America, Western Europe, Australia, New Zealand and several Latin American countries show the highest levels of diversity of food supply, followed by Eastern Europe, Japan and several Latin American countries (e.g. Mexico, Chile). One explanation is that these regions have higher consumption per capita levels, which enable them to import more nutritious foods compared to other regions. In contrast, South Asian countries have low diversity of food supply, particularly Bangladesh and Nepal. In Africa there is some heterogeneity, but DFS is very low in West Africa, Ethiopia and much of southern Africa.

Figure 2.1 Calories supplied from non-staples across countries, 2010



Source: Authors' estimates from FAO (2016) data
Note: Each country is coloured according to value of corresponding diversity of food supply.

Table 2.3 reports trends in DFS for income groups, major regions and countries over 1961-2010. For income groups (as defined by 2010 data), the major result is that dietary diversification was slow in the poorest income groups, with just a 5 percentage point increase over 1961-2011 for both the low income and lower middle income groups. In contrast, upper middle income and high income OECD groups saw 11 point and 9 point changes over this period. Regionally, Latin America and the Caribbean saw moderate changes on average, though changes in countries like Mexico and Brazil were rapid (14 point changes in both countries). Sub-Saharan Africa has seen very little diversification in food supplies, just 5 points on average, and there is relatively little variation in DFS changes (or at least, no country experiencing rapid improvements). In South Asia Pakistan saw a sizeable improvement in DFS (11 points) but changes in India and Bangladesh were very modest (3 and 4 points). In East Asia and the Pacific there was similar variation: China and Vietnam experienced dramatic increases in DFS (25 and 23 points respectively), but Indonesia saw only a modest 6 point increase.

Table 2.3 Trends in calories supply from non-staples for income groups, major regions and countries, 1961-2010

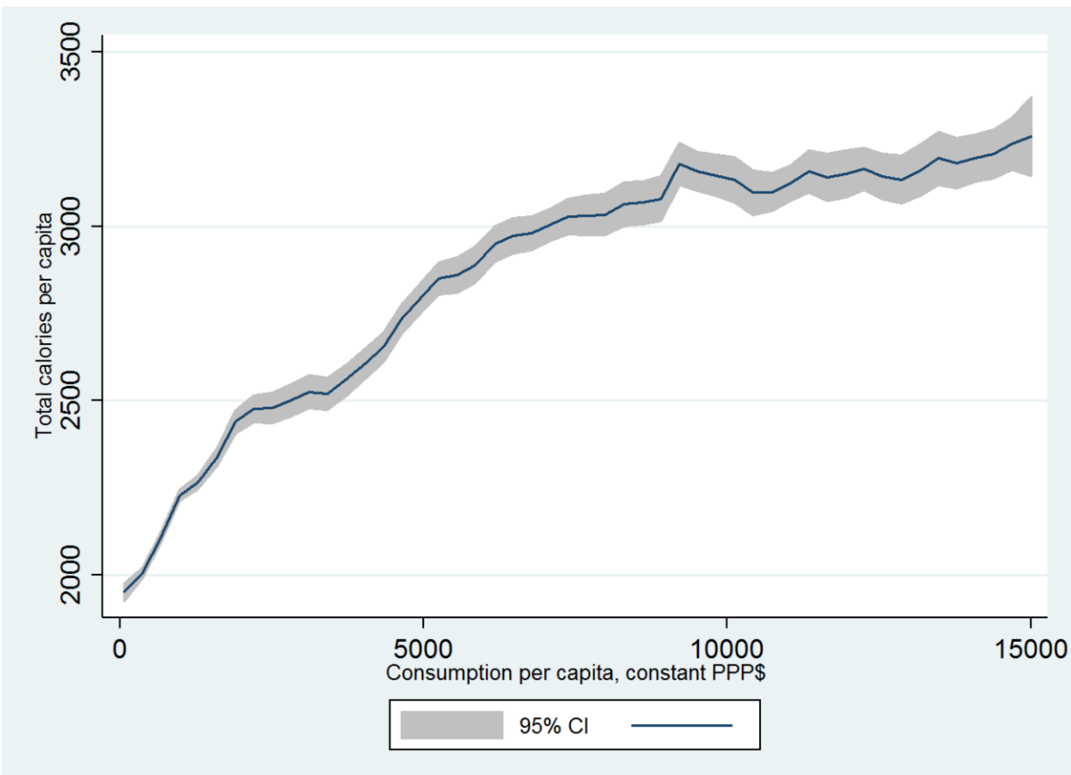
	Sample median: 1961	Sample median: 2010	Change in median
High income OECD	61%	70%	9%
Japan	34%	58%	24%
Upper middle income	44%	55%	11%
Lower middle income	35%	40%	5%
Lower income	25%	30%	5%
Latin America & Caribbean	48%	55%	7%
Mexico	41%	55%	14%
Brazil	50%	65%	14%
Sub-Saharan Africa	32%	36%	5%
Nigeria	34%	34%	0%
Kenya	34%	41%	7%
South Asia	30%	37%	7%
India	36%	39%	3%
Pakistan	40%	51%	11%
Bangladesh	15%	19%	4%
East Asia and Pacific	33%	43%	10%
Vietnam	16%	39%	23%
China	23%	48%	25%
Indonesia	23%	29%	6%

Source: FAO (2016). Notes: 3-letter World Bank country codes denote specific observations.

2.4.1 Nonparametric estimates of the relationship between household consumption per capita and calories per capita and DFS

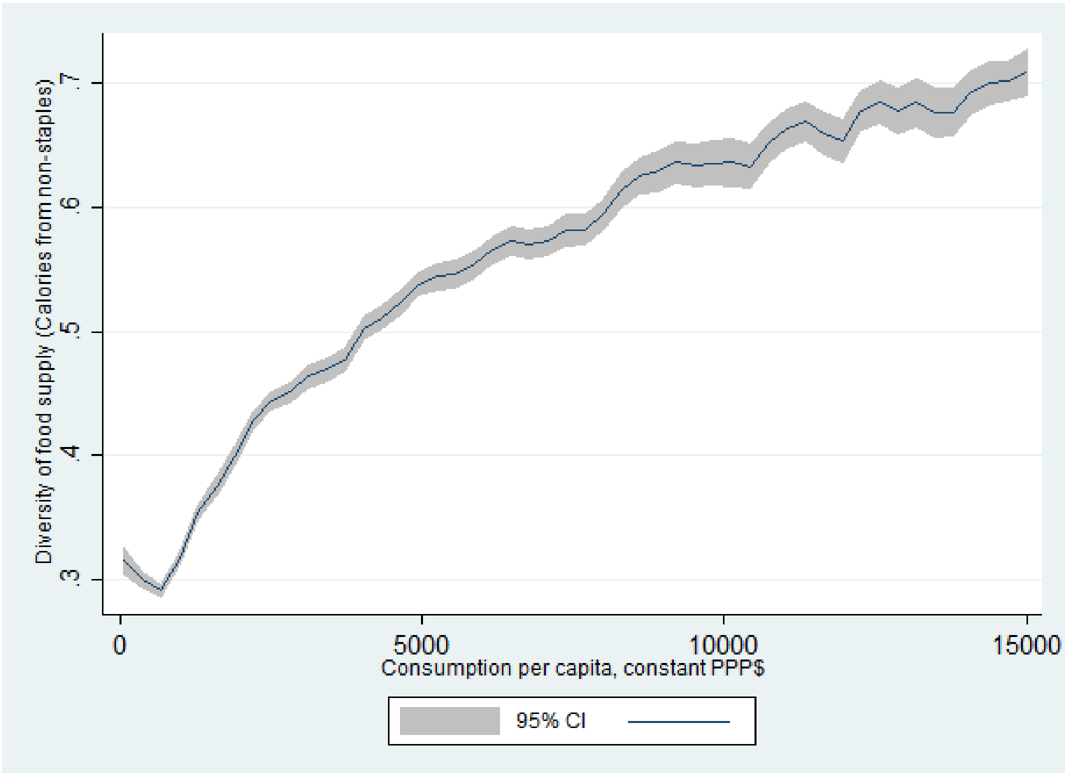
In Figures 2.2 and 2.3, we look at the association between calories per capita, diversity of food supply indicator and household consumption per capita. We observe concave relationships that are reasonably strong.

Figure 2.2 Calories per capita and household income per capita



Source: Authors' estimates
Notes: These are local polynomial smoother estimates with 95% confidence intervals estimated in Stata 14.

Figure 2.3 Calories supplied from non-staples and household consumption per capita



Source: Authors' estimates

Notes: These are local polynomial smoother estimates with 95% confidence intervals estimated in Stata 14.

2.5 Regression results

Table 2.4 reports FE and CRE regressions of diversity of food supply indicator against time-varying indicators of structural transformation, as well as a series of time-invariant indicators of infrastructure and agroecological characteristics using semi-log specifications.

As the nonparametric results suggested, per capita consumption expenditure is a strong predictor of changes in DFS, even in terms of within-country effects. For every doubling of household consumption expenditure, calories supplied from non-staples will go up by nearly six percentage points, an association that is strongly significant at the 1% level in both FE and CRE regressions.

However, other indicators of structural transformation are also highly significant. Indeed, point estimates of the partial elasticity of DFS with respect to urbanisation are somewhat larger than that of consumption per capita (though not significantly so). Even more strikingly, the population aged 0–14 years has a large, negative and highly significant association with DFS in both the FE and CRE models. Moreover, these associations are significantly larger than the coefficients on consumption per capita. Perhaps surprisingly, however, we do not find any significant association between the years of education variable and DFS.

As noted in Section 2.3, the CRE model also allows us to test associations between DFS and time-invariant factors, such as infrastructure variables and agroecological indicators. Most of these other determinants have much smaller partial elasticities. In terms of transport infrastructure, the partial elasticity for road density is 0.04 in the non-staple share regression for the full sample (regression 1), while the elasticity associated with shipping costs is insignificant. This likely reflects the fact that many nutrient-rich foods are highly perishable and are not shipped large distances. For example, eggs are scarcely traded at all across international borders (FAO 2016).

Consistent with economic theories of highly imperfect markets in underdeveloped rural settings, we observe some significant associations between DFS and various agroecological characteristics. Land suitability for crop production is positive and significantly associated with DFS (0.02). More strikingly, rural population density has relatively large and negative partial elasticities of -0.11, -0.14 and -0.16 (regressions 4, 5 and 6), which suggests that land constraints inhibit dietary diversification. Lowland areas have an insignificant association (regression 4), and hilly and mountainous countries appear to have somewhat increased consumption of non-staple foods.

Table 2.4 CRE and fixed effects regressions of the semi-log DFS model

	(1)	(2)	(3)	(4)	(5)	(6)
Estimator	FE	FE	FE	CRE	CRE	CRE
Sample restrictions	None	Consumption <10K	Consumption <5K	None	Consumption <10K	Consumption <5K
Time-varying indicators						
Consumption per capita	0.055***	0.057***	0.060***	0.059***	0.062***	0.062***
	(0.006)	(0.007)	(0.007)	(0.012)	(0.014)	(0.015)
Education (years)	0.006	-0.003	-0.011	0.014	-0.001	0.010
	(0.012)	(0.014)	(0.015)	(0.024)	(0.027)	(0.029)
Urban population	0.066***	0.055***	0.046***	0.067***	0.073***	0.064**
	(0.011)	(0.012)	(0.013)	(0.023)	(0.025)	(0.027)
Population ages 0-14 years	-0.095***	-0.063***	-0.033	-0.088**	-0.066	-0.076
	(0.018)	(0.022)	(0.025)	(0.036)	(0.044)	(0.050)
Time-invariant indicators						
Electricity consumption				-0.003	-0.019	-0.061***
				(0.012)	(0.016)	(0.020)
Road density				0.039***	0.049***	0.057***
				(0.004)	(0.005)	(0.006)
Shipping costs				-0.002	0.008	0.023***
				(0.004)	(0.005)	(0.006)
Suitable land				0.024***	0.007	-0.009
				(0.007)	(0.009)	(0.013)
Population density				-0.114***	-0.140***	-0.156***
				(0.012)	(0.015)	(0.017)
Hills and mountains				0.006**	0.014***	0.025***
				(0.003)	(0.004)	(0.006)
Lowland areas				0.002	0.008*	0.016***
				(0.003)	(0.004)	(0.005)
Groundwater depth				-0.014***	-0.013**	-0.004
				(0.005)	(0.006)	(0.007)
Average rainfall				-0.028***	-0.027**	-0.031**
				(0.010)	(0.013)	(0.015)
Rainfall variation				-0.011	0.007	0.021
				(0.007)	(0.010)	(0.013)
Time effects	Yes	Yes	Yes	Yes	Yes	Yes
Constant	0.120	0.025	-0.081	-0.367***	-0.247*	-0.153
	(0.094)	(0.111)	(0.123)	(0.102)	(0.127)	(0.167)
Observations	557	447	354	557	447	354
R-squared				0.870	0.801	0.754
R-squared within	0.624	0.595	0.597			

Source: Authors' estimates. ***p < 0.01, **p < 0.05, *p < 0.1. Standard errors are in parentheses.

Groundwater has a negative association with DFS, meaning that higher water tables predict lower levels of DFS, but rainfall is also negatively associated with DFS, suggesting that the relationship between water supply and diversification may be quite complicated.

Finally, both models produce large coefficients of determination, suggesting that these specifications do a good job in predicting spatial and temporal variation in DFS. The difference in R-squared coefficients between the full model and models with sample restrictions is relatively small for both CRE and FE regressions. Overall, the results support Bennett's (Bennett 1941) prediction that economic growth leads to diversification of food supplies, but the models are also highly consistent with broader theories of structural transformation, and microeconomic theories of market failures in agrarian settings (Section 2.2).

We now use these regressions results from Table 2.4 to analyse the predicted sources of DFS change over time using a simple decomposition at means technique, the results of which we report in Table 2.5.[2] These decompositions are based on the fixed effects model reported above, since the time-invariant indicators in the CRE model obviously cannot explain changes over time. To see how these figures are derived, consider the second row of column 5 of Table 2.5, which reports the predicted change in DFS – the mean change in consumption per capita from 1961 to 2010, multiplied by the coefficient of consumption per capita on DFS from regression 1 in Table 2.4. This calculation suggests that increases in consumption per capita from 1961 to 2010 resulted in a 0.06 percentage point increase in the share of calories supplied from non-staples. In other words,

[2] A more flexible alternative to a simple decomposition at means is Oaxaca-Blinder decomposition, which allows coefficients to vary over time. However, the relatively small size of our sample produces some instability in the size of the coefficients when we restrict regressions to a single cross-section.

among the sources of predicted change, consumption per capita stands out as the single largest factor, explaining 41% of the predicted change in diversity of food supply. In addition to the modest impact of consumption per capita, we observe sizeable contributions from urbanisation (0.04) and reductions in the share of the population aged 0–14 (0.04). In aggregate, the model predicts an average change in DFS of 13 percentage points, which is slightly more than the actual change observed (11 points). Overall, though, it appears that these three structural transformation indicators do a good job of predicting changes in DFS over time.

Table 2.5 Decomposing sources of DFS change for the full sample, 1961–2010

	Estimated β	Sample mean: 1961	Sample mean: 2010	Change in mean	Predicted DFS change	Share of predicted DFS change
Diversity of food supply		0.43	0.52	0.10	0.13	100%
Consumption per capita	0.06	7.58	8.58	1.00	0.06	41%
Urban population	0.07	3.47	4.09	0.62	0.04	31%
Population ages 0–14	-0.1	3.63	3.23	-0.4	0.04	28%

Source: Authors' estimates.

2.6 Robustness tests

In this section, we engage in a series of robustness checks designed to establish the extent to which the results presented in the previous section stand up to alternative specifications and to a more confident causal interpretation.

Table 2.6 reports FE and CRE regression results using an alternative indicator of diversity of food supply: the share of proteins supplied by animal-sourced foods (ASF supply). Animal-sourced foods have been cited as beneficial for child nutrition outcomes and for reducing deficiencies in major micronutrients (Hoppe, Mølgaard and Michaelsen 2006; Iannotti, Muehlhoff and McMahon 2013; Iannotti et al. 2014; Murphy and Allen 2003)[3]. In general, results in Table 2.6 are similar to those in Table 2.4, however, there are a few differences as well. The coefficients on household consumption per capita are slightly larger in the context of ASF supply. The coefficients on urbanisation are insignificant in all the regressions reported in Table 2.6, however, the share of the population aged 0–14 years reveals a large and negative elasticity. Moreover, in the CRE model, we observe positive but modest relationships between ASF supply and electricity supply and road density, but again, there is no significant association with shipping costs. As with the result in regression 4, land suitability is positively associated with ASF supply but negatively associated with population density. Groundwater depth is also negatively associated with ASF supply, but rainfall has a positive association with the dependent variable, possibly reflecting the importance of rainfall for increasing feed availability.

[3] Chapter 3 analyses the impact of household dairy production on child growth in rural Bangladesh. We find evidence that dairy milk production is positively associated with linear growth in young children.

Table 2.6 CRE and fixed effects regressions of the semi-log DFS model using alternative indicator of diversity of food supply: protein share of ASF

	(1)	(2)	(3)	(4)	(5)	(6)
Estimator	FE	FE	FE	CRE	CRE	CRE
Sample restrictions	None	Consumption <10K	Consumption <5K	None	Consumption <10K	Consumption <5K
Time-varying indicators						
Consumption per capita	0.063***	0.062***	0.067***	0.059***	0.056***	0.048***
	(0.008)	(0.008)	(0.009)	(0.012)	(0.013)	(0.014)
Education (years)	0.012	-0.020	-0.037**	0.011	-0.025	-0.029
	(0.015)	(0.017)	(0.018)	(0.024)	(0.027)	(0.028)
Urban population	0.023	0.011	0.010	0.030	0.029	0.023
	(0.014)	(0.015)	(0.016)	(0.023)	(0.025)	(0.026)
Population ages 0-14 years	-0.155***	-0.133***	-0.108***	-0.165***	-0.153***	-0.196***
	(0.023)	(0.027)	(0.030)	(0.037)	(0.043)	(0.049)
Time-invariant indicators						
Electricity consumption				-0.004	-0.012	-0.058***
				(0.012)	(0.015)	(0.020)
Road density				0.012***	0.011**	0.019***
				(0.004)	(0.005)	(0.006)
Shipping costs				-0.001	0.003	0.011*
				(0.004)	(0.005)	(0.006)
Suitable land				0.031***	0.017*	-0.007
				(0.007)	(0.009)	(0.013)
Population density				-0.128***	-0.136***	-0.152***
				(0.012)	(0.014)	(0.017)
Hills and mountains				-0.006**	-0.008**	-0.011*
				(0.003)	(0.004)	(0.006)
Lowland areas				0.006*	0.013***	0.019***
				(0.003)	(0.004)	(0.005)
Groundwater depth				-0.034***	-0.036***	-0.029***
				(0.005)	(0.006)	(0.007)
Average rainfall				0.040***	0.026**	0.004
				(0.010)	(0.012)	(0.015)
Rainfall variation				-0.010	0.008	0.037***
				(0.007)	(0.010)	(0.013)
Time effects	Yes	Yes	Yes	Yes	Yes	Yes
Constant	0.337***	0.334**	0.220	-0.390***	-0.361***	-0.128
	(0.118)	(0.135)	(0.149)	(0.102)	(0.125)	(0.165)
Observations	557	447	354	557	447	354
R-squared within	0.541	0.501	0.505			
R-squared				0.885	0.839	0.807

Source: Authors' estimates ***p < 0.01, **p < 0.05, *p < 0.1. Standard errors are in parentheses.

Table 2.7 reports results from adding alternative indicators of education. The education indicator used in the previous section was years of schooling from Barro and Lee (2010), but Cohen and Soto (2007) criticised the quality of that data and produced an alternative series measured every 10 years. The coefficient on years of education is still insignificant, however, and there is no evidence that education contributes to DFS.

Table 2.7 Fixed effects regressions of the semi-log DFS model using an alternative indicator of education

	(1)	(2)
Estimator	FE	FE
Education (years) (Barro and Lee 2010)	0.006	
	(0.012)	
Education (years) (Cohen and Soto 2007)		0.028
		(0.018)
Consumption per capita	0.055***	0.051***
	(0.006)	(0.009)
Urban population	0.066***	0.061***
	(0.011)	(0.014)
Population ages 0–14 years	-0.095***	-0.119***
	(0.018)	(0.025)
Constant	0.120	0.218*
	(0.094)	(0.129)
Observations	557	304
R-squared within	0.624	0.662

Sources: Authors' estimates ***p < 0.01, **p < 0.05, *p < 0.1. Standard errors are in parentheses.

Next, we consider a series of different indicators of agricultural and trade policies – tariff rate, agricultural tax and subsidy, price level of consumption and public spending on agriculture. These indicators were not available for all countries and all years, and were therefore omitted from the results reported in the previous section. Table 2.8 reports FE results from including these indicators.

In regression 1, we include indicators of real rates of assistance to agriculture (RRA) from the World Bank agricultural distortions database (Anderson 2008). We separate the RRA indicators into subsidies and taxes, where positive RRA values are agricultural subsidies and negative RRA values are agricultural taxes. We find a positive and significant partial elasticity of DFS with respect to agricultural subsidies, though the association is small in magnitude (0.02). We find no effects of agricultural taxation.

We also find no effect of agricultural tariff rates on DFS and do not find any association between the price level of consumption (the PPP for consumption relative to the official exchange rate) and DFS. Yet, we do find a small positive association between public spending on agriculture and DFS. Thus, there is some evidence that greater public support for agriculture (as a share of total spending) enhances diversification, although the associations are modest. Future research could possibly concentrate on using better indicators of agricultural development strategies – differentiating strategies that focus on staple foods versus more nutrient-rich foods.

Table 2.8 Fixed effects regressions of the semi-log DFS model using alternative indicators of agricultural and trade policies

	(1)	(2)	(3)	(4)
Estimator	FE	FE	FE	FE
Consumption per capita	0.053***	0.041**	0.056***	0.049***
	(0.010)	(0.017)	(0.006)	(0.011)
Education (years)	-0.002	0.077***	0.006	0.055***
	(0.017)	(0.028)	(0.012)	(0.019)
Urban population	0.096***	0.087**	0.068***	0.045**
	(0.016)	(0.039)	(0.011)	(0.019)
Population ages 0-14 years	-0.114***	-0.099***	-0.091***	-0.090***
	(0.027)	(0.030)	(0.018)	(0.024)
Tariff rate		0.006		
		(0.005)		
Agricultural tax	-0.018			
	(0.015)			
Agricultural subsidy	0.020*			
	(0.009)			
Price level of consumption			0.005	
			(0.005)	
Public spending on agriculture				0.015***
				(0.004)
Time effects	Yes	Yes	Yes	Yes
Constant	0.109	0.018	0.074	0.114
	(0.148)	(0.232)	(0.103)	(0.143)
Observations	300	171	557	287

Sources: Authors' estimates ***p < 0.01, **p < 0.05, *p < 0.1. Standard errors are in parentheses.

2.7 Conclusions

While most economic studies tend to focus on the determinants of calorie consumption, this paper looks at factors that drive the diversification of national food supplies over time across countries and regions. We adopt a novel methodological method, utilising a multi-country panel economics approach where our dependent variable is derived from FAO food balance sheets, while most of our independent indicators are from alternative sources. By using a CRE model, we are able to estimate the effects of time-invariant characteristics whilst still controlling for other unobserved time-invariant effects, as well as fixed effects. Our regression models find strong support for

Bennett's (1941) prediction that economic growth leads to DFS, but are also highly consistent with broader theories of structural transformation, notably, urbanisation and the demographic transition from a younger to an older population. These associations, the latter in particular, are significantly larger than the coefficients on consumption per capita. We can deduce that this demographic transition not only stimulates demand for food by influencing disposable income, but also may allow parents to demand higher quality nutrient-rich foods, potentially shifting their food preferences. Such pathways warrant future research.

Although structural transformation is clearly a very important driver of diversification, we also find evidence of some significant association between DFS and various agroecological characteristics, consistent with economic theories of highly imperfect markets in underdeveloped rural settings. One explanation may be that countries such as Bangladesh and Indonesia have lower levels of DFS, since they share certain agroecological characteristics that give them a comparative disadvantage in the production of non-staple foods. Our results support this hypothesis, revealing that high population density is in fact a very strong predictor of DFS. Population density, which is also a proxy for land availability and comparative disadvantage in agriculture, may highlight that land constraints somehow inhibit dietary diversification. On the other hand, our regression analysis also supports the hypothesis that higher water tables are a constraint to diversification, particularly in terms of fruit and vegetable production.

We believe that some of these findings yield some important implications for future research. It is worth mentioning that the regression analysis provides results that are highly consistent with existing economic theory and evidence. We find enough evidence to suggest that structural transformation indicators make sizeable contributions towards predicting changes in DFS over time, although some countries face constraints to this diversification process as a result of certain agroecological characteristics. Yet, a major challenge going forward is to understand policy options for promoting diversification. Firstly, policies should be tailored towards economic and agricultural conditions in specific countries. In the case of low-income countries, the target may be towards diversifying their production. For instance, in the case of Bangladesh, a country that clearly shows low levels of DFS, agricultural research should emphasise the production of more nutritious foods, namely, micronutrient-rich crops and livestock products such as Harvest Plus (http://www.harvestplus.org/).

Secondly, while there are many nutrition-sensitive interventions and programs designed to enhance dietary diversification, there is inconclusive evidence on such programs leading to improvements in diets without sustained growth in incomes (Pinstrup-Andersen 2013; Ruel et al. 2013). One way to improve diets is to focus on solving both supply (access to foods) and demand (knowledge) constraints. For instance, behavioural communication change policies can increase demand for nutrient-rich foods by changing household preferences, while food policies can be implemented to increase the affordability of nutrient-rich foods. Therefore, assessing the effectiveness of these kinds of policies in accelerating diversification would seem to be an important area for future research.

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Appendix: Supplementary Table

Table 2.9 List of countries in the sample

Algeria	Ghana	Nicaragua
Argentina	Greece	Panama
Australia	Hungary	Paraguay
Austria	India	Peru
Bangladesh	Indonesia	Philippines
Benin	Ireland	Portugal
Brazil	Italy	Romania
Bulgaria	Jamaica	Senegal
Cameroon	Japan	South Africa
China	Jordan	Spain
Costa Rica	Kenya	Syrian Arab Republic
Denmark	Malaysia	Thailand
Dominican Republic	Mexico	Tunisia
Ecuador	Morocco	Turkey
Finland	Nepal	Uruguay
France	Netherlands	Zambia
Gabon	New Zealand	Zimbabwe

Chapter 3:

Socio-economic and geographical determinants of dietary diversity among pre-school children in 39 countries

Samira Choudhury

(with Derek Headey & William Masters)

Abstract

Malnutrition in early childhood has severe long-term physical and economic costs. Critically, much of this malnutrition emerges at around 6 months of age when children are first introduced to monotonous diets low in protein and various micronutrients. The causes of low quality diets in young children are not well understood. Economic evidence has substantially focused on the income and price dimensions of household food/calorie demand, while nutritionists have focused on nutritional knowledge and under-emphasised the economic dimensions. To explore the determinants of children's diets more systematically, this paper first reviews the extensive economic literature on consumers' demand for diversity (Bennett's law), health production functions and nutritional knowledge, intra-household decision making, and farm household models that emphasise non-separability of decision making in the presence of market failures. To test the predictions of this literature we link Demographic and Health Survey (DHS) data on dietary diversity for 67,241 children aged 6-23 months from 39 developing countries to household socioeconomic characteristics and community level indicators of climate and infrastructure. Multivariate regressions uncover strong support for linear "Bennett curves" linking greater diversity to household wealth, but also large and nonlinear associations with parental education, access to health services, infrastructure and climate, and modest associations with an indicator of women's empowerment. These results yield important insights for dietary diversification strategies.

Key words: Child malnutrition; Child diets; Dietary diversity; Bennett's law.

3.1 Introduction

Child undernutrition remains a major and costly problem in least developed countries, including stunting and key micronutrient deficiencies such iron and vitamin A deficiency. About 165 million children under the age of five are affected by stunting (height-for-age z scores (HAZ) <-2), a generic indicator of chronic undernutrition (Black et al. 2013), and almost half are affected by one or more micronutrient deficiencies (Ahmed et al. 2012). Early childhood undernutrition is strongly associated with poor health and cognition, in addition to low educational attainment and reduced lifetime earnings (Glewwe et al. 2001; Horton et al. 2008; Hoddinott 2009).

Critically, the emergence of growth faltering and micronutrient deficiencies typically emerges at age 6 months when children are first introduced to solid foods (Shrimpton et al. 2001; Victora et al. 2010). Whilst the emergence of undernutrition at this age could partly be due to increased exposure to pathogens and higher rates of infection, the introduction of low quality undiversified diets also undoubtedly plays a critical role. Black et al. (2013) report strong evidence that promoting appropriate diets and complementary feeding in the first two years of life decreases the prevalence of stunting and micronutrient deficiencies. Evidence from Arimond and Ruel (2004) and Mallard et al. (2014) indicates that nutrient-rich diets (particularly diets rich in animal-sourced foods) are associated with decreases in chronic malnutrition.

Despite the importance that nutritionists attach to dietary diversification and appropriate feeding patterns in early childhood, the determinants of dietary patterns in young children are not well understood. Nutritional interventions have tended to focus on improving nutritional knowledge, presumably viewing that as a key constraint (Dewey 2008; Kuchenbecker et al. 2017), or on combined agriculture-nutrition interventions that implicitly assume that households are unable to fully satisfy their demand for nutrient-rich foods via markets (Berti et al. 2004; Leroy and Frongillo 2007; Masset et al. 2012).[4] Economic research has emphasised consumer demand for diversity at least since Marshall (1890, 1961), with significant theoretical (Jackson 1984) and empirical applications in recent decades (e.g. Bennett 1941; Moon et al. 2002; Stewart and Harris 2005). Most of this research is focused on household diets in developed countries, however.

Research on diets in low-income countries has also focused on household demand. This evidence has tended to emphasise the role of household income in determining the demand for aggregate calories (Engel's law), though many studies confirm that non-staple nutrient-dense foods, such as animal-sourced foods, fruits and vegetables have higher income elasticities compared to starchy staples (Melo et al. 2015), suggesting consumers at least implicitly demand more diversity as their incomes rise. These results are consistent with Bennett's Law (1941), which states that economic growth results in diversification away from starchy staples (Clement, Wu and Zhang 2006; Theil and Finke 1983; Choudhury and Headey 2017).

An emerging literature examines agricultural determinants of child or household level dietary diversity in low income countries, often exploring the separability hypothesis that market failures produce strong linkages between production diversity and dietary diversity (Hoddinott, Headey and Dereje 2015; Hirvonen et al. 2017; Sibhathu et al. 2015; Jones et al. 2017; Carletto et al.

[4] A handful of observational studies (Senarath et al. 2012) by nutritionists do indeed explore a much broader set of socio-economic determinants of dietary diversity and other infant and young child feeding practices in low-income countries. The regression models in these studies certainly bear some similarities to those used in this paper, but with no real emphasis on the theory behind the diversification of diets, nor any application of somewhat more sophisticated econometric methods or geospatial data.

2015). But these studies typically only focus on agricultural determinants and not on the broader determinants of dietary diversity during the critical window of early childhood development.

In this paper, we first make the case that a more theoretical thought needs to be given as to the determinants of children's diets in developing countries. The extensive economic literature on consumers' income-elastic demand for diversity is clearly highly relevant, but any treatment of children's diets must also emphasise the importance of health production functions and nutritional knowledge among parents and other caregivers, as well as intra-household decision making models that often posit conflicting preferences between parents. Moreover, farm household models emphasise the non-separability of decision making in the presence of market failures, suggesting that community-level agricultural and infrastructural characteristics may also shape diets.

To test the different hypotheses emerging from this literature, we use non-parametric and parametric regression models to analyse an exceptionally rich multi-country dataset combining indicators of children's dietary diversity scores (the number of 12 food groups consumed by the child 6-23 months in the last 24 hours) and household characteristics from Demographic and Health Survey (DHS) data (ICF International 2015) with community-level geographic information systems (GIS) data on climate, agricultural potential and infrastructure. As a result, this study has several important and innovative features.

First, we use a measure of individual dietary diversity that is nutritionally meaningful. In the DHS, foods are grouped by nutritional attributes, using ex-ante classification based on nutrient composition. Second, rather than focusing on expenditure or income to estimate Engel curves, we measure household socioeconomic status via a multi-country wealth index via principal components analysis. This type of index has previously been shown to have many desirable properties (Filmer and Pritchett 2001). We also argue that the specific index we construct appears to have substantial cross-country comparability. Third, GIS data on infrastructure and agro-climatic factors allows us to explore ecological determinants of children diets, which have largely been neglected in both the economic and nutrition literatures on this subject.

The paper is structured as follows. Section 3.2 provides a brief review of the diverse theoretical and empirical literature on consumer demand for dietary diversity, health production functions and nutritional knowledge, intra-household decision making models and rural household models that emphasise market failures. Sections 3.3 and 3.4 report the data and methods used in the paper. Section 3.5 presents the empirical results. Section 3.6 discusses a range of sensitivity tests. Section 3.7 concludes and addresses policy implications and areas for future research.

3.2 Literature review

This section outlines some key literature relating to the determinants of child dietary diversity. First, we review some of the theory and evidence on consumer demand for diversity since Marshall (1890, 1961), with significant theoretical (Jackson 1984) and recent empirical applications (e.g. Moon et al. 2002; Stewart and Harris 2005). Second, we examine the importance of nutritional knowledge among parents and other caregivers. Third, we examine the literature on intra-household decision making models that often posit conflicting preferences between mothers. Finally, we turn to rural household models that highlight the non-separability of decision making in the presence of imperfect markets, suggesting that community-level agricultural and infrastructural factors determine access to diverse diets.

3.2.1 Consumer demand for diversity

The idea that individuals demand more dietary diversity as their incomes rise is certainly not new. Senior (1836) and Marshall (1890, 1961) focused on the principle of increasing needs. They discuss the problem of consumer's absolute satiation, which results in a long-lasting search for novelty (Marshall (1961) refers to Senior's Law of Variety). Following Senior, Jevons (1971) was among the first to examine the insatiability of consumers' taste for diversity.

Traditional demand theory indicates that a consumer has an inherent preference towards diversifying his/her choices. The consumer demands additional goods every time he or she is introduced to a wider bandwidth of goods arising from product differentiation and innovation (Falkinger and Zweimüller 1996). Likewise, this assumption is also understood in the axiom of convexity of preferences, which states that the consumption of combined goods is preferred to a consumption of the same amount of any single item. However, because the traditional model assumes homothetic preferences (i.e. constant income elasticities), higher income has no effect on the demand for diversity; instead, higher income leads to a constant rise in food expenditure in such models.

Various extensions of traditional demand theory to model consumer demand for food diversity have been applied. Jackson (1984) developed the "hierarchical model of consumer demand" as a more appropriate framework for modelling demand for diversity, based on Maslow's hierarchy of needs (Maslow 1943).[5] The hierarchical model of consumer demand posits that the consumer purchases additional goods only after he or she earns a certain level of income that satisfies demand for “necessities.” Amongst foods, it stands to reason that poor consumers first satisfy calorie requirements because of the importance of calories for physical survival. When consumers’ incomes reach higher levels, new and additional goods are purchased, referred to as “luxuries”, which in the case of food could refer to tastier sources of calories, or other nutritional objectives such as meeting protein, fat and micronutrient requirements.

According to Jackson (1984), these hierarchical preferences are functions that alter the set of purchased goods as incomes rise. These hierarchical preferences shape increases in diversity in a specific way, conditional on prices. The increase in diversity occurs asymptotically with income at a decreasing rate. Demand for any good is contingent on the position of the good in the hierarchy of purchases and on the consumer’s budget constraint. In this context, diversification clearly involves a combination of taste and knowledge of the nutritional properties of different foods.

Empirical work on the demand for variety has increasingly emphasised the link between income and diversity. Jackson (1984) examines the demand for diversity using cross-sectional household data, demonstrating that diversity of goods purchased rises with incomes. In terms of food consumption, various country-level studies confirm Jackson’s finding, and in addition reveal which socio-economic characteristics influence preferences for dietary diversity other than food expenditure (Thiele and Weiss 2003; Theil and Finke 1983; Torheim et al. 2004; Thorne-Lyman

[5] Benassy (1996) motivates demand for diversity by generating a parameter representing the utility gain the consumer acquires from consuming diversity instead of consuming a single item.

et al. 2010; Rashid et al. 2011; Bhagowalia et al. 2012; Drescher and Goddard 2011; Shimokawa 2013; Pollack 2001; Regmi 2001). Conventional consumer demand studies also indirectly corroborate consumer demand for diversity through systematic differences in income elasticities. A meta-analysis of demand studies from Africa south of the Sahara by Melo et al. (2015), for example, estimates that non-staple nutrient-dense foods, such as animal-sourced foods, fruits and vegetables, have higher income elasticities compared to cereals, legumes and nuts, and roots and tubers, implying that income gains will translate into more diversified diets.

3.2.2 Nutritional knowledge, formal education and health services

Grossman (1972) developed the concept of health production functions by which household members produce household health by combining economic resources including financial expenditures on food and non-food goods and services as well as time devoted to caregiving, nutritional knowledge and resources to promote the health of their members (Berman, Kendall and Bhattacharyya 1994). A key insight of this approach is that health outcomes partly reflect household decision making under financial and time constraints. These decisions partly reflect health knowledge, including nutritional knowledge.

In economics, a number of recent studies have explored the role of maternal education as a potentially important determinant of nutritional knowledge, and hence nutrition outcomes (Burchi 2012; Headey 2013; Thomas, Strauss and Henriques 1991; Webb and Block 2004). Block (2004; 2007), in particular, analyses the associations between maternal education, maternal nutritional knowledge, child malnutrition and the demand for micronutrient-rich foods. He reports that, in Indonesia, mothers with enhanced nutritional knowledge assign a greater proportion of their food budget towards foods rich in micronutrients, such as fruits and vegetables. Block (2007) addresses the distinct roles of maternal education versus maternal nutritional knowledge as determinants of child micronutrient status and shows that maternal education influences child micronutrient status directly but also indirectly through its impact on nutritional knowledge and household expenditure. Alderman and Headey (2017) find evidence that maternal education is more relevant than paternal education in explaining both stunting and a range of potential impact pathways, including child dietary diversity.

Other studies suggest that the importance of parental education or nutritional knowledge is conditional on wealth or access to markets (or vice versa). Several studies have shown that the impact of household wealth on child nutrition varies according to maternal education (Bairagi 1980; Solon et al. 1985; Reed et al. 1996). For example, Reed et al. (1996) show that wealth and maternal education interact to determine child nutritional status (weight-for-age z-scores). Similarly, the study by Leroy et al. (2014) on rural Mexico observes the interaction between household wealth and maternal education on child stunting controlling for relevant covariates. Their results find that household wealth is associated with increases in child height among more educated mothers (Hirvonen et al. 2017).

Another strand of literature focuses on the importance of Behavioural Change Communication (BCC) interventions designed to improve nutritional knowledge (Dewey et al. 2008; USAID 2014). In a number of randomized control trials in various settings, BCC has shown to be useful in improving child feeding practices, especially in areas characterised by greater access to food markets (Santos et al. 2001; Bhandari et al. 2004; Penny et al. 2005; Zaman, Ashraf and Martines 2008; Dewey et al. 2008).

In addition to the well-documented effects of education and nutritional knowledge on child nutrition, there is evidence linking health service utilization to nutrition outcomes (Headey 2013). Health service utilization indicators, such as if mothers had antenatal check-ups, neonatal care (a medical facility birth) and postnatal care in the form of vaccinations, have been found significant in studies focusing on the determinants of child stunting (Headey and Hoddinott 2015; Headey et al. 2015). Few of these studies look specifically at children's diets, however, and little is known about how much dietary information is imparted by conventional health services.

3.2.3 Intra-household models

The most restrictive health production function models assume unitary decision making in which all household members pool resources before allocating them according to a common set of preferences. Substantial evidence shows that the unitary version of the model has been rejected in various country settings, especially in low-income countries (Strauss and Thomas 1995; Behrman 1997; Haddad et al. 1997). Instead the evidence favours a model where individuals within the household do not behave in a unitary manner when making decisions (Alderman et al. 1995; Haddad, Hoddinott and Alderman 1997). This suggests that men and women do not pool their resources and hence may allocate resources differently, depending on their bargaining power within a household (Alderman et al. 1995; Hoddinott and Haddad 1995; Quisumbing and Maluccio 2003; Quisumbing 2003). Moreover, there is substantial evidence that women and men have quite different preferences, especially regarding child care. Increasing women's control over resources tends to have positive impacts on various child development outcomes, and has provided a rationale for a wide range of microfinance, social protection, health and nutrition programs to target interventions at women in general or mothers in particular (Hoddinott and Haddad 1995; Duflo and Udry 2004; Doss 2006; Malapit et al. 2015).

Although women's empowerment is widely regarded as crucial for improving nutrition, robust evidence of strong linkages has proven to be difficult to come by (van den Bold et al. 2013; Carlson et al. 2014). Because women are often primary caregivers, they are more likely to have an impact on child health and nutrition outcomes implicitly through their own nutritional status and also through childcare practices (Bhagowalia et al. 2012; Smith et al. 2003). A growing body of evidence using direct and indirect measures of women empowerment has shown the important linkages between women's empowerment and child nutrition as well as their own nutritional status (Bhagowalia et al. 2012; Engel 1993; Fafchamps, Kebede and Quisumbing 2009; Frost, Forste and Haas 2005; Smith and Haddad 2000). For instance, in Bangladesh, increases in women empowerment, as measured by decision making power within the household, have been associated with greater diversity scores and decreases in child stunting (Bhagowalia et al. 2012). Research conducted in Andhra Pradesh, India has found that measures of participation in decision making positively influence infant feeding and growth outcomes (Shroff et al. 2011). By contrast, women who are not empowered can have adverse nutritional impacts on their health as well as their children's health (Bhagowalia et al. 2012; Smith and Haddad 2000; Smith et al. 2003; Quisumbing and Maluccio 2003).

3.2.4 Rural household models

The majority of rural households in poor countries may consume food from their own farm production, partly due to multiple market failures arising from both demand and supply constraints. On the demand side, low incomes may be associated with reduced demand for nutrient-rich foods. On the supply side, farm households experience very high transaction costs (De Janvry, Fafchamps and Sadoulet 1991; Singh, Squire and Strauss 1986) associated with poor infrastructure that increase the costs of selling and purchasing food items in local markets, therefore encouraging self-sufficiency of food consumption. In many instances, perishable items such as fruits, vegetables and animal-sourced foods are consumed only if they can be locally produced, suggesting that community-level agricultural characteristics can significantly affect consumption patterns in poor settings.

Various studies have observed agricultural determinants of child or household level dietary diversity in underdeveloped countries, often testing the separability hypothesis that there are strong linkages between production diversity and dietary diversity in the presence of imperfect markets (Hoddinott, Headey and Dereje 2015; Hirvonen and Hoddinott 2017; Sibhatu et al. 2015; Jones et al. 2017; Carletto et al. 2015). Moreover, good infrastructure is likely to be important for agricultural diversification since non-staple foods are more perishable than staple foods, even after controlling for socio-economic conditions. For instance, evidence from Ethiopia finds that households with better access to markets have more diverse diets (Stifel and Minten 2017). Furthermore, market access can substitute for household level production diversity for food consumption if production choices are limited by agro-climatic conditions (Hirvonen and Hoddinott 2017; Hoddinott, Headey and Dereje 2015). Additionally, recent evidence by Shively (2016) suggests that continuing investments in health and transport infrastructure are essential for improving child nutrition.

3.2.5 Hypotheses

Based on these theories, we hypothesize that:

(1) income increases raise the demand for diversity (Bennett’s law);

(2) parental education is positively associated with child dietary diversity scores;

(3) maternal education has larger effects than paternal education;

(4) women's empowerment positively influences child dietary diversity scores;

(5) community-level agro-ecological and infrastructural conditions positively influence households' access to diverse foods; and

(6) there are significant interactions between these factors, since relaxing individual constraints may leave other constraints binding.

3.3 Data

We utilize data from 39 countries from Phases 5 and 6 of the Demographic Health Surveys (DHS) (ICF International 2015), which we then combine with Geographical Information Systems (GIS) data on infrastructure and agroecological conditions.

The DHS are generally acknowledged as high quality and are particularly useful for multi-country analysis due to their standardization. For our purposes these more recent phases of the DHS contain data on child diet diversity and a wide range of relevant explanatory indicators. For this paper, we used all available DHS data across countries and survey rounds (Table 3.10 in the Appendix lists the countries). Notably, 63% of our sample of children is from sub-Saharan Africa, and 19% from Latin America and the Caribbean sample. Other regions are relatively under-represented, with just two countries from the Middle East and North Africa (Egypt and Jordan), two from East Asia (Cambodia and Timor-Leste) and one from South Asia (Nepal). The primary outcome variable for this study is child dietary diversity, which is the unweighted sum of the number of 12 food groups consumed by the child 6-23 months in the past 24 hours (as reported by the child's mother or caretaker). The 12 food groups include two starchy staple food groups (cereals, roots and tubers), legumes and nuts, a range of different types of fruits and vegetables (vitamin A rich vegetables, vitamin A rich fruits, dark green leafy vegetables, other fruits and vegetables), and five types of animal-sourced foods (meat, organ meat, fish, eggs, and dairy products). In robustness tests we also use a common but more aggregated 7-food group indicators of child dietary diversity, which is used for constructing the official World Health Organisation minimum dietary diversity indicator (4 or more of 7 food groups).

Although the DHS does not include information regarding income or expenditures, it does contain information regarding assets and housing characteristics. These include ownership of household durables (radio, TV, refrigerator, motorbike, car) and housing characteristics (floor materials, access to electricity, access to piped water or an improved toilet). The precise list of assets is different across countries. For our paper, we include the set of assets, which are available in all rounds for each country and this information is used to construct an asset (or wealth) index (following Filmer and Pritchett 2001) via principal component analysis, which measures wealth linearly in quintiles of the national distribution (Sahn et al. 2003). Doing so allows this variable to have country specific impacts. Using all the pooled rounds of data available for a given country, we conduct a principal components analysis (PCA) to derive weights for the different assets in this index. For each country, common weights are applied across rounds to confirm that asset scores are consistently measured over time. Then we re-scale the index such that it varies between a maximum score of 10 and a minimum score of zero observed across all rounds in a given country.As it happens, country-specific weighting produce indices that were very highly correlated with the commonly weighted index (r=0.97), but the commonly weighted index has the advantage of cross-country comparability[6]. Another important socioeconomic indicator is whether the partner/father has a non-farm occupation as his primary source of income. Non-farm jobs may be useful in stabilizing incomes.

To capture the importance of formal education for nutritional knowledge we use years of formal schooling of mothers and their partners (usually the father of the child). We pool years of education into different year brackets whereby 1-6 years represent "primary education", 7-9 years denote "lower secondary" or "middle school" and 10-plus refer to attending "upper secondary" and receiving some amount of tertiary education. Nutritional knowledge may also be accumulated via exposure to health services. To this end we construct a health access index that equals 1 if mothers had antenatal check-ups, neonatal care (a medical facility birth) and postnatal care in the form of vaccinations. We also use an indicator of whether a child was breastfed within 1 hour of birth, as recommended by nutritionists. Likewise, an indicator of women's participation in decision making in determining her own healthcare is used more as a proxy for maternal empowerment, which may be particularly important insofar as mothers are usually directly responsible for feeding young children.[7]

Another series of indicators of importance are community characteristics. Access to markets may be an important prerequisite for a sufficient variety of affordable foods, especially perishable foods that are costly to trade long distances. The DHS records whether a cluster is urban or not,

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[6] An advantage of constructing our own asset/wealth quintile rather than using DHS wealth quintile is that we have control over which assets are included. In this sample of 67,241 children, both scores are quite comparable. The average score of household wealth quintile is 2.95 in contrast to the DHS score, which is 2.68.

[7] We experimented with other control variables reported in the DHS, but these were invariably insignificant and therefore were dropped from the model.

but definitions of urban vary somewhat arbitrarily across countries (United Nations Department of Economic and Social Affairs/Population Division 2012). To measure access to towns and cities we therefore use GIS estimates of travel time to cities to construct a "remote location" dummy variable that equals one if the DHS cluster is more than 1 hour travel time to a town or city of 20,000 people or more. Greater travel time to cities would limit households' access to nutrient-rich foods and thereby lower children's dietary diversity. Since other infrastructural conditions may also influence availability of nutrient-rich foods under imperfect markets, we also measure a night lights intensity index to capture local economic development and electricity infrastructure, distance to coastline, and population density. An increase in the night lights intensity index raises the scope for agricultural diversification and is likely to be positively associated with child dietary diversity. Households situated near the coastline are more likely to have access to cheaper nutrient-rich foods because of lower transport costs. On the other hand, higher population density reflects rapid urbanization and allows for greater consumption of diverse foods. In addition, agricultural conditions can substantially influence consumption patterns among poor households. We include agro-climatic factors such as average temperature, average rainfall, length of the growing period in days and cluster altitude to determine their effects on child dietary diversity. More rainfall might encourage farmers to diversify production while increased temperatures are poorly suited to the production of fruits and vegetables and consequently lower child dietary diversity. As these agro-climatic and infrastructural indicators demonstrate substantial non-linearity in their relationship with diets, we measure these indicators with terciles to flexibly capture these non-linearities.

3.4 Methods

In terms of methods, we implement a variety of statistical techniques via Stata version 14.0. Graphically, we apply non-parametric techniques, specifically the local polynomial smoother with 95% confidence intervals (the *lpolyci* command) to first assess patterns of growth faltering and anemia in this sample, and then to assess non-linear relationships between dietary diversity and various explanatory variables of interest.

We then use ordinary least squares regression models to estimate a multilevel regression model with dietary diversity (D) as a function household characteristics (H) (household wealth, maternal and paternal education brackets, paternal non-farm occupation, health access, child was breastfed immediately, mother can decide on own healthcare), community characteristics (C) (remote location, night lights intensity index, population density, length of growing period, rainfall, temperature, altitude, distance to coastline) and child demographics (Z) (age, sex of child, number of children under 5), country fixed effects ($\boldsymbol{\mu_k}$), where *i*, *j*, and *k* respectively denote child, cluster and country identifiers and ε is an error term:

$$\boldsymbol{D_{i,j,k} = \beta_H H_{i,j,k} + \beta_C C_{i,j,k} + \delta Z_{i,j,k} + \mu_k + \varepsilon_{i,j,k}} \qquad (1)$$

The key parameters of interest in equation (1) are the coefficients captured by the vectors $\boldsymbol{H'\beta}$ and $\boldsymbol{C'\beta}$. Under the strong assumption that equation (1) is appropriately specified and key variables such as wealth are measured with relatively little error, these parameters could be interpreted as marginal effects. In practice this assumption is unlikely to hold, and we instead interpret these parameters as stylized associations that nevertheless yield potentially important insights on the main determinants of children's diets in developing countries.

3.5 Results

3.5.1 Descriptive results

Descriptive statistics for the key variables used in our regressions are reported in Table 3.1. The dependent variable, child dietary diversity score (12 food groups), is low in this sample. Children consumed 3 out of 12 food groups, on average, in the past 24 hours. Only 14 percent and 13 percent of mothers and fathers have attended "lower secondary" or "middle school" (7-9 years) while more than half of the women in this sample can decide on their own healthcare. Only 27 percent of children have had access to the full measured spectrum of antenatal, neonatal and postnatal health care. Finally, 35 percent of the sample takes 1 hour or more to travel to cities.

Table 3.1 Descriptive statistics[8]

Variable	Observations	Mean	Standard deviation	Minimum	Maximum
DHS indicators					
Child dietary diversity score (12 food groups) 6-23 months	67,241	3.24	2.34	0.00	12.00
Child dietary diversity score (7 food groups) 6-23 months	67,241	2.70	1.78	0.00	7.00
Child minimum dietary diversity (≥ 4 food groups) 6-23 months	66,791	0.28	0.45	0.00	1.00
Household wealth (quintile)	67,241	2.95	1.32	1.00	5.00
No maternal education (omitted category)	67,241	0.37	0.48	0.00	1.00
Maternal primary education (1-6 years)	67,241	0.27	0.44	0.00	1.00
Maternal secondary education (7-9 years)	67,241	0.14	0.34	0.00	1.00
Maternal tertiary education (10-plus years)	67,241	0.23	0.42	0.00	1.00
No paternal education (omitted category)	67,241	0.30	0.46	0.00	1.00
Paternal primary education (1-6 years)	67,241	0.26	0.44	0.00	1.00
Paternal secondary education (7-9 years)	67,241	0.13	0.34	0.00	1.00
Paternal tertiary education (10-plus years)	67,241	0.31	0.46	0.00	1.00

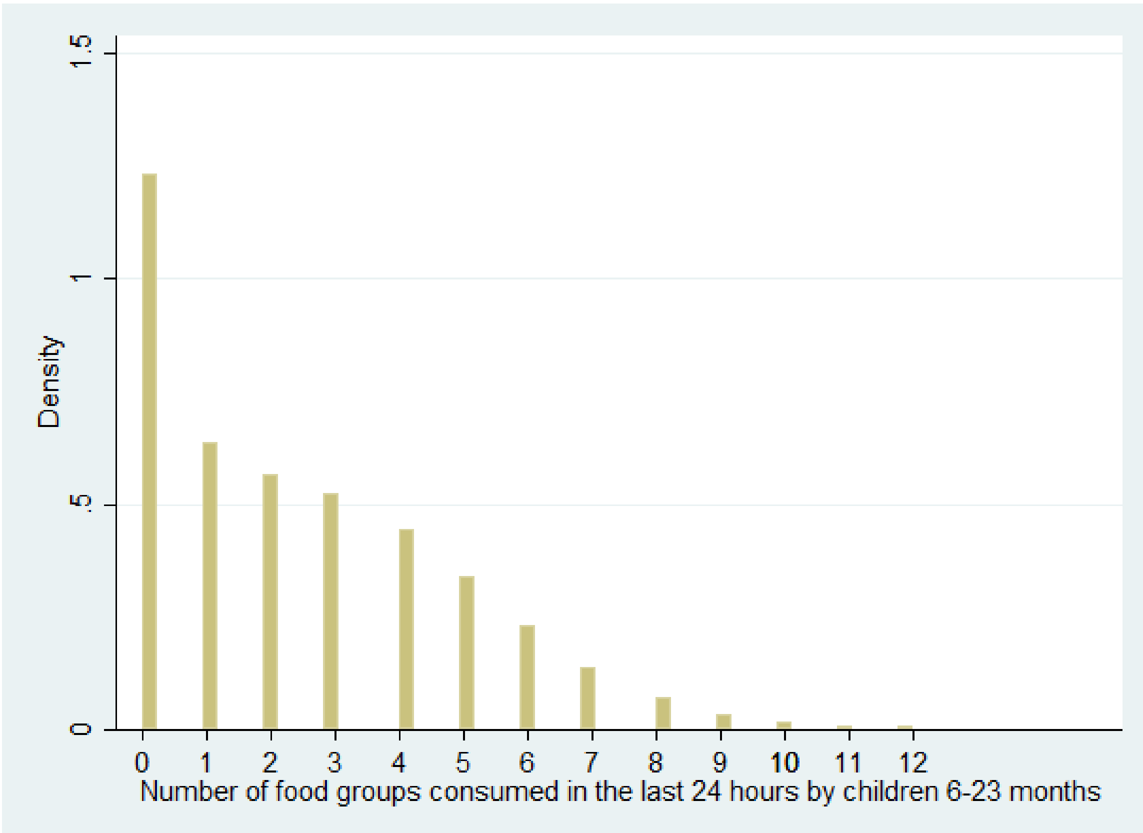
[8] We employ multiple samples for our analysis. Table 3.2 presents linear regression analysis of the determinants of child dietary diversity score (12 food groups) with a total of 67,241 children aged 6-23 months using both socio-economic determinants from the DHS and community-level GIS data. Other sub-samples in Table 3.2 include 24,182 children (6-11 months) in column 2 and 43,059 children (12-23 months) in column 3. Table 3.4 reports the use of child dietary diversity score (7 food groups) and minimum dietary diversity score (a dummy variable generated from the 7 food group indicator) with a total of 74,313 and 72,030 children. 2,283 observations are dropped when constructing the minimum dietary diversity score dummy variable since these observations are missing. Table 3.5 reports dietary diversity (12 groups) with a total of 43,059 children aged 12-23 months using disaggregated health variables. Analogous to Table 3.2 (column 3), Table 3.6 reports results excluding GIS indicators with a sample size of 66,698 children while Table 3.7 reports results excluding socio-economic determinants with a sample size of 58,451 children.

Father's occupation is non-agricultural (cluster-level)	67,241	0.59	0.49	0.00	1.00
Health access (antenatal care, medical birth, vaccinations)	67,241	0.27	0.44	0.00	1.00
Women can decide on own healthcare	67,241	0.61	0.49	0.00	1.00
Child was breastfed immediately	67,241	0.66	0.47	0.00	1.00
Number of children under 5 (two)	67,241	0.42	0.49	0.00	1.00
Number of children under 5 (3 plus)	67,241	0.14	0.35	0.00	1.00
Child is male	67,241	0.51	0.50	0.00	1.00
Child's age in months	67,241	14.01	5.11	0.00	23.00
GIS indicators					
Remote location (travel time>=1 hr to towns of >20k pop)	67,241	0.35	0.48	0.00	1.00
Night lights intensity index by cluster, middle tercile	67,241	0.11	0.32	0.00	1.00
Night lights intensity index by cluster, upper tercile	67,241	0.32	0.47	0.00	1.00
Population density, middle tercile	67,241	0.39	0.49	0.00	1.00
Population density, upper tercile	67,241	0.30	0.46	0.00	1.00
Medium length of growing period in days	67,241	0.37	0.48	0.00	1.00
High length of growing period in days	67,241	0.30	0.46	0.00	1.00
Mean rainfall (mm) over 1981-2010, middle tercile	67,241	0.37	0.48	0.00	1.00
Mean rainfall (mm) over 1981-2010, upper tercile	67,241	0.32	0.47	0.00	1.00
Mean temperature (Celsius) over 1981-2010, middle tercile	67,241	0.31	0.46	0.00	1.00
Mean temperature (Celsius) over 1981-2010, upper tercile	67,241	0.40	0.49	0.00	1.00
Altitude (meters) by cluster, middle tercile	67,241	0.38	0.48	0.00	1.00
Altitude (meters) by cluster, upper tercile	67,241	0.31	0.46	0.00	1.00
Distance to coastline, middle tercile	67,241	0.32	0.47	0.00	1.00
Distance to coastline, upper tercile	67,241	0.33	0.47	0.00	1.00

Source: Phase 5 & 6 DHS data for 39 countries.

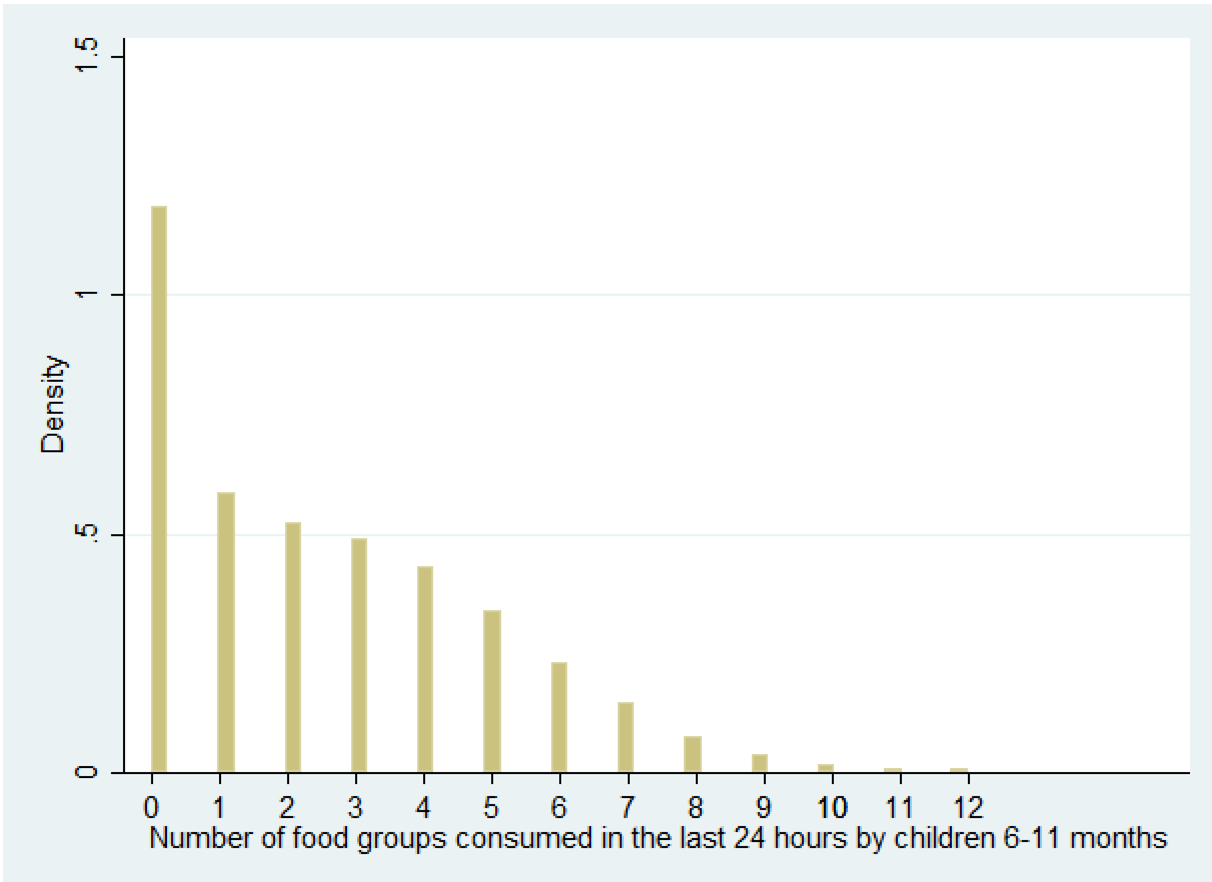
Figures 3.1.1-3.1.3 show the distribution of the dietary diversity indicator for 67,241 children between 6-23 months, 24,182 children between 6-11 months and 43,059 children between 12-23 months in our sample. Children between 6- 23 months residing in the average household eat from 3 food groups while children between 6-11 months consume only 2 food groups. There are a number of children whose mothers reported that they consumed none of these foods in the last 24 hours because they were either ill or because their child was only consuming breastmilk.

Figure 3.1.1 Distribution of the dietary diversity indicator (12 food groups) among children 6-23 months



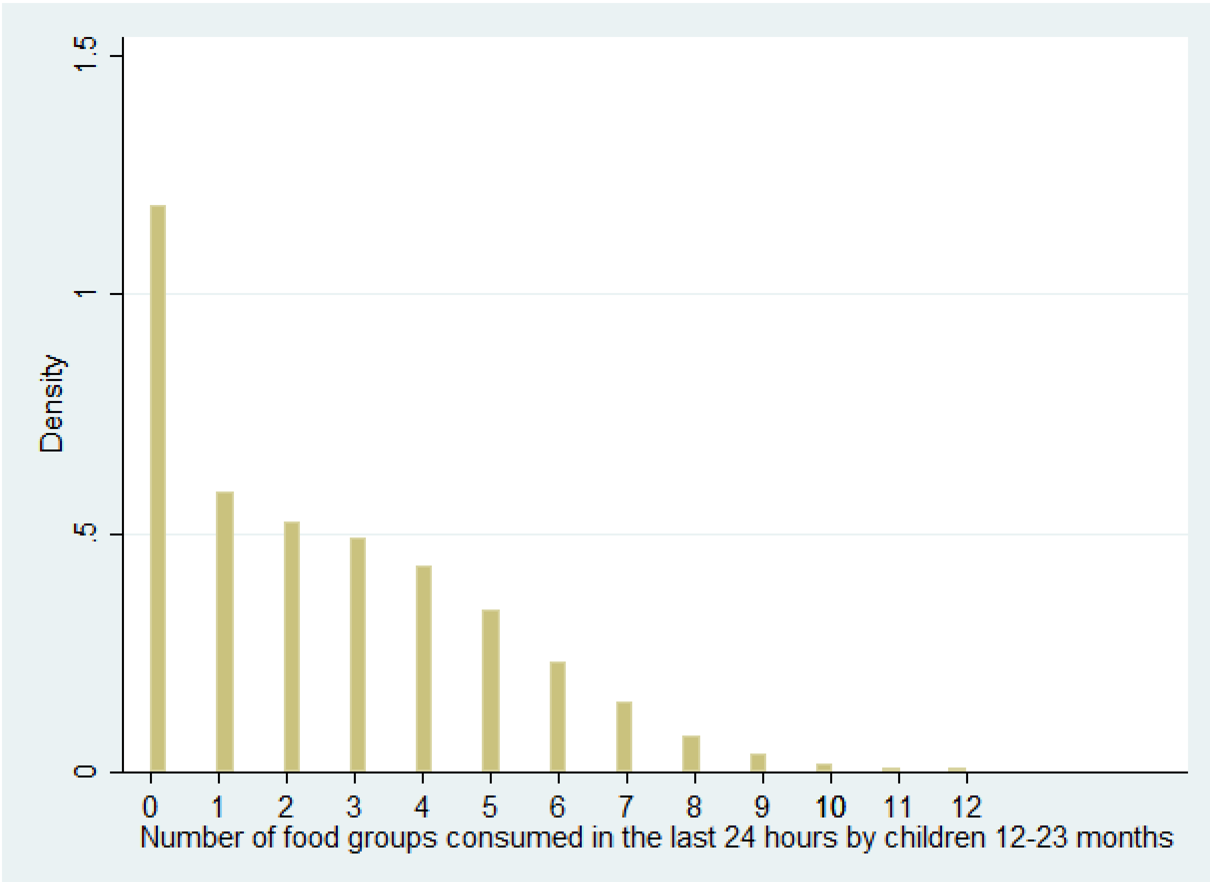
Notes: Dietary diversity score is measured for 67,241 children. Source: Phase 5 & 6 DHS data for 39 countries.

Figure 3.1.2 Distribution of the dietary diversity indicator (12 food groups) among children 6-11 months



Notes: Dietary diversity score is measured for 67,241 children. Source: Phase 5 & 6 DHS data for 39 countries.

Figure 3.1.3 Distribution of the dietary diversity indicator (12 food groups) among children 12-23 months



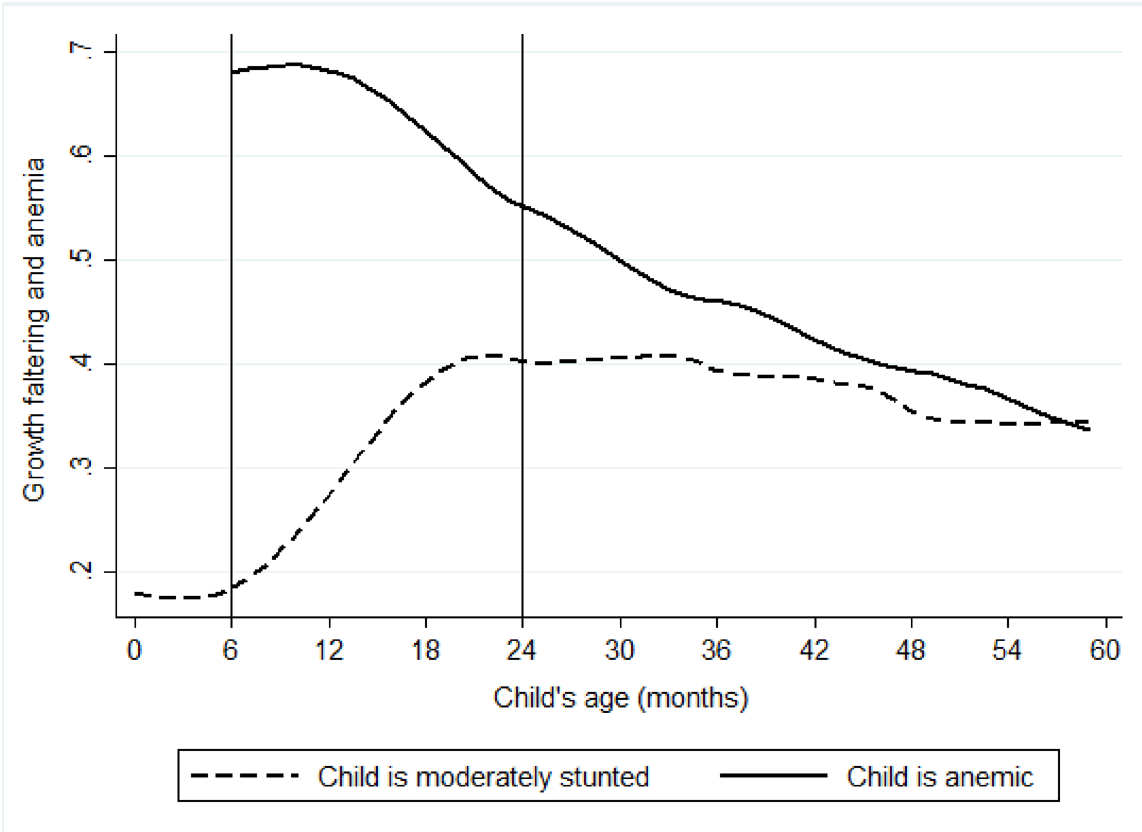
Notes: Dietary diversity score is measured for 43,059 children. Source: Phase 5 & 6 DHS data for 39 countries.

3.5.2 Graphical results

We begin our analysis by graphically applying the local polynomial smoother with 95% confidence intervals (the *lpolyci* command) to assess non-linear relationships in key parameters of interest. Figure 3.2 underlines that patterns of growth falter and that anemia varies by child's age. This figure shows that growth faltering emerges at age 6 months when children are first introduced to solid foods and starts declining after 23 months, which is consistent with other studies (Shrimpton et al. 2001; Victora et al. 2010). Moreover, Figure 3.2 shows that anemia peaks at about 6 months because exclusive breastfeeding prior to 6 months results in an adequate transfer of iron via breastmilk. Hence the addition of iron (and other micronutrients) via weaning foods is critical for reducing anemia in young children. As a result, the introduction of weaning foods at around 6 months of age marks the beginning of a critical window when children require ever-greater quantities of macro and micronutrients for physical growth and cognitive development. Inadequate child feeding in this window is therefore an important explanation of why undernutrition emerges so starkly in this age window across such a broad range of developing countries.[9] This provides a strong justification for focusing our analysis on this 6-23 month age bracket.

[7] Of course, poor diets constitute only one reason. Children at 6 months and older are also exposed to more pathogens through crawling, mouthing behaviours and food contamination.

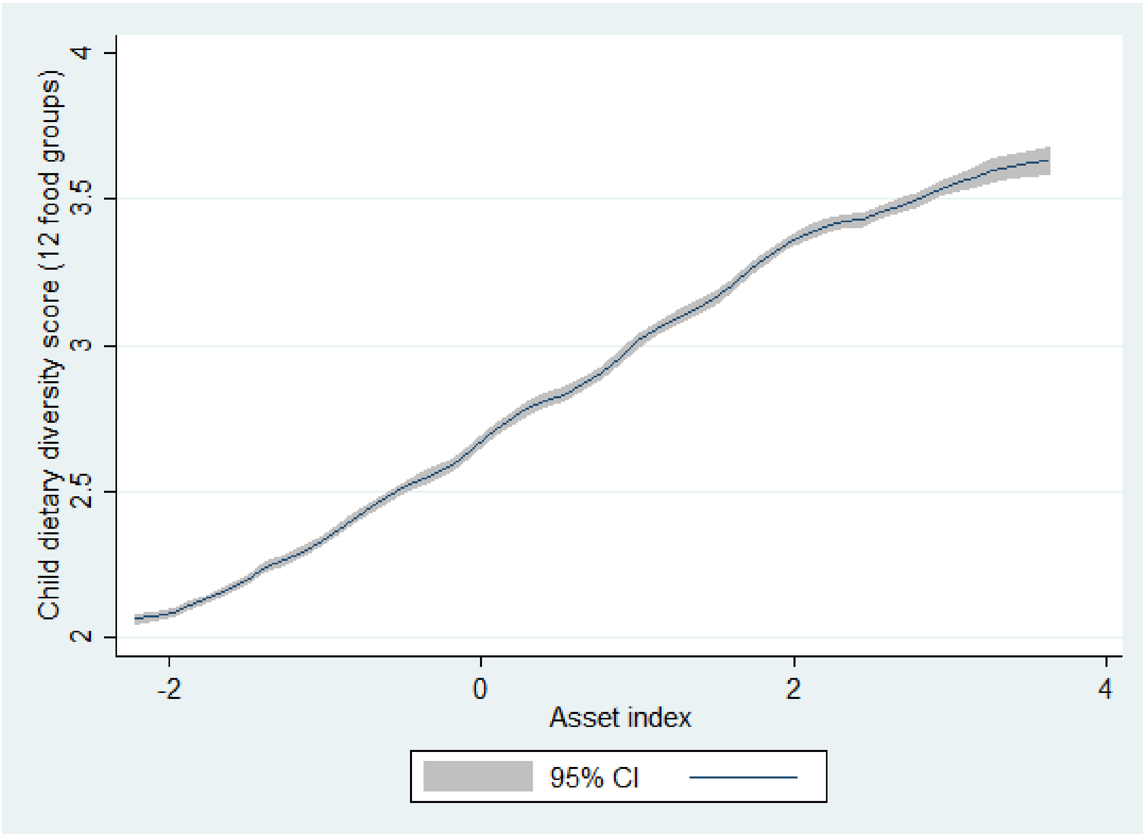
Figure 3.2 Patterns of growth faltering and anemia by child's age (months)



Notes: According to WHO guidelines, screening for haemoglobin levels begins from 6 months of age. Therefore, this graph plots anemia levels for children at 6 months. Therefore, this graph plots anemia levels for children starting at 6 months. In the DHS sample, 34% of all children aged 0-59 months (559,164) are moderately stunted while 51% of children aged 6-59 months (298,533) are anemic. For our analysis, the reported sample size of 67,241 children is aged between 6-23 months. Source: These are local polynomial smoothing estimates from Phase 5 & 6 DHS data for 39 countries.

Figures 3.3 to 3.6 show the estimated relationship between our explanatory variables and child dietary diversity score (12 food groups) for those aged 6-23 months. Figure 3.3 shows a mostly linear relationship between dietary diversity and the raw wealth index scores, consistent with Bennett's observation that consumers diversify away from starchy staples as their incomes increase. In Figure 3.3, there is some suggestion that the marginal effect of wealth may eventually decline, but in this relatively poor sample, the diminishing effects are modest, and in our regression estimates, we specify wealth linearly.

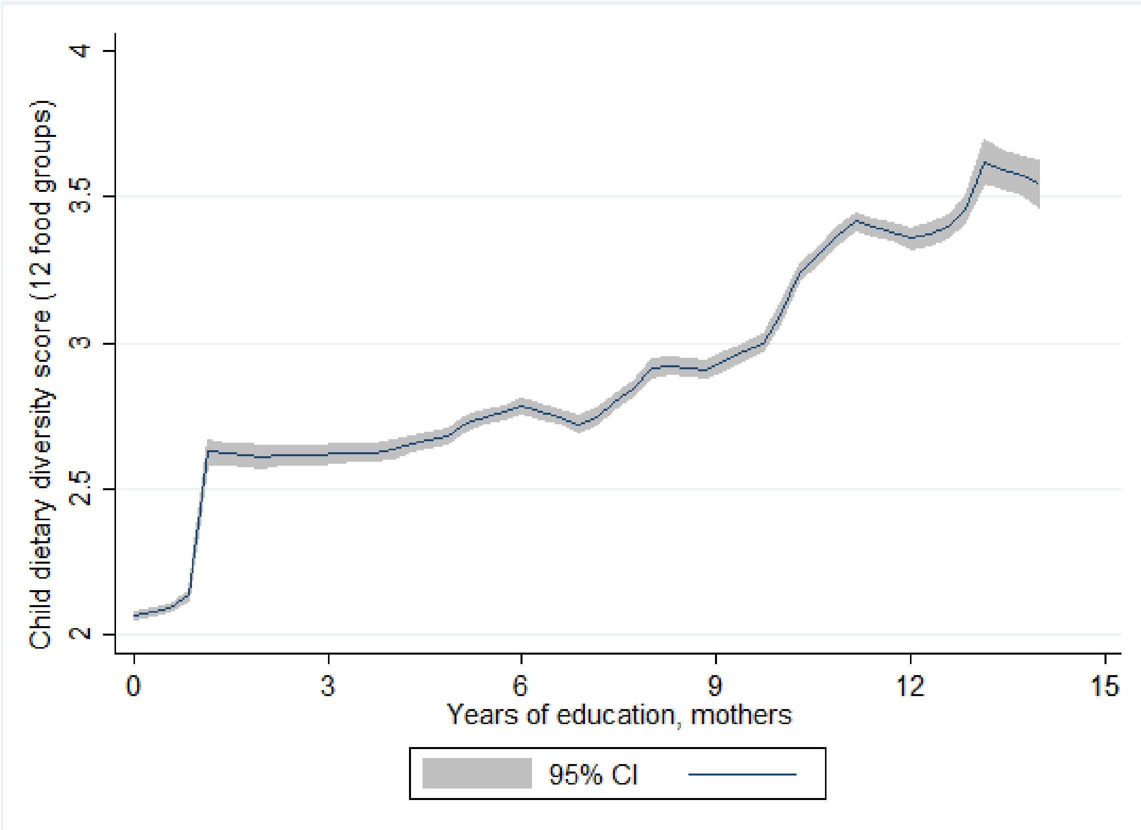
Figure 3.3 Nonparametric estimates of the relationship between child dietary diversity score (12 food groups) and the raw wealth index scores



Source: Phase 5 & 6 DHS data for 39 countries. These are local polynomial smoothing estimates with 95% confidence intervals (CI)

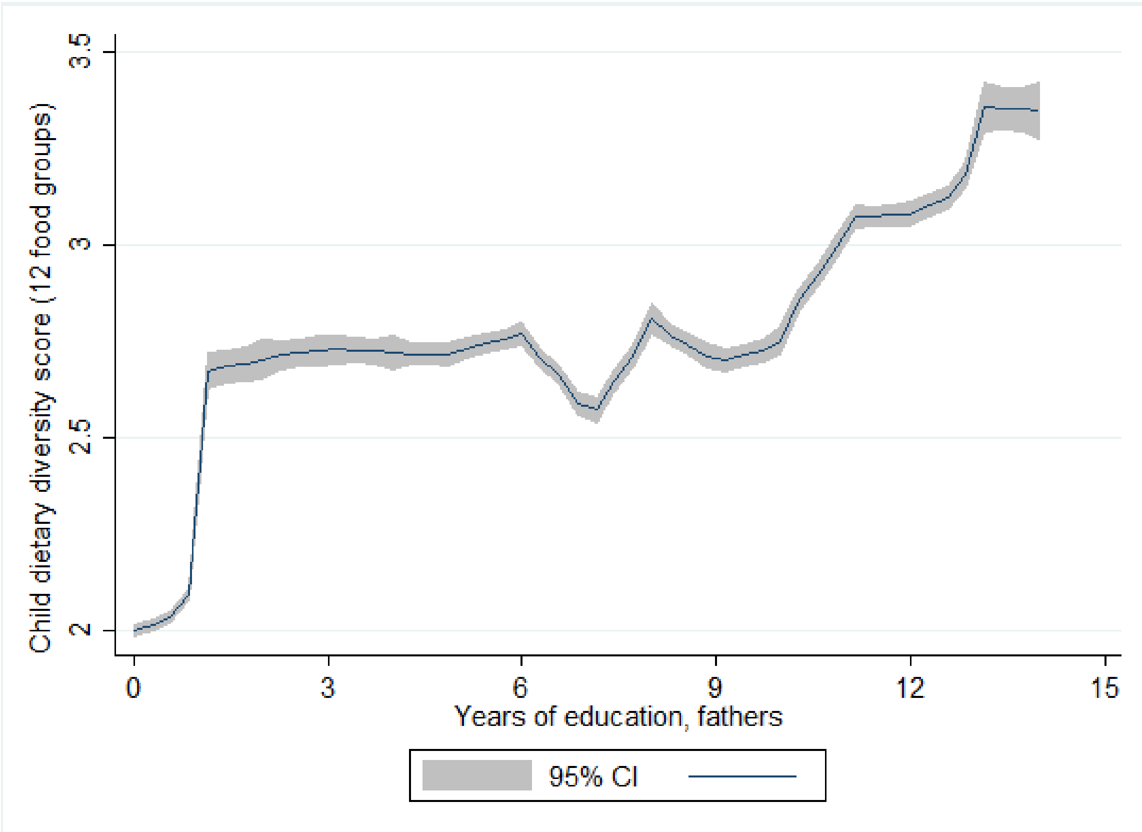
Figures 3.4 and 3.5 plot a locally weighted regression of the association between dietary diversity score and parental education. In both cases, we find that the education gradient is very non-linear, consistent with Alderman and Headey's (2017) results for stunting and parental education. Specifically, the returns to education increase markedly in what is typically secondary school (7 years or greater). Figures 3.9 and 3.10 in the Appendix show the coefficient plots of paternal education.

Figure 3.4 Nonparametric estimates of the relationship between child dietary diversity score (12 food groups) and years of education (mothers)



Source: Phase 5 & 6 DHS data for 39 countries. These are local polynomial smoothing estimates with 95% confidence intervals (CI)

Figure 3.5 Nonparametric estimates of the relationship between child dietary diversity score (12 food groups) and years of education (fathers)

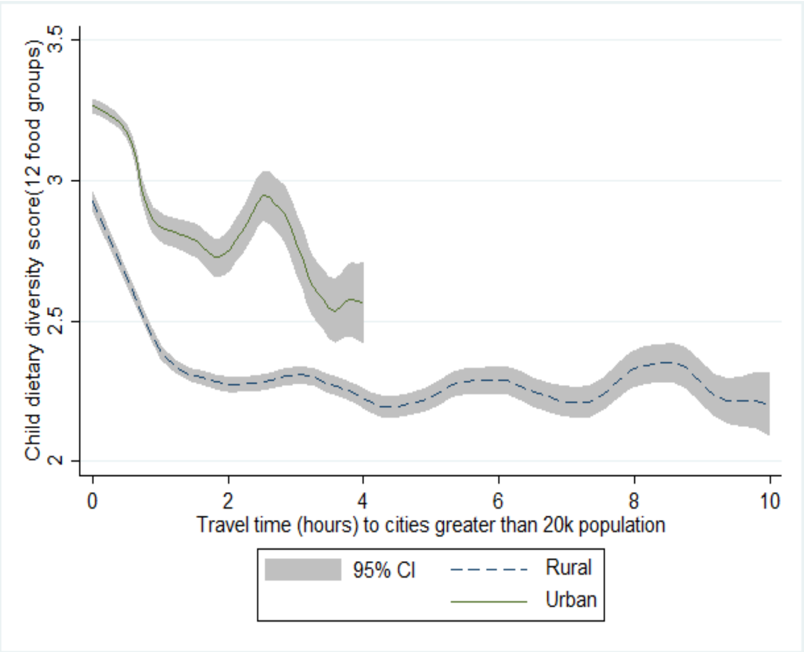


Source: Phase 5 & 6 DHS data for 39 countries. These are local polynomial smoothing estimates with 95% confidence intervals (CI)

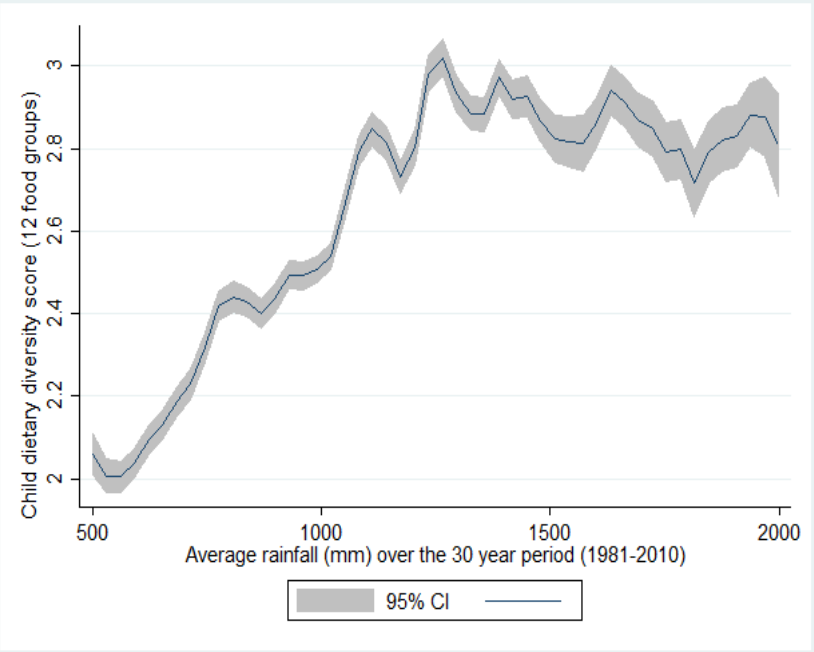
In Figure 3.6, we observe locally weighted regressions of the associations between dietary diversity and several GIS indicators. These indicators have strikingly non-linear relationships. For example, panel (a) shows that being within 1 hour from a city/town of more than 20,000 people (20K hereafter) is beneficial for dietary diversification, but that these benefits decline rapidly as the travel time extends beyond 1 hour. For the other indicators, the results are more complex. For travel time we therefore create a dummy if the cluster is more than 1 hour from a 20K city/town, but we split the other indicators into terciles to capture these non-linearities.

Figure 3.6 Nonparametric estimates of the relationship between child dietary diversity score (12 food groups) and GIS indicators

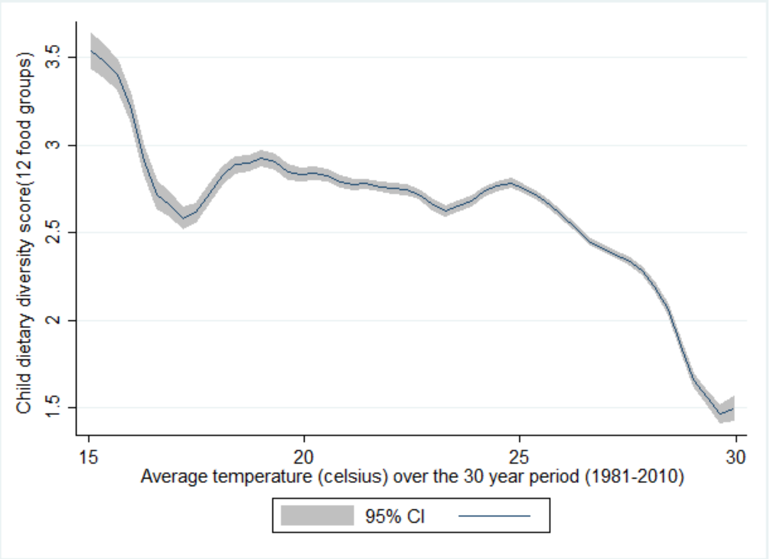
(a) Travel time (hours) to cities greater than 20k population



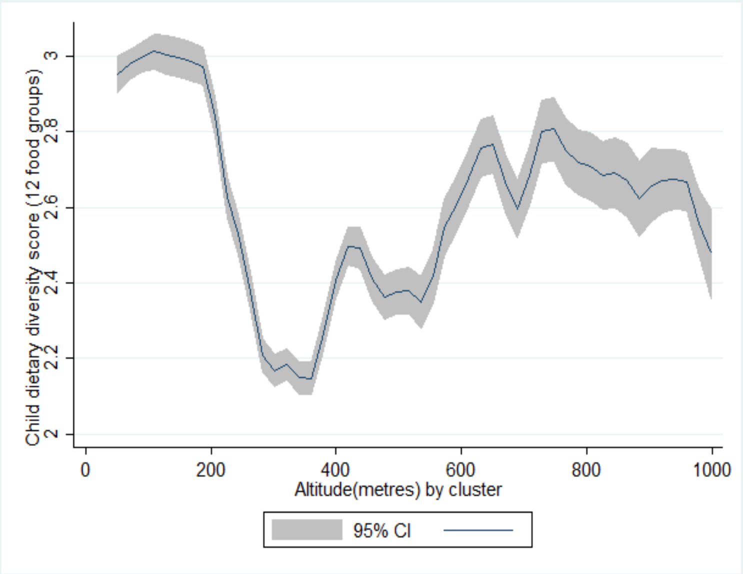
(b) Average rainfall over the 30 year period (1981-2010)



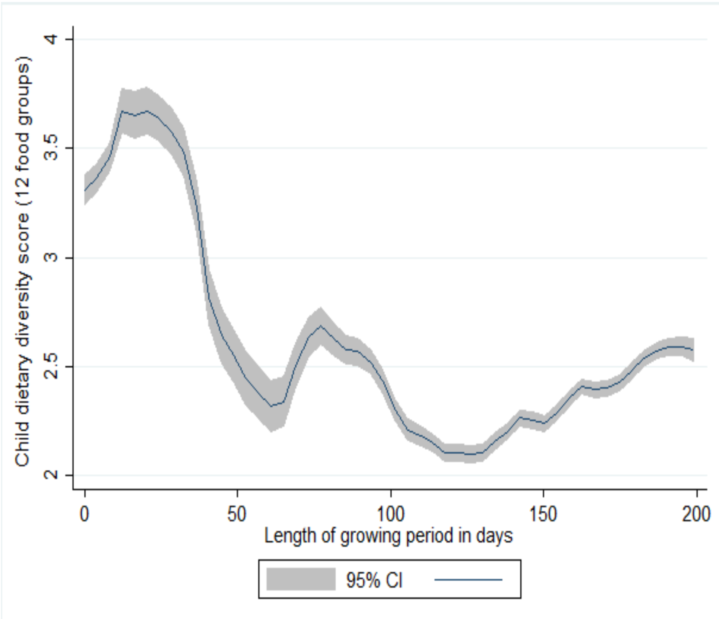
(c) Average temperature over the 30 year period (1981-2010)



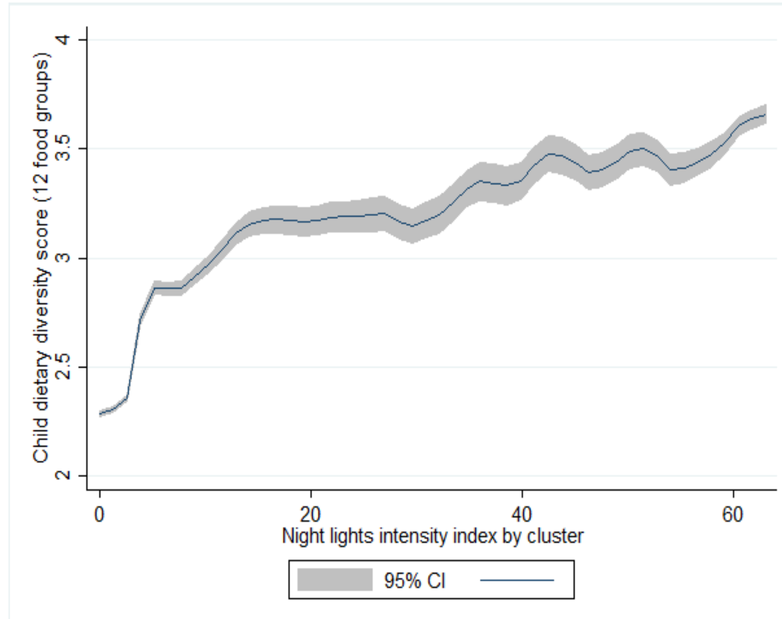
(d) Altitude by cluster



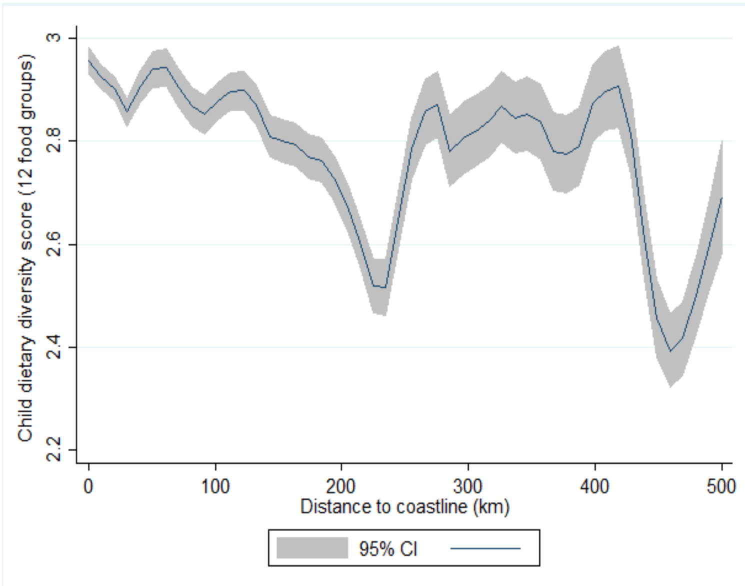
(e) Length of growing period in days



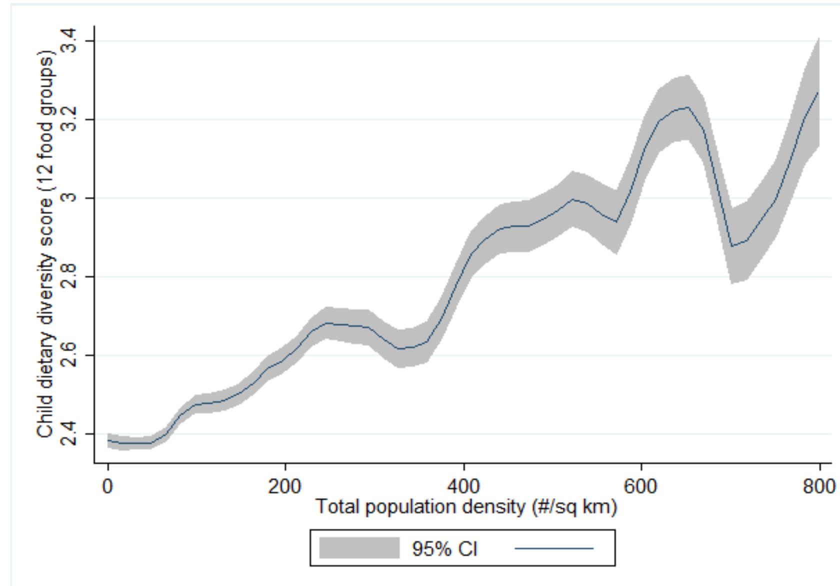
(f) Night lights intensity index by cluster



(g) Distance to coastline



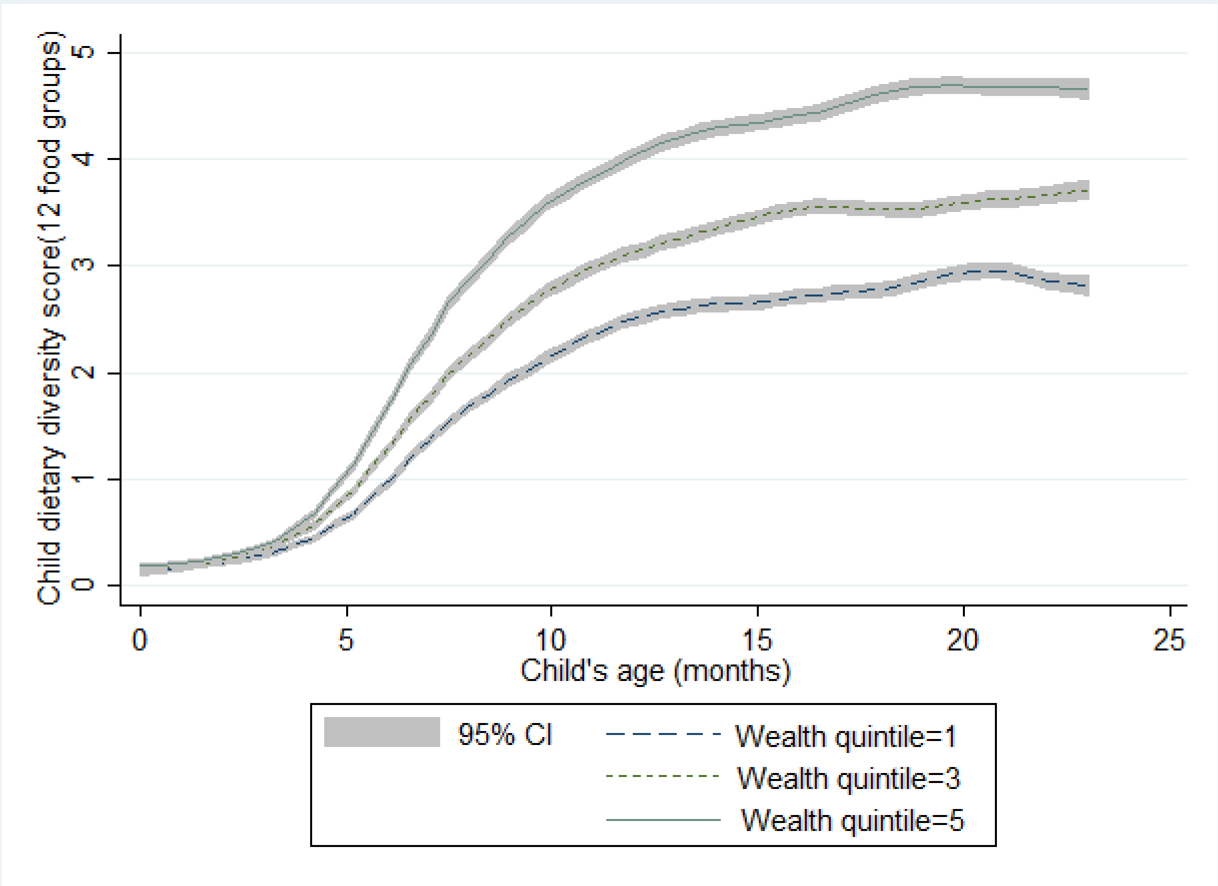
(h) Total population density (#/sq km)



Source: Phase 5 & 6 DHS data for 39 countries. These are local polynomial smoothing estimates with 95% confidence intervals (CI)

Figure 3.7 investigates whether these relationships are likely to be sensitive to the age range because dietary diversity is likely to increase with age for young children as they are gradually introduced to more and more food types. Feeding practices of very young children (e.g. 6-11 months) may therefore be less informative than those of older children. To examine this possibility, Figure 3.7 shows a locally weighted regression of the association between dietary diversity and child age by different wealth quintiles as an example (Figure 3.8 in the Appendix shows the coefficient plot of wealth quintiles). This figure implies that the impacts of wealth rise with age. We therefore use the 12-23 month range as our preferred sample, but test sensitivity to other samples.

Figure 3.7 Nonparametric estimates of the relationship between child dietary diversity score (12 food groups) and child's age (months) by wealth quintiles



Source: Phase 5 & 6 DHS data for 39 countries. These are local polynomial smoothing estimates with 95% confidence intervals (CI)

3.5.3 Parametric multivariate regression results

Table 3.2 presents linear regression analysis of the determinants of child dietary diversity score (12 food groups) by three different child age groups (6-23 months, 6-11 months and 12-23 months). For the most part the results are broadly robust across these samples, though in many cases the coefficients in the 12-23 month sample are larger in magnitude. In all regressions, the R-squared coefficients are relatively large in magnitude, explaining just under one-third of the variation in dietary diversity.

We find clear evidence for Bennett's law applying to child diet diversity, just as it does to macroeconomic and household level data: the number of nutritionally-defined food groups fed to children for all ages rises linearly with each wealth quintile, with a magnitude of about 0.13 to 0.20 food groups per quintile. This is statistically significant at the 1 percent level, and implies that, at most, children from the richest wealth quintile consume about 1 extra food group relative to children from the poorest quintile. This impact is less than half of a standard deviation and is therefore relatively modest.

The surprisingly limited estimated impact of wealth on dietary diversity may be explained by the importance of a number of other significant associations in Table 3.2. For example, in all specifications, the returns to maternal education appear especially high, a finding similar to the results on stunting reported in Alderman and Headey (2017): a child of a mother with some tertiary education would be expected to have a dietary diversity score about 0.40-0.62 food groups larger than a child with a mother with no education, controlling for other factors. The coefficients for maternal education are also significant larger than those for paternal education (typically more than double). Maternal education's large impacts likely reflect the importance of nutritional knowledge among the parent primarily responsible for child feeding, but mother's education may also reflect her empowerment, which is only imperfectly measured by our indicator of health decision-making, which only has a very modest association with dietary diversity.

Another striking result is the large association between access to health services and child dietary diversity. Although nutritionists perceive that there is insufficient nutritional messaging in standard health services, it appears that mothers' receiving a continuum of care

are more likely to feed their children a more diverse diet, with the marginal effects ranging from 0.21 to 0.29.

Finally, indicators of geographical and infrastructural characteristics share a number of significant associations with child dietary diversity scores. The coefficient on travel time to towns greater than 1 hour with population greater than 20k, as hypothesized, is negative and statistically significant at the 5 percent level for the age sample 12-23 months, but the effect is very modest: just 0.07 food groups in our preferred 12-23 month sample. The night lights intensity index – which may capture urbanisation, local economic development and electricity infrastructure – has a somewhat stronger association with child dietary diversity, with high intensity clusters possessing children with 0.14-0.16 extra food groups. Our results also reveal that another measure of urbanisation – medium and high population density – increases child's dietary diversity score by about 0.07-0.13 food groups. Although the marginal effects of each individual indicator of urbanisation and infrastructure indicators is moderate, the joint significance of these various coefficients implies reasonably strong associations between access to urban markets and road and electricity infrastructure.

In terms of climate indicators, the coefficients of average rainfall and average temperature are large and significant. Medium and high yearly average rainfall predicts increases in child dietary diversity scores of 0.17 and 0.23 food groups, which is statistically significant at the 1 percent level for our preferred age sample 12-23 months. Conversely, medium and high temperatures are constraints to dietary diversification and are associated with 0.21 to 0.17 fewer food groups statistically for the age sample 12-23 months. However, medium and high average temperatures do not have significantly different coefficients for the age sample 6-23 months, implying an advantage to cooler climates. Lastly, we find no consistent associations with distance to coastlines and dietary diversity; surprisingly, the coefficient on the middle tercile is significant and positive which increases child dietary diversity scores by 0.14 food groups compared to the omitted lowest tercile, but the most distant tercile yields an insignificant coefficient.

Table 3.2 Dietary diversity by child age (6-23 months, 6-11 months and 12-23 months)[10]

	(1) Child dietary diversity score (12 food groups) 6-23 months	(2) Child dietary diversity score (12 food groups) 6-11 months	(3) Child dietary diversity score (12 food groups) 12-23 months
Household wealth (quintile)	0.167***	0.126***	0.193***
	(0.011)	(0.017)	(0.014)
Maternal primary education	0.142***	0.106***	0.179***
	(0.024)	(0.038)	(0.031)
Maternal secondary education	0.317***	0.203***	0.400***
	(0.032)	(0.050)	(0.040)
Maternal tertiary education	0.516***	0.377***	0.617***
	(0.035)	(0.054)	(0.044)
Paternal primary education	0.117***	0.086**	0.132***
	(0.025)	(0.039)	(0.030)
Paternal secondary education	0.164***	0.125**	0.183***
	(0.032)	(0.051)	(0.040)
Paternal tertiary education	0.215***	0.158***	0.248***
	(0.030)	(0.048)	(0.038)
Father’s occupation is non-agricultural	-0.037	-0.097**	-0.000
	(0.028)	(0.038)	(0.034)
Health access	0.281***	0.288***	0.219***
	(0.022)	(0.049)	(0.026)
Child was breastfed immediately	0.077***	0.030	0.104***
	(0.018)	(0.028)	(0.022)
Mother can decide on own healthcare	-0.022	0.011	-0.040
	(0.020)	(0.030)	(0.026)
Number of children under 5 (two)	0.035**	0.015	0.040*
	(0.017)	(0.028)	(0.021)
Number of children under 5(3 plus)	0.041	0.029	0.037
	(0.026)	(0.038)	(0.034)
Child is male	0.001	-0.007	0.004
	(0.015)	(0.024)	(0.019)
Remote location (>1 hour to towns of >20k pop)	-0.047*	-0.004	-0.069**
	(0.025)	(0.034)	(0.031)
Night lights intensity index by cluster, medium tercile	0.074**	0.065	0.077*
	(0.037)	(0.050)	(0.045)
Night lights intensity index by cluster, upper tercile	0.141***	0.102*	0.162***
	(0.040)	(0.055)	(0.049)
Population density, middle tercile	0.066**	0.058	0.071**
	(0.027)	(0.037)	(0.033)
Population density, upper tercile	0.110***	0.072	0.131***
	(0.037)	(0.051)	(0.044)
Medium length of growing period in days	0.078	0.029	0.109*
	(0.050)	(0.062)	(0.062)

[10] We have estimated multi-level models by clustering standard errors at the region and country levels. Doing so provides quantitatively similar results to those reported in Table 3.2. In addition, we have run models of child dietary diversity score against cluster fixed effects for our sample using the unique cluster identifier and the R-square on this regression is 0.35. This high R-square suggests that a large part of the variation in diets is explained by community level factors.

High length of growing period in days	0.019	-0.003	0.033
	(0.057)	(0.074)	(0.071)
Mean rainfall, middle tercile	0.157***	0.117*	0.174***
	(0.051)	(0.063)	(0.063)
Mean rainfall, upper tercile	0.238***	0.253***	0.232***
	(0.058)	(0.076)	(0.072)
Mean temperature, middle tercile	-0.195***	-0.186***	-0.206***
	(0.033)	(0.049)	(0.040)
Mean temperature, upper tercile	-0.194***	-0.264***	-0.166***
	(0.045)	(0.067)	(0.055)
Altitude by cluster, middle tercile	0.072**	0.084*	0.063
	(0.034)	(0.048)	(0.042)
Altitude by cluster, upper tercile	0.052	0.033	0.047
	(0.045)	(0.063)	(0.054)
Distance to coastline, middle tercile	0.079**	-0.040	0.144***
	(0.033)	(0.047)	(0.040)
Distance to coastline, upper tercile	-0.015	0.014	-0.027
	(0.048)	(0.068)	(0.057)
Observations	67,241	24,182	43,059
R-squared	0.307	0.249	0.254

Cluster-robust standard errors reported in parenthesis. Clustering is at the enumeration level. ***p<0.01, **p<0.05, *p<0.1. Controls included but not reported are child age dummies, country and survey fixed effects. Source: Phase 5 & 6 DHS data for 39 countries.

As Section 3.2 noted, previous research has hypothesized that wealth has more impact on diets when parents have greater knowledge or better access to markets. Table 3.3 therefore reports wealth interaction results for our preferred child age sample 12-23 months. There is no evidence that differences in parental education, health access, travel time to cities or the food environment alters wealth effects. The only significant effect modifier is the women's decision making indicator, although the association is very modest: for each wealth quintile increase empowerment adds just 0.05 food groups to the wealth effect of 0.17 food groups. Table 3.9 in the Appendix reports results of all other controls.

Table 3.3 Wealth interactions for children 12-23 months of age

	(1) Child dietary diversity score (12 food groups) 12-23 months
Wealth * Maternal primary education	-0.009
	(0.025)
Wealth * Maternal secondary education	0.014
	(0.032)
Wealth * Maternal tertiary education	0.028
	(0.036)
Wealth * Paternal primary education	-0.028
	(0.026)
Wealth * Paternal secondary education	-0.009
	(0.031)
Wealth * Paternal tertiary education	-0.025
	(0.031)
Wealth * Father's occupation is non-agricultural	0.010
	(0.025)
Wealth * Health access	0.017
	(0.020)
Wealth * Child was breastfed immediately	-0.009
	(0.016)
Wealth * Mother can decide on own healthcare	0.047**
	(0.019)
Wealth * Remote location (>1 hour to towns of >20k pop)	0.005
	(0.024)
All socio-economic controls?	Yes
All infrastructural and geographical controls?	Yes
Observations	43,059
R-squared	0.254

Cluster-robust standard errors reported in parenthesis. Clustering is at the enumeration level. ***p<0.01, **p<0.05, *p<0.1. Controls included but not reported are child age dummies, country and survey fixed effects. Source: Phase 5 & 6 DHS data for 39 countries.

3.6 Robustness Tests

In this section we engage in a series of robustness tests designed to establish the extent to which the results presented in the previous section stand up to alternative specifications. In Table 3.4, regression results are derived from linear probability models using alternative indicators of child dietary diversity score: WHO 7-food group indicator where the minimum dietary diversity threshold is 4 and minimum dietary diversity (≥ 4 food groups). Minimum dietary diversity (MDD) indicator is a dichotomous indicator, calculated based on the consumption of at least four of the seven food groups (Jones et al. 2014). The results in Table 3.4 are similar to those in Table 3.2, although most of the coefficients are smaller in magnitude in the context of the 7-food group indicator (Figure 3.11 in the Appendix shows the distribution of the dietary diversity indicator (7 food groups)), as one would expect given the contraction from 12 to 7 food groups. But one difference in these models is that we see no significant association between distance to coastline with respect to the middle tercile and child dietary diversity. However, in regression (2), we do find a moderate effect on minimum dietary diversity with regards to the coefficient on wealth quintile. The coefficient implies that moving from the poorest quintile to the richest quintile improves the probability of meeting minimum dietary diversity by about 15 percentage points. This finding is consistent with several studies that have explored the nutritional impacts of economic growth (Haddad et al. 2003; Ruel and Alderman 2013; Vollmer et al. 2013; Headey 2013). Likewise, in the nutrition literature, meeting minimum dietary diversity has been cited as important for improving child growth. For instance, one recent study using DHS data from 14 low-income countries shows that the consumption of minimum dietary diversity is associated with lowering the risk of stunting (Marriott et al. 2012).

Table 3.4 Extensions to the use of a 7 food group indicator and a dummy variable of 4 or more of the 7 food groups rather than a 12-group indicator for children 6-23 months

	(1) Child dietary diversity score (7 food groups)[1] 6-23 months	(2) Child minimum dietary diversity (≥ 4 food groups)[2] 6-23 months
Household wealth (quintile)	0.136*** (0.008)	0.031*** (0.002)
Maternal primary education	0.119*** (0.017)	0.011** (0.005)
Maternal secondary education	0.267*** (0.022)	0.052*** (0.006)
Maternal tertiary education	0.431***	0.090***

	(0.024)	(0.007)
Paternal primary education	0.086***	0.009**
	(0.018)	(0.005)
Paternal secondary education	0.122***	0.013**
	(0.022)	(0.006)
Paternal tertiary education	0.160***	0.028***
	(0.021)	(0.006)
Father's occupation is non-agricultural	-0.015	0.002
	(0.019)	(0.005)
Health access	0.212***	0.067***
	(0.015)	(0.004)
Child was breastfed immediately	0.037***	0.015***
	(0.013)	(0.004)
Mother can decide on own healthcare	0.001	-0.007*
	(0.014)	(0.004)
Number of children under 5 (two)	0.006	0.004
	(0.012)	(0.003)
Number of children under 5 (3 plus)	0.010	0.005
	(0.018)	(0.005)
Child is male	-0.001	0.000
	(0.011)	(0.003)
Remote location (>1 hour to towns of >20k pop)	-0.021	-0.011**
	(0.018)	(0.005)
Night lights intensity index by cluster, medium tercile	0.048*	-0.002
	(0.025)	(0.007)
Night lights intensity index by cluster, upper tercile	0.146***	0.016**
	(0.028)	(0.007)
Population density, middle tercile	0.042**	0.016***
	(0.019)	(0.005)
Population density, upper tercile	0.042*	0.021***
	(0.025)	(0.007)
Medium length of growing period in days	0.028	0.007
	(0.031)	(0.008)
High length of growing period in days	-0.020	-0.007
	(0.036)	(0.010)
Mean rainfall, middle tercile	0.112***	0.020**
	(0.032)	(0.008)
Mean rainfall, upper tercile	0.127***	0.017*
	(0.037)	(0.010)
Mean temperature, middle tercile	-0.105***	-0.025***
	(0.023)	(0.007)
Mean temperature, upper tercile	-0.185***	-0.041***
	(0.031)	(0.009)
Altitude by cluster, middle tercile	0.039*	0.011*
	(0.023)	(0.006)
Altitude by cluster, upper tercile	0.015	0.009
	(0.030)	(0.008)
Distance to coastline, middle tercile	0.014	0.008
	(0.022)	(0.006)
Distance to coastline, upper tercile	-0.024	-0.007
	(0.032)	(0.009)
Observations	74,313	72,030
R-squared	0.359	0.241

Notes: [1]The 7 food groups include (1) grains, roots and tubers (2) legumes and nuts (3) dairy products (4) flesh foods (5) eggs (6) vitamin A-rich fruits and vegetables (7) other fruits and vegetables.[2]The 4-food group minimum dietary diversity indicator has been validated as a good predictor of micronutrient intake (Working Group on Infant and Young Child Feeding Indicators 2007). Cluster-robust standard errors reported in parenthesis. Clustering is at the enumeration level. ***p<0.01, **p<0.05, *p<0.1. Controls included but not reported are child age dummies, country and survey fixed effects. Source: Phase 5 & 6 DHS data for 39 countries.

In Table 3.5, we estimate a model that includes the three individual health access variables rather than the health index. Adding other control variables, including mothers' take-up of antenatal care, being born in a medical facility and access to vaccinations, does not materially affect our findings. Moreover, the magnitudes of the coefficients tend to be quite similar.

Table 3.5 Dietary diversity (12 food groups) for children 12-23 months with disaggregated health variables

	(1) Child dietary diversity score (12 food groups) 12-23 months
Household wealth (quintile)	0.183*** (0.014)
Maternal primary education	0.158*** (0.031)
Maternal secondary education	0.376*** (0.040)
Maternal tertiary education	0.596*** (0.044)
Paternal primary education	0.114*** (0.030)
Paternal secondary education	0.163*** (0.040)
Paternal tertiary education	0.227*** (0.038)
Father's occupation is non-agricultural	-0.008 (0.034)
ANC+4 visits	0.127*** (0.025)
Born in medical facility	0.138*** (0.027)
All vaccinations	0.157*** (0.026)
Child was breastfed immediately	0.096*** (0.022)
Mother can decide on own healthcare	-0.047* (0.026)
Number of children under 5 (two)	0.045** (0.021)
Number of children under 5 (3 plus)	0.044 (0.034)
Child is male	0.002 (0.019)
Remote location (>1 hour to towns of >20k pop)	-0.060* (0.031)
Night lights intensity index by cluster, medium tercile	0.074* (0.045)
Night lights intensity index by cluster, upper tercile	0.166*** (0.049)

Population density, middle tercile	0.066**
	(0.033)
Population density, upper tercile	0.125***
	(0.044)
Medium length of growing period in days	0.093
	(0.062)
High length of growing period in days	0.012
	(0.071)
Mean rainfall, middle tercile	0.166***
	(0.063)
Mean rainfall, upper tercile	0.222***
	(0.072)
Mean temperature, middle tercile	-0.213***
	(0.040)
Mean temperature, upper tercile	-0.172***
	(0.055)
Altitude by cluster, middle tercile	0.070*
	(0.042)
Altitude by cluster, upper tercile	0.051
	(0.054)
Distance to coastline, middle tercile	0.143***
	(0.040)
Distance to coastline, upper tercile	-0.007
	(0.057)
Observations	43,059
R-squared	0.254

Cluster-robust standard errors reported in parenthesis. Clustering is at the enumeration level. ***p<0.01, **p<0.05, *p<0.1. Controls included but not reported are child age dummies, country and survey fixed effects. Source: Phase 5 & 6 DHS data for 39 countries.

Table 3.6 estimates a model for our preferred child age sample 12-23 months that excludes GIS indicators. Overall, we find our results are robust to these changes, though with some exceptions. Excluding these indicators leads to a decrease in the coefficient on maternal secondary education but increases in the coefficients on all other controls. Another small difference is that non-farm employment now has a very modest positive effect on child dietary diversity: just 0.11 food groups.

Table 3.6 Dietary diversity (12 food groups) for children 12-23 months excluding GIS indicators

	(1) Child dietary diversity score (12 food groups) 12-23 months
Household wealth (quintile)	0.215***
	(0.010)
Maternal primary education	0.220***
	(0.024)
Maternal secondary education	0.396***
	(0.030)
Maternal tertiary education	0.639***
	(0.033)
Paternal primary education	0.189***
	(0.025)
Paternal secondary education	0.211***
	(0.030)
Paternal tertiary education	0.279***
	(0.030)
Father’s occupation is non-agricultural	0.109***
	(0.024)
Health access	0.259***
	(0.020)
Child was breastfed immediately	0.140***
	(0.018)
Mother can decide on own healthcare	0.019
	(0.020)
Number of children under 5 (two)	0.027
	(0.017)
Number of children under 5 (3 plus)	0.019
	(0.027)
Child is male	-0.009
	(0.015)
Observations	66,698
R-squared	0.230

Cluster-robust standard errors reported in parenthesis. Clustering is at the enumeration level. ***p<0.01, **p<0.05, *p<0.1. Controls included but not reported are child age dummies, country and survey fixed effects. Source: Phase 5 & 6 DHS data for 39 countries.

Table 3.7 reports results for our child age sample 12-23 months specifying GIS indicators and excluding socio-economic variables shown in Table 3.6. We find that excluding socio-economic variables leads to large increases in the coefficients on GIS indicators (except for the coefficient on the middle tercile with respect to distance to coastline) in terms of magnitude compared to Table 3.2. However, in this model, distance to a coastline for the most distant tercile now yields a negative coefficient and is significant at the 1 percent level.

Table 3.7 Dietary diversity (12 food groups) for children 12-23 months excluding socio-economic determinants

	(1) Child dietary diversity score (12 food groups) 12-23 months
Remote location (>1 hour to towns of >20k pop)	-0.175***
	(0.029)
Night lights intensity index by cluster, medium tercile	0.201***
	(0.038)
Night lights intensity index by cluster, upper tercile	0.550***
	(0.040)
Population density, middle tercile	0.089***
	(0.031)
Population density, upper tercile	0.184***
	(0.043)
Medium length of growing period in days	0.171***
	(0.059)
High length of growing period in days	0.111*
	(0.066)
Mean rainfall, middle tercile	0.194***
	(0.059)
Mean rainfall, upper tercile	0.336***
	(0.067)
Mean temperature, middle tercile	-0.270***
	(0.038)
Mean temperature, upper tercile	-0.256***
	(0.052)
Altitude by cluster, middle tercile	0.035
	(0.039)
Altitude by cluster, upper tercile	0.026
	(0.052)
Distance to coastline, middle tercile	0.083**
	(0.036)
Distance to coastline, upper tercile	-0.252***
	(0.054)
Observations	58,451
R-squared	0.181

Cluster-robust standard errors reported in parenthesis. Clustering is at the enumeration level. ***p<0.01, **p<0.05, *p<0.1. Controls included but not reported are child age dummies, country and survey fixed effects. Source: Phase 5 & 6 DHS data for 39 countries.

The regional results in Table 3.8 show variation across major regions for our preferred specification 12-23 months, but the pattern of results seems consistent with our key variables of interest reported in Table 3.2. For example, the wealth coefficients are smaller in magnitude compared to other significant associations. In contrast, we find reasonably high returns to maternal education particularly for Latin America and South Asia. Paternal education coefficients are mostly significant but appear to be smaller in magnitude. Moreover, access to health services yields large coefficients for Sub-Saharan African sub-sample, Latin America and South Asia, consistent with results from the pooled sample.

Table 3.8 Testing heterogeneity of Dietary diversity (12 food groups) results for children 12-23 months across major regions

	(1) Latin America & Caribbean	(2) Middle East & North Africa	(3) South Asia	(4) Sub-Saharan Africa
Household wealth (quintile)	0.292***	0.354***	0.070***	0.165***
	(0.015)	(0.060)	(0.018)	(0.009)
Maternal primary education	0.488***	-0.009	0.202***	0.178***
	(0.050)	(0.091)	(0.049)	(0.020)
Maternal secondary education	0.720***	0.081	0.377***	0.164***
	(0.060)	(0.091)	(0.053)	(0.027)
Maternal tertiary education	0.811***	0.317***	0.544***	0.345***
	(0.061)	(0.075)	(0.064)	(0.033)
Paternal primary education	0.099**	0.087	0.251***	0.244***
	(0.048)	(0.090)	(0.051)	(0.022)
Paternal secondary education	0.123**	0.076	0.216***	0.172***
	(0.062)	(0.096)	(0.052)	(0.026)
Paternal tertiary education	0.099*	0.182**	0.244***	0.221***
	(0.057)	(0.082)	(0.058)	(0.026)
Father’s occupation is non-agricultural	0.037	0.104	0.038	0.016
	(0.033)	(0.099)	(0.041)	(0.022)
Health access	0.455***	0.125***	0.321***	0.491***
	(0.037)	(0.047)	(0.046)	(0.026)
Child was breastfed immediately	0.014	0.077*	0.288***	0.157***
	(0.029)	(0.043)	(0.034)	(0.016)
Mother can decide on own healthcare	0.094***	0.118**	0.001	0.018
	(0.034)	(0.059)	(0.034)	(0.017)
Number of children under 5 (two)	-0.037	0.051	-0.047	0.067***
	(0.028)	(0.044)	(0.036)	(0.016)
Number of children under 5(3 plus)	-0.023	0.211***	-0.051	0.042**
	(0.050)	(0.077)	(0.058)	(0.020)
Child is male	-0.048*	-0.044	0.000	0.006
	(0.026)	(0.042)	(0.033)	(0.013)
Observations	18,732	6,985	11,353	73,224
R-squared	0.522	0.319	0.215	0.339

In this table, we exclude GIS indicators in order to preserve the sample size across the various regions. Cluster-robust standard errors reported in parenthesis. Clustering is at the enumeration level. ***p<0.01, **p<0.05, *p<0.1. Controls included but not reported are child age dummies and survey fixed effects. Source: Phase 5 & 6 DHS data.

3.7 Conclusions

Existing economic evidence on diets is largely confined to the evidence provided by analysis of household level food demand. These food demand studies have primarily focused on estimating income elasticities of different food groups, rather than diversity as a whole, and they have not informed the nutritionally vital issue of dietary diversity among young children during their most critical window of physical and cognitive development. Hence, this paper examines the various potential determinants of child dietary diversity score among pre-school children utilizing a rich cross-country dataset of 39 countries from Phases 5 and 6 of the Demographic Health Surveys (DHS) (ICF International 2015).

There are six major findings in this paper.

Our first finding of note is a precisely estimated linear association between child diet diversity and household wealth. Although we find strong support for Bennett's law applying to children diets, the magnitude of this association is arguably smaller than one might expect from previous literature. This may be because nutritional knowledge is more important for the feeding of young children than for the household as a whole.

Second, consistent with the hypothesized importance of nutritional knowledge, we find clear evidence for large and nonlinear effects of maternal education; effects roughly twice as large as those of paternal education. These strong and non-linear associations between women's education and child dietary diversity score are consistent with the results on stunting reported in Alderman and Headey (2017). In contrast, women's decision making on her own health predicts only small improvements in dietary diversity.

Third, access to maternal and child health services index predicts considerable improvements in children's dietary diversity. This result is perhaps surprising given that nutritionists typically view health services as not delivering enough nutritional advice and messaging. It is also difficult to infer a precise causal mechanism at work. This association may reflect nutritional message, but it might also reflect the fact that parents with greater nutritional knowledge and stronger preferences for child health seek out more health services.

Fourth, we find no evidence that differences in parental schooling, health access or the food environment alters wealth effects. This suggests our results identify a very robust association between household purchasing power and child diet diversity that can be shifted up by differences in education and health service provision. The only significant wealth effect modifier is gender empowerment but the association is quantitatively very small.

Fifth, indicators of geographical and infrastructural characteristics have robust associations with child dietary diversity scores. Individual indicators of urbanisation tend to have modest (but highly significant) associations with dietary diversity, but the significance of a wide range of urbanisation and infrastructure indicators (night lights intensity, proximity to cities, population density), implies that these are important factors.

Finally, we find strong but non-linear relationships between climate indicators and dietary diversity. More rainfall may increase crop production diversity, but also cereal yields, which in turn translates into greater feed availability for animal sourced foods. In terms of temperature, both medium and high temperatures are negatively associated with the dependent variable, with similar effects. We note that the majority of the research on climate change has only focused on yield impacts but not on diversity of production or consumption

(Lobell et al. 2010; Schlenker and Lobell 2010). Here we don't yet find any strong impact of extreme heat on diet diversity, but we do find benefits of more temperate/cooler conditions. Previous research has suggested cooler condition benefits agricultural growth and broader development because of the benefits of winter frosts for eliminating both crop and livestock diseases (Masters and McMillan 2001).

This study has several limitations and strengths. Our data are observational so these results should not be interpreted as causal; rather our focus is on observing the associations of these factors with child dietary diversity scores and testing whether these associations are consistent with economic theory. Another potential limitation is the measurement of wealth. Household expenditure is often regarded as the preferred measure of household economic status, though it too is measured with substantial error (Beegle et al. 2012). It has been argued that rural-urban wealth indices are not perfectly comparable (Rutstein et al. 2013), and the DHS arguably does a poor job of measuring farm assets. Nevertheless, our estimates of the benefits of wealth are estimated with a high degree of precision, suggestion attenuation bias is not obviously a significant concern.

These limitations aside, this study has several strengths. Most studies of dietary diversification have focused on single country analyses of household level consumption data. Diets, however, are an intrinsically individual concept, and the diets of young children are particularly important for their longer term physical and cognitive development, as well as human capital accumulation (Glewwe et al. 2001; Horton et al. 2008; Hoddinott 2009). And no previous study that we are aware of has examined geographical predictors of dietary differences. In contrast, this study uses a large multi-country survey that allows us to examine how a broad range of parental, household and community level determinants influence dietary diversification.

Overall, our findings have important implications for future research and policy design, especially for countries with the highest burdens of malnutrition. Our results suggest that while wealth accumulation is indeed an important driver of diversification, there are strong grounds to also invest heavily in women's education. There may also be benefits to expanding basic health care, although further research is needed to as the associations reflect the potentially bidirectional relationship between exposure to health services and nutritional knowledge. Moreover, it is likely that the health access benefits could be further strengthened by improving the nutritional messaging of conventional health services (Menon et al. 2015).

In terms of community characteristics we find strong indications that urbanisation and infrastructure – broadly defined – are important for dietary diversification, though no single measure has large marginal effects. Future studies might also examine the impacts of rural-urban migration on dietary change. The associations between climate and dietary diversification are also quite striking. Rainfall appears to be quite a strong predictor of dietary diversity, and cooler temperatures appear to be associated with greater diversity. Future work could confirm that this association stems from strong impacts of climatic factors on production diversity, and test how climate influences production and availability of specific food groups. Clearly, with accelerating climate change, understanding the impacts of climate changes on production and dietary diversity is an issue of mounting importance.

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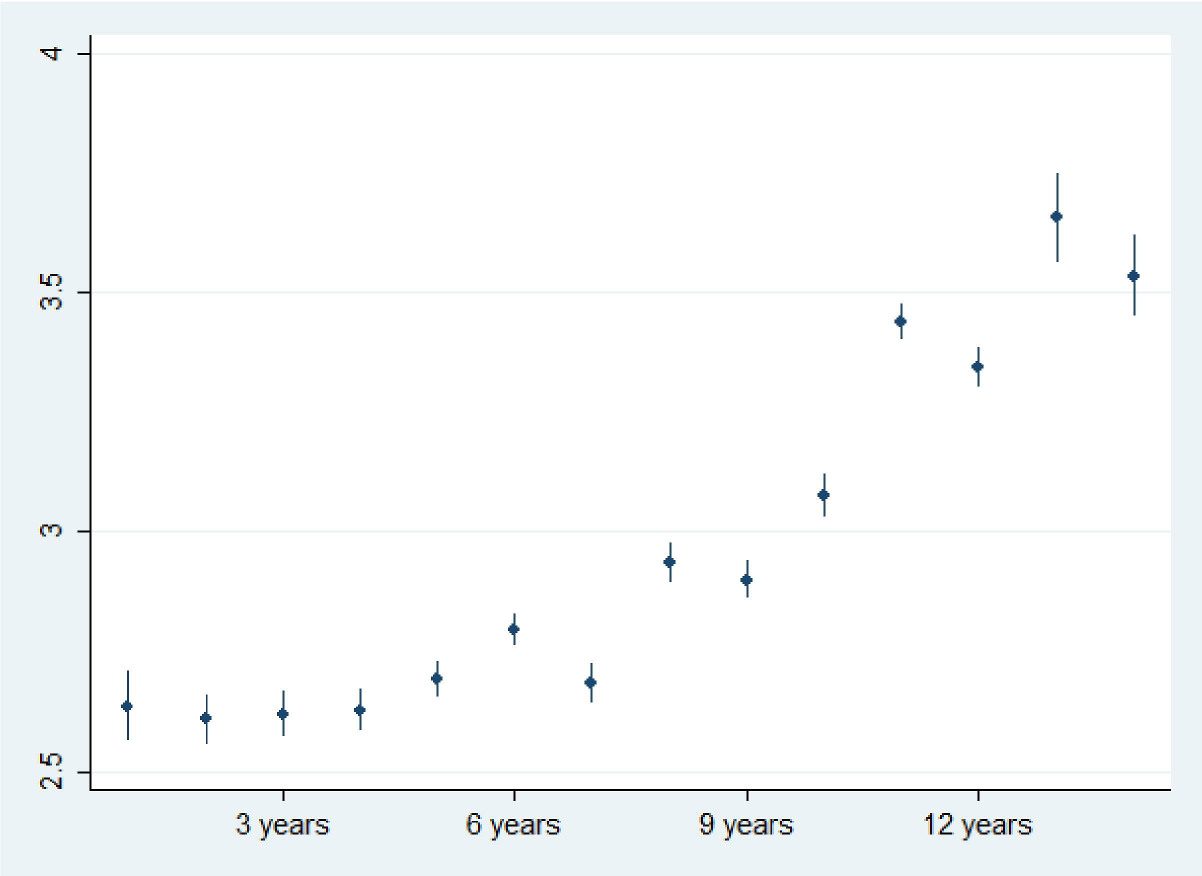
Appendix

Figure 3.8 Coefficient plot of wealth quintiles

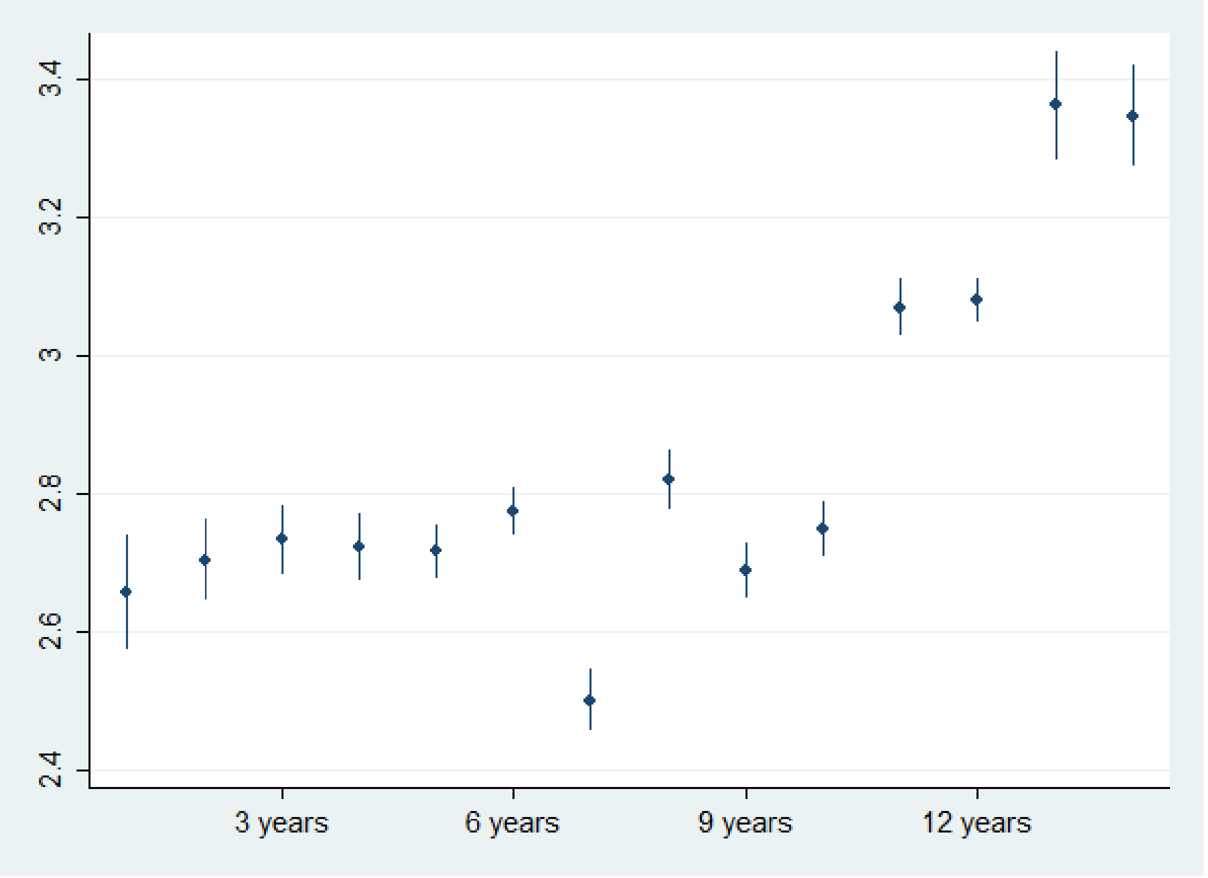
Source: Phase 5 & 6 DHS data for 39 countries.

Figure 3.9 Coefficient plot of years of education (mothers)



Source: Phase 5 & 6 DHS data for 39 countries.

Figure 3.10 Coefficient plot of years of education (fathers)



Source: Phase 5 & 6 DHS data for 39 countries.

Figure 3.11 Distribution of the dietary diversity indicator (7 food groups)

Notes: Dietary diversity score is measured for 74,313 children. Source: Phase 5 & 6 DHS data for 39 countries.

Table 3.9 Wealth interactions for children 12-23 months of age

	(1) Child dietary diversity score (12 food groups) 12-23 months
Household wealth (quintile)	0.169*** (0.031)
Maternal primary education	0.208*** (0.069)
Maternal secondary education	0.360*** (0.099)
Maternal tertiary education	0.504*** (0.127)
Paternal primary education	0.203*** (0.069)
Paternal secondary education	0.205** (0.092)
Paternal tertiary education	0.316*** (0.098)
Father's occupation is non-agricultural	-0.022 (0.072)
Health access	0.162** (0.067)
Child was breastfed immediately	0.133*** (0.052)
Mother can decide on own healthcare	-0.170*** (0.058)
Number of children under 5 (two)	0.040* (0.021)
Number of children under 5 (3 plus)	0.039 (0.034)
Child is male	0.004 (0.019)
Remote location (>1 hour to towns of >20k pop)	-0.080 (0.065)
Wealth * Maternal primary education	-0.009 (0.025)
Wealth * Maternal secondary education	0.014 (0.032)
Wealth * Maternal tertiary education	0.028 (0.036)
Wealth * Paternal primary education	-0.028 (0.026)
Wealth * Paternal secondary education	-0.009 (0.031)
Wealth * Paternal tertiary education	-0.025 (0.031)
Wealth * Father's occupation is non-agricultural	0.010 (0.025)
Wealth * Health access	0.017 (0.020)
Wealth * Child was breastfed immediately	-0.009 (0.016)
Wealth * Mother can decide on own healthcare	0.047** (0.019)
Wealth * Remote location (>1 hour to towns of >20k	0.005

pop)	
	(0.024)
Night lights intensity index by cluster, medium tercile	0.083*
	(0.045)
Night lights intensity index by cluster, upper tercile	0.161***
	(0.050)
Population density, middle tercile	0.070**
	(0.033)
Population density, upper tercile	0.127***
	(0.044)
Medium length of growing period in days	0.110*
	(0.063)
High length of growing period in days	0.032
	(0.071)
Mean rainfall, middle tercile	0.174***
	(0.063)
Mean rainfall, upper tercile	0.234***
	(0.072)
Mean temperature, middle tercile	-0.200***
	(0.040)
Mean temperature, upper tercile	-0.159***
	(0.055)
Altitude by cluster, middle tercile	0.063
	(0.042)
Altitude by cluster, upper tercile	0.050
	(0.054)
Distance to coastline, middle tercile	0.144***
	(0.040)
Distance to coastline, upper tercile	-0.031
	(0.057)
Observations	43,059
R-squared	0.254

Cluster-robust standard errors reported in parenthesis. Clustering is at the enumeration level. ***p<0.01, **p<0.05, *p<0.1. Controls included but not reported are child age dummies, country and survey fixed effects. Source: Phase 5 & 6 DHS data for 39 countries.

Table 3.10 List of countries and rounds from the various DHS surveys (Phase 5 and 6)

Country	Observations per country	Survey years	Observations per survey
Albania	370	2009	370
Benin	2,907	2012	2,907
Bolivia	2,065	2008	2,065
Burkina Faso	1,843	2010	1,843
Burundi	965	2010	965
Cambodia	1,080	2010	1,080
Cameroon	1,423	2011	1,423
Colombia	3,949	2010	3,949
Comoros	527	2012	527
Cote d'Ivoire	788	2012	788
Dominican Republic	2,477	2007	1,881
		2013	596
Egypt	3,070	2008	3,070
Ethiopia	2,473	2011	2,473
Gabon	661	2012	661
Ghana	693	2008	693
Guinea	919	2012	919
Guyana	281	2009	281
Haiti	1,710	2006	671
		2012	1,039
Honduras	2,477	2012	2,477
Jordan	1,717	2012	1,717
Kyrgyz Republic	1,203	2012	1,203
Lesotho	143	2009	143
Liberia	748	2013	748
Madagascar	1,176	2009	1,176
Malawi	1,415	2010	1,415
Mali	1,317	2013	1,317
Mozambique	2,546	2011	2,546
Namibia	789	2007	596
		2013	193
Nepal	2,179	2006	1,515
		2011	664
Nigeria	10,217	2008	2,654
		2013	7,563
Rwanda	923	2010	923
Senegal	2,654	2011	1,083
		2013	1,571
Sierra Leone	1,604	2008	505
		2013	1,099
Swaziland	359	2007	359
Tajikistan	1,292	2012	1,292
Timor-Leste	2,416	2010	2,416

Uganda	1,151	2006	608
		2011	543
Zambia	1,448	2007	1,448
Zimbabwe	2,305	2011	1,266

Chapter 4:

Household dairy production and child growth: Evidence from rural Bangladesh

Samira Choudhury

(with Derek Headey)

Abstract

Experimental and observational research from developed country settings has found that dairy consumption has strong positive associations with linear growth in children. Surprisingly little evidence exists on the importance of regular dairy intake for child growth in less developed countries. One exception is a development economics literature that uses the notion of incomplete dairy markets to identify the impacts of dairy production on child growth. Those impacts are assumed to stem from regular availability of dairy products for children residing in cattle-owning households or cattle-producing villages. This paper builds on this literature by analysing the importance of cow ownership for child nutrition outcomes in rural Bangladesh. Unlike previous papers, however, we exploit the fact that, in any given year, some cows will not be lactating. This permits a stronger placebo test, which more convincingly rules out endogeneity concerns with cattle ownership. Our results reveal a robust positive association between ownership of lactating cows and child growth among young children (6–23 months), but not among older children (24–59 months). The sizes of effects for children 6–23 months are close in magnitude to more experimental results, and larger in magnitude than obtained in more observational studies with weaker identification strategies. In addition, we find an unusual positive association between ownership of lactating cows and wasting. The results therefore suggest that increasing access to dairy products is beneficial to infants' nutrition, but may need to be accompanied by efforts to improve nutritional knowledge and appropriate breastfeeding practices.

Key words: Agriculture; Livestock; Dairy production; Cow ownership; Animal-sourced foods; Undernutrition; Stunting; Wasting.

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4.1 Introduction

Worldwide, child undernutrition is increasingly recognised as a major constraint to economic development. Nutritionists estimate that child undernutrition contributes to almost 3.1 million child deaths (Black et al. 2013). Child malnutrition has been shown to contribute to impaired cognitive development in early childhood (Walker et al. 2011; Grantham et al. 2007), and a sizeable economics literature links malnutrition in early childhood to reduced school attendance and attainment in childhood, and lower labour productivity and wages in adulthood (Hoddinott et al. 2013; Shekar, Heaver and Lee 2006). Nutritionists, moreover, have increasingly emphasised that early childhood physical growth – the first 1000 days of nutrition (in utero plus the first 24 months after birth) – is critical (Shrimpton et al. 2001; Victora et al. 2010). Child growth retardation can start from conception (especially in South Asia), and malnourished children continue to experience growth retardation until aged two. Thereafter, child stunting seems substantially irreversible, at least at the population level, implying that there are potentially very high returns to preventing early childhood malnutrition among infants and young children.

Improving nutrition in early childhood will require, among other things, major improvements in children's diets and feeding practices. Within the overall objective of improving diets, increasing the amount of animal-sourced food (ASF) consumption is increasingly thought to be crucial for improving linear growth, cognitive function, and overall child health (Allen 2003; Black 2003; Brown 2003; Bwibo and Neumann 2003; Demment, Young and Sensenig 2003; Hop 2003; Neumann, Harris and Rogers 2002). Animal-sourced foods are not only rich in several nutrients, but the protein and micronutrients they contain tend to be more bioavailable than those contained in plant foods. They contain higher sources of energy, protein, essential micronutrients such as iron, zinc, riboflavin, vitamin A, vitamin B12, and calcium (Murphy and

Allen 2003), as well as choline, insulin-like growth factors and essential amino acids that are thought to be crucial for the processes of cellular growth and bone formation (Semba et al. 2016). Dairy products also contain insulin-like growth factor-1 (IGF-1), which promote growth in young children (Iannotti, Muelhoff and McMahon 2013; Dror and Allen 2011; Wiley 2009; Sadler and Catley 2009; Hoppe et al. 2008).

Given the substantial biological evidence on the importance of ASFs, it is hardly surprising that around half of agriculture for-nutrition projects in developing countries contain a substantial focus on increasing livestock production (Turner et al. 2013). Most such projects have been found to increase household consumption of ASFs by means of household production and purchase of other high-quality foods (Alam 1997; Ayele and Peacock 2003; Iannotti, Muelhoff and McMahon 2013; Leroy and Frongillo 2007). However, evidence of impacts on child nutritional outcomes in developing countries remains very limited (Iannotti, Muelhoff and McMahon 2013). Moreover, the evidence garnered from agriculture for-nutrition projects often has many other limitations, including low methodological quality, lack of scale and external validity, and limited assessment of sustainability or cost-effectiveness (Iannotti, Muelhoff and McMahon 2013; Leroy and Frongillo 2007). Observational evidence on the linkages between dairy consumption and child growth is also limited by the paucity of high-quality data on "usual diets" in developing countries.[11]

Because of these limitations, economists have increasingly utilised observational or quasi-experimental analyses to explore the associations between dairy production and child nutrition

[11] The widely used Demographic Health Surveys (DHS) (ICF International 2015) now have 24-hour recall indicators of food consumption, but this is likely to be a relatively poor indicator of regular consumption of dairy products in many settings. Some children who did consume milk in the past 24 hours may not be regular consumers of milk, and vice versa. This misclassification may lead to attenuation bias when trying to estimate the impact of milk consumption on child growth with observational data.

outcomes in less developed country settings. A significant theoretical motivation for these studies is the idea that dairy and other ASF products are substantially non-tradable over large distances in underdeveloped settings because of their perishability. This creates conditions wherein farm households make production decisions partly with their own consumption objectives in mind (non-separability).

In light of these limitations in the existing literature, this paper utilises a unique dataset to attempt a more comprehensive assessment of the nutritional implications of dairy production and consumption in Bangladesh. Bangladesh is a particularly important case study in the context of dairy production. In addition to its extremely high rates of stunting (36%) (see Srinivasan, Zanello and Shankar (2013), which focuses on rural-urban disparities in child nutrition outcomes in Bangladesh) , Headey and Hoddinott (2016) emphasise that Bangladesh has an exceptionally under-diversified food supply, pointing to FAO data suggesting that ASFs account for less than 5% of total calories supplied. They describe this situation as stemming partly from exceptionally low levels of milk consumption, which in per capita terms is less than half that of neighbouring India. A likely explanation is land constraints (and hence feed constraints), with average farm sizes in Bangladesh averaging just half a hectare, and rural landlessness widespread.

In this paper, we use the nationally representative Bangladesh Integrated Household Survey (BIHS) (2011/2012 and 2015) of rural areas (published by the International Food Policy Research Institute, IFPRI, 2016). Uniquely for such a large survey, this dataset contains information on individual-level food consumption, sources of food consumption (household production, markets), annual livestock production, measures of income, socioeconomic status and other nutrition-relevant factors, and individual anthropometric outcomes.

Methodologically, we propose a novel approach to assessing the impact of dairy cow ownership on child nutrition outcomes, by distinguishing between lactating dairy cows that have produced milk over the past 12 months and those that have not. This identification assumption rests upon the fact that smallholder dairy producers in Bangladesh typically own only a few cows. In this sample, 80% of cow owners own just one or two cows and none own more than four. At any given time, all or some of these cows will not be lactating since there is a minimum 12-month inter-calving cycle for each animal, even among the most technologically sophisticated dairy producers. Hence, there is a non-trivial proportion of dairy cow owners in Bangladesh who would be unable to produce milk on a continuous basis for exogenous biological reasons. Other potentially endogenous determinants of the lactation cycle include seasonal diseases and heat stress, land access, poor management practices related to oestrus detection, poor animal nutrition, and poor access to male cattle or artificial insemination services (Shamsuddin et al. 2007; Kamal 2010).[12]

The remainder of this paper is organised as follows. Section 4.2 reviews more extensively the previous literature on ASF consumption, dairy production and child nutrition. Section 4.3 describes the data and the methods used to analyse them. Section 4.4 tests associations between

[12] Kamal (2010) writes:

> Many farms in Bangladesh are so small that only one cow can be kept. Cows are tethered in a stable or on available grazing land. They are used for draught work as well as milk production. These management practices promote the occurrence of post-partum anoestrus and limit behavioural manifestations of oestrus. This is explained by the fact that in intensive farming or in small holdings having one cow, oestrus cannot be detected by primary signs such as standing to be mounted as the cows are always tied up. However, the main weakness affecting the accuracy of oestrus detection is that farmers are missing or misinterpreting or are unaware of secondary signs of oestrus such as mucus discharge and swollen vulva. Detection of oestrus and of the return to oestrus after unsuccessful artificial insemination (AI) is clearly difficult under such conditions and inefficiencies have been documented (Shamsuddin, 1995). Traditionally, pregnancy diagnosis is not carried out as part of the artificial insemination programmes. Generally suckling and weaning is not controlled in dairy production system in Bangladesh. The main constraints of cattle reproduction is prolonged postpartum intervals to conception and low Conception Rate (CR), which were the results of inefficiencies in the management of nutrition, oestrus and Artificial Insemination (AI) services.

livestock ownership and various nutrition outcomes. Section 4.5 provides some important sensitivity tests and extensions, and Section 4.6 concludes with a discussion of the implications of these findings for programs and policies, as well as for future research.

4.2 Previous literature

In this section, we first outline differences in the biological value of different ASFs. Second, we briefly summarise the literature on agricultural household models to consider the dimensions of nutrition under complete and imperfect markets. Third, we review the empirical evidence on dairy production, dairy consumption and child nutrition.

4.2.1 Biological theory on ASF consumption for child nutrition and health

Relative to non-ASFs, ASFs are nutritionally richer sources of energy, protein, various micronutrients such as iron, zinc, riboflavin, vitamin A, vitamin B12 and calcium, and essential fatty acids and amino acids (Murphy and Allen 2003). In general, red meat (beef, mutton) has a greater zinc and iron content compared to other ASFs, such as poultry, fish and eggs, while milk has no iron. Milk, eggs and fish are vital sources of preformed vitamin A, fish and milk supply calcium and phosphorus (Hansen et al. 1998), and milk contains insulin-like growth factors that appear to play a key role in programming linear growth. Meat and milk are major sources of vitamin B12 (Watanabe 2007), in addition to providing high-quality protein containing all the necessary amino acids (Williamson et al. 2005). Eggs are exceptionally high in choline, but are low in bio-available B12 (Watanabe 2007). Eggs and poultry may also be problematic for poultry-owning households: several papers, including empirical papers on Bangladesh, raise concerns about contamination of the homestead by poultry faeces, which may promote chronic gut infections that retard infant and child linear growth (George et al. 2015; Headey and Hirvonen 2016; Headey et al. 2016). Fish products tend to be high in a wide range of micronutrients as well as choline, and some fish varieties are uniquely high in essential fatty acids. Traditional Bangladeshi small fish varieties are exceptionally high in a wide range of nutrients (Bogard et al. 2015).

4.2.2 Conceptual model on dairy production, dairy consumption and child nutrition

We adapt the standard neoclassical agricultural household model to consider dimensions of nutrition – intake of foods and child nutrition outcomes – under complete and imperfect markets (Singh, Squire and Strauss 1986). Previous research in this area is shown in Singh, Squire and Strauss (1986), with the implications for nutrient intake and child nutritional status explained in Behrman and Deolalikar (1988).[13]

The conceptual model described in Hoddinott, Headey and Dereje (2015) is a useful starting point for thinking about household decision-making processes with respect to dairy production, dairy consumption and child nutrition. They posit a household utility model in which child nutrition is one argument. Nutritional status is itself a function of nutrient (food) intake, as well as nutritional knowledge, culture, healthcare, genetic endowments, and locational characteristics (e.g. the prevalence of disease; access to information about good childcare practices). In a world of perfectly functioning markets[14], nutrient intake would be influenced primarily by income and relative prices, and households could sequentially maximise farm and nonfarm income before deciding how to spend that income to then maximise nutrition outcomes subject to other arguments in the utility function. (Strauss, 1986, provides an example of this

[13] For a recent discussion, with new extensions, see LaFave and Thomas (2014).
[14] Separability of production and consumption decisions suggests that initially, a household maximises profits from production and then maximises utility from consumption. Under separability, there are perfect markets for agricultural inputs and outputs, and goods are tradable without prohibitive transaction costs. With a set of complete markets, households would be indifferent between their own consumption and goods purchased from markets (Taylor and Adelman 2003) and consumption levels should be contingent entirely on prices, income and preferences, just as they would in highly urbanised settings.

approach). In other words, certain types of agricultural assets affect nutritional status only via their impact on household income.

However, in the presence of imperfect rural markets[15], these assumptions can break down for many reasons, for instance productivity, and as a result, wages may be determined by nutrient intake (Strauss and Thomas 1995) or there may be prohibitively high transaction costs for market interactions (de Janvry, Fafchamps and Sadoulet 1991). In addition, product-specific agricultural assets, such as cows, can have direct impacts on child nutritional status[16]. In the case we consider here, the assumption of imperfect markets is indeed a natural way to begin. The perishability of milk in poorly developed value chains (lack of cold storage, poor transport) renders household production and consumption decisions non-separable. In other words, if households struggle to access affordable milk via markets, they could opt to own dairy cows. This implies that the decision to own dairy cows may be highly endogenous, influenced as it is by nutrition knowledge and farm production parameters such as the availability of capital (income, savings, wealth), access to land (feed), access to input and output markets to obtain feed and sell produce, household labour supply, farm management skills, and the role of women in household decision-making and labour supply (since dairy production is largely under the purview of women). Since omission of these kinds of factors could lead to biased coefficients on the impacts of cattle ownership or milk production on child growth, our empirical models need to control for these factors as extensively as possible. Section 3.3 provides detailed information on the data used in this paper.

[15] In this situation, factors that have an impact on consumption decisions (wealth, prices of consumer goods, tastes, and other household characteristics that affect consumption, e.g. demographic structure and nutritional knowledge) can also affect production decisions.

[16] As de Janvry, Fafchamps and Sadoulet (1991) note, the presence or absence of markets will have an impact on household consumption behaviour.

4.2.3 Empirical evidence on dairy production, dairy consumption and child nutrition

A wide range of empirical evidence from developing countries tends to confirm the importance of ASFs for growth and development outcomes (McLean et al. 2007; Neumann et al. 2013; Neumann et al. 2007; Neumann, Harris and Rogers 2002). Much of the existing biological evidence linking ASFs to nutrition outcomes has focused on dairy (Nicholson 2003; Vella et al. 1995; Grosse 1998; Hoddinott, Headey and Dereje 2015). So too has much of the project and observation-based evidence from developing countries (Leegwater, Ngolo and Hoorweg 1991; Pimkina et al. 2013; Ayele and Peacock 2003). Research on other countries, particularly those in East Africa, has also established the importance of dairy cow ownership in determining the nutritional status of children (Hoddinott, Headey and Dereje 2015; Hoorweg, Leegwater and Veerman 2000; Nicholson et al. 2003; Rawlins et al. 2014; Vella et al. 1995). This strand of literature focuses increasingly on observational or qausi-experimental work, in part to understand larger scale associations and processes linking agriculture and nutrition.

In economic history studies, Baten and colleagues (Baten and Murray 2000; Baten 2009; Baten and Blum 2014) test this "protein proximity" hypothesis in 19th century European military recruitment data from Central Europe. They find that adult men in closer proximity to dairy production were substantially less likely to be short. In contemporary developing countries, several studies have examined associations between household livestock ownership and child growth outcomes, though not all studies focus on dairy producing animals specifically. Mosites et al. (2015) find significant negative associations between total livestock ownership and stunting in Ethiopia and Uganda, but not in Kenya. Azzarri et al. (2015) apply an instrumental variable (IV) approach to a smaller Ugandan household survey and find no impact of large ruminants on stunting outcomes, but some negative associations with underweight status. Hoddinott, Headey and Dereje (2015) use two large surveys from Ethiopia to explore the association between cattle ownership, dairy consumption and height-for-age[17] (HAZ) scores. They cite the fact that 90% of milk produced in rural Ethiopia is consumed by the household producing it, implying that cattle ownership ought to be a strong predictor of regular dairy intake. Consistent with that conjecture, they find strong positive associations with HAZ (as high as 0.47 standard deviations in the 12–23-month age-range). They also implement placebo tests to explore the concern that cattle ownership proxies for generic wealth effects on child nutrition. However, they also find that the direct nutritional effects of cattle ownership tend to be weaker in villages with regular markets, which would seem to support the agricultural household model with market imperfections. Finally, Rawlins et al. (2014) evaluate Heifer International's dairy cow and goat ownership programs in Rwanda, albeit in a non-randomised quasi-experimental design with a small sample of 217 children aged 0–59 months (precluding the possibility of detailed age disaggregation). They find that children from households who received a goat 12 months ago show no growth differential over those in a control group, while transfers of pregnant cows (high-productivity foreign breeds) improved HAZ scores by 0.57 standard deviations (albeit imprecisely estimated). Overall, there is some evidence that dairy cow ownership is associated with child growth in less developed country settings, though the evidence is confined to East Africa and suffers from several internal validity issues.[18]

In general, there are very few empirical papers on dairy interventions in low-income developing countries since trials are expensive to implement and potentially lack external validity, because diets and determinants of malnutrition tend to be very context-specific. One exception is a comprehensive systematic review on milk and dairy programs affecting nutrition in developing countries, which finds that six of 24 studies establish a causal link between milk intervention

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[17] A child is considered stunted if HAZ falls below -2.0 (WHO 2006).

[18] Here we review only published studies on cattle ownership and child growth. Rawlins et al. (2014) review several much earlier unpublished studies on this topic, though all involve very small sample sizes, and all still pertain to East Africa (Kenya, Malawi, Rwanda).

and nutrition outcomes, showing promise for improving nutrition worldwide (Iannotti, Muelhoff and McMahon 2013). However, many of these interventions were consumption-based, such as school feeding programs, rather than production-based. We provide a brief summary of the outcomes of these programs.

With regards to dairy production and agriculture programs, the national Dairy Development Project (DDP) in Kenya, which aimed to enhance dairy management practices, showed that both milk consumption and the HAZ and weight-for-age (WAZ) z-scores among children from households of DDP farmer groups have increased compared to controls. The Dairy Goat Development Project in Ethiopia led to increases in milk consumption and additional dietary intake improvements but failed to show impacts on nutritional status (Ayele and Peacock 2003). The Operation Flood dairy intervention in India increased per capita milk consumption in dairy farmers (Cunningham 2009). However, in the Karnataka Dairy Development Project, households in villages with cooperatives consumed less milk compared to households in villages without cooperatives, because milk prices were higher in the villages with cooperatives (Alderman, Mergos and Slade 1987).

Most studies have reported positive associations between nutritional outcomes and school-based milk programs (Du et al. 2005; Neumann et al. 2007). An important example is the study conducted in the Embu District of Kenya, which found that milk consumption has positive effects on height and cognitive development among school-aged children (Murphy and Allen 2003; Neumann et al. 2007). In contrast, there has been relatively little work establishing the importance of other livestock products, including fish.

Dairy consumption and linear growth

Milk has been cited as essential for growth and development of children older than 12 months, providing several critical micronutrients as well as insulin-like growth factor-1 (IGF-1) (Iannotti et al. 2013; Dror and Allen 2011; Wiley 2009; Sadler and Catley 2009; Hoppe et al. 2006). Proteins influence the growth-stimulating effect of dairy products, although it is yet to be confirmed as to which components in milk could cause this possible growth-stimulating effect (Hoppe et al. 2004; Dror and Allen 2011).

IGF-1 contributes in raising the uptake of amino acids that are incorporated into new proteins and promotes growth in bone length (Wiley 2005). Specifically for poorly nourished children, adding milk to the diet supplies nutrients that are essential for growth and lacking in the diet (Hoppe, Molgaard and Michaelsen 2006). In contrast, for well-nourished children, the impact of milk on linear growth is possibly through stimulating IGF-1 instead of reducing micronutrient deficiencies (Hoppe, Molgaard and Michaelsen 2006). Both growth hormone and nutrition play a role in maintaining synthesis of IGF-1, though it is expected that this is more important during infancy, when IGF-1 concentrations are low, compared to childhood and adulthood (Hoppe, Molgaard and Michaelsen 2006). Milk intervention trials among children have been related to increases in circulating IGF-1 (Cadogan et al. 1997; Hoppe et al. 2004). Even though cow milk consists of IGF-1, oral consumption of this growth factor is not absorbed (Larsson et al. 2005). Instead, bioactive peptides (available in both casein and whey), milk IGF-1, amino acids or milk minerals (including calcium) are responsible for the insulin-like growth factors (IGFs) (Hoppe, Molgaard and Michaelsen 2006). Calcium or zinc may also be additional factors in stimulating growth. Hoppe et al.'s (2006) review on assessing the relationship between cow's milk and linear growth argue that cow's milk may have the strongest impacts on linear growth among malnourished children even though not all studies have shown impacts.

Dairy consumption and weight status

Epidemiological studies on dairy and obesity can be generally classified as those that consider the positive impact of dairy on weight gain and those that analyse the protective function of dairy (specifically) against weight gain. A recent review of cohort studies by Louie et al. (2011) has assessed the longitudinal association between dairy and obesity. Out of 19 studies, eight have shown a protective relationship of dairy consumption against weight gain, seven have reported no effect on weight, one has revealed a significant protective relationship in overweight men, one has shown a high probability of weight gain in children with increased milk intake, and two studies have reported both high and low probability of weight gain, conditional on the type of dairy product. Yet, there is some evidence of a protective impact of dairy on weight even though it is inconclusive, suggesting that if an impact does exist, the magnitude is likely to be minimal (Louie et al. 2011).

With regards to dairy consumption and childhood obesity, IGF-1 may be indicative of fat-cell formation since it suppresses the secretion of growth hormones and thereby contributes to obesity development (Hoppe, Molgaard and Michaelsen 2006; Dougkas et al. 2011). Consumption of dairy protein during infancy may enhance the probability of excess weight gain in childhood (Hoppe et al. 2004; Gunther et al. 2007). Nonetheless, it is important to bear in mind that body weight consists of fat, muscle and bone mass, and the link between dairy protein and weight gain among children may be correlated with the increase in non-fat mass during growth and development (Cadogen et al. 1997; Spence, Cifelli and Miller 2011).

In contrast, a recent systematic review of 16 studies suggests that, based on observational evidence, dairy fat does not lead to obesity and that high fat dairy consumption is negatively related to risk of obesity (Kratz, Baars and Guyenet 2013). Calcium and 1,25-hydroxyvitamin

D maintain lipid metabolism in adipose cells through stimulation of fatty acid oxidation and suppression of lipogenesis. Related literature regarding a potential biological effect on weight loss through increased calcium, finds that higher-calcium intakes, in particular dairy products, are associated with weakening adipocyte lipid accretion and weight gain, which thereby accelerates fat loss (Zemel 2004). This is because dairy products have extra bioactive compounds and have a greater degree of branched-chain amino acids in whey, which together acts with calcium to reduce adiposity.

Caan et al. (2007) report that calcium may reduce fatty acid absorption and increase faecal fat losses. However, experimental data regarding this topic is inconclusive. Few studies have analysed the impact of calcium on weight and those available are of short duration with small sample sizes, so their outcomes should be interpreted with caution (Theobald 2005; Caan et al. 2007). But much evidence from observational, clinical intervention, and mechanistic studies now support this finding (Zemel et al. 2000; Bursey et al. 1989; Lin et al. 2000; Lovejoy et al. 2001; Buchowski et al. 2002) although most studies that have reported the inverse relationship between dairy products and weight gain have been conducted in adults; few studies have focused on children and adolescents (Tanasescu et al. 2000; Carruth and Skinner 2001; Skinner et al. 2003; Phillips et al. 2003). Findings from an exceptional 5-year longitudinal study of pre-school children from 2 months of age by Carruth and Skinner (2001) reveal a significant negative association between dietary calcium and body fat. Likewise, other epidemiological studies have supported dairy as part of a weight loss strategy (Zemel 2004).

4.3 Data and methods

4.3.1 Data

The BIHS is a large survey representative of rural Bangladesh that has been implemented in two rounds (2011/2012 and 2015) and constitutes a panel for the majority of households (since 66% of the population is rural). The surveys were implemented by IFPRI and funded by USAID (Ahmed 2013, IFPRI 2016). However, because we are interested in child growth in the first five years of life, we treat both rounds as repeated cross-sections rather than as a panel. The combined rounds make up a sample of 11,796 households (some surveyed twice), which includes 4,268 pre-school children aged from 0 to 59 months. Fortunately, the BIHS contains not only detailed data on children's food intake and nutrition outcomes, but also an exceptionally rich array of data on income, wealth, agricultural production and assets, access to markets, women's empowerment and women's nutrition knowledge (Ahmed 2013, IFPRI 2016).

Anthropometric measurements of height and weight, which provide the basic information required to evaluate a child's nutritional status (Quinn 1992), constitute our primary nutrition outcomes of interest. In this study, the ratios of height-for-age and weight-for-height are converted to z-scores conditional on age and sex, as outlined by the World Health Organization's global child growth reference standards (WHO Multicentre Growth Reference Study Group 2006). Wasting is defined as having a weight-for-height z-score (WHZ) less than -2, indicating acute malnutrition and associated with short-term deficiencies and illness. Chronic malnutrition or stunting, on the other hand, is more prevalent than acute malnutrition, but emerges cumulatively over a longer time period due to prolonged nutritional deficiencies and repeated or chronic infections (Puffer and Serrano 1973). According to WHO Multicentre

Growth Reference Study Group (2006), a child is considered stunted if HAZ falls below -2.0. In addition to its strong associations with health outcomes, undernutrition in early childhood is also strongly associated with cognitive development, school attainment and adult earnings (Victora et al. 2008).

Unlike other standard household surveys, which do not provide information on dietary intake of individual household members, the BIHS provides the opportunity to determine intra-household dynamics related to food. Specifically, enumerators first collected details (recipe, ingredients, raw and cooked weights) on food consumed in the household in the previous day from the main female interviewee in the household (usually the mother). This interviewee was then asked about the amount of each recipe consumed by individual family members, including guests. In addition, the BIHS contains estimates of food consumption data (covering around 300 items) in the past seven days, captured at the household level. This module records information on quantity of food consumed from market purchases, home production and other sources outside the house (loans and gifts from relatives/friends, government and nongovernment aid, and food received in exchange for labour), which can be used to identify the relative importance of household production and market supply.

In principle, these individual consumption data could be used to examine the impacts of dairy consumption on child growth, but for two problems. First, longer term growth is a cumulative process taking place over many months of a child's early life, but the consumption data is 24-hour recall, and therefore potentially characterised by significant measurement error and attenuation bias. Second, milk consumption by itself might be highly endogenous, as milk is an income-elastic good.

In contrast, the variation in milk production related to inter-calving cycles is more likely to be exogenous once we have controlled for several important determinants of cattle reproduction. We therefore use two indicators in the BIHS to define households in Group A, which own a cow and report producing milk in the past 12 months (milk-producing dairy cow ownership households), as well as Group B households, which owned cows but did not produce milk (no milk-producing dairy cow ownership households). We also control extensively for other forms of livestock (bullock/buffalo, goat, sheep, chicken, duck and other birds) and aggregate livestock into an index of tropical livestock units (TLU), which can be thought of as a measure of aggregate livestock wealth. These other livestock controls are important because of potential substitution between livestock types, but also because livestock may represent rural wealth, and because access to male cattle may be an important determinant of cattle reproduction efficiency.

Our remaining set of control variables comprises an extensive set of factors that could simultaneously influence the decision to own a cow or to produce milk more frequently, as well as standard variables common to most nutrition specifications. This set of variables includes household characteristics (parental age and schooling), child characteristics (sex, age), per capita monthly expenditure, the aggregate value of 26 household assets, hectares of cultivable land owned by the household (a likely determinant of cattle ownership), household toilet and water access, access to electricity, and exposure to NGO services. We also control for several community characteristics such as distances to the nearest weekly/periodic outdoor market and to the nearest health centre.

4.3.2 Methods

Our empirical analysis begins with some basic descriptive results to look at associations between dairy production, 24-hour milk consumption and child growth outcomes (Section 4.4).

We then turn to a regression analysis in which we stratify by children 6–23 and 24–59 months. These age disaggregations are selected for several reasons. At the lower end, children below 6 months of age should not, ideally, be consuming any solid foods or dairy products, and those that do are likely to be systematically different (e.g. they may have encountered breastfeeding problems). The 23-month cut-off was chosen as the end of the first 1000 days of growth faltering, and it is probable that the impact of a wide range of factors systematically differs between 6–23 month and 24–59 month year old children.

We use linear regression models to assess the associations between nutritional outcomes N, (measured by their HAZ and WHZ scores) for a child i and mc_i, which takes the value of 1 if the child's household owns a milk-producing dairy cow and c_i, which takes the value of 1 if the child's household owns no milk-producing dairy cow and 0 if the child's household does not own any type of dairy cow. X_i is a vector of control variables including other types of livestock ownership (buffalo/bullock, goat/sheep, poultry/duck/other birds, fish), demographic characteristics, parental characteristics (age, sex, education), socioeconomic status, total cultivated land, child-specific characteristics (sex, age), dummy variables for households that have access to improved water supply and toilet, market access indicators; μ_j is the district fixed effects and T denotes time dummies for each survey round.

The vector of coefficients (β_1 and β_2) constitutes the parameters of principal interest. With the addition of an error term (ε_i), we represent the relationship by equation (1)[19]:

$$\boldsymbol{N_i = \beta_1 . mc_i + \beta_2 . c_i + \beta_3 . X_i + \mu_j + T_t + \varepsilon_i} \quad (1)$$

We also employ binary logistic regressions to estimate the probability that a child is stunted and the probability that a child is wasted using the same set of controls as outlined in equation (1). While the linear regression models for z-scores are interpreted as linear changes in outcome because of unit changes in explanatory variables, these logistic regressions report the average marginal effect for each explanatory variable and thereby explain which dairy cow ownership reduces the probability of stunting and wasting. According to the logistic regression model, the dependent variable Y_i (child is stunted; child is wasted) takes values of one and zero:

$$\boldsymbol{Y_i = \begin{cases} 1 & N_i < 2.0 \\ 0 & \text{otherwise} \end{cases}}$$

[19] There may be concerns about potential endogeneity arising from correlation between our explanatory variables and the error terms in the regressions. Although an instrumental variables (IV) approach is often preferred in these situations, we have difficulty in trying to implement an IV approach because that entails as least as many valid instruments as potentially problematic regressors. We decide to use OLS because using invalid instruments can lead to results that are even more biased than OLS and, in addition, including weak instruments does not inevitably overcome the potential bias of OLS and can also mislead about the size of standard errors (Murray 2006). Our opinion is that any potential endogeneity between child anthropometric outcomes and milk-producing dairy cow ownership is likely to be very small. Further, we acknowledge that our ability to completely eliminate endogeneity concerns is limited, especially with cross-sectional data.

4.4 Descriptive results

4.4.1 Overview of the BIHS survey characteristics

Although our data includes 4,268 pre-school children aged 0–59 months, we restricted the sample to children 6–59 months, excluding 470 children aged less than 6 months. For our analysis, we focus primarily on children 6–23 months and 24–59 months, since based on previous research on cattle ownership and growth outcomes in Ethiopia (Hoddinott, Headey and Dereje 2015) and the biology of growth faltering identified in Victora et al. (2010), we can expect that growth benefits of regular milk consumption peak in the 6–23 month window. Of these data, 43 observations were dropped, because the primary female respondent was either unavailable on the day of the interview or did not respond to questions on child anthropometric status. Therefore, our final estimation sample consists of 3,755 children.

Table 4.1 provides descriptive statistics for the key variables used in the study of children 6–59 months of age. The anthropometric indicators show that stunting, where children with HAZ scores less than -2, is high in this rural sample for children 6–59 months of age (43%).

Next, we report descriptives for some basic assets of interest. As expected, we find that ownership rates of livestock are very high, for instance, 64% of households have owned poultry/duck and 29% have engaged in fish production over the past 12 months. The average area of land cultivated in this sample is around 0.22 hectares, suggesting that land might be a major constraint to cow ownership. With regard to community-level characteristics, more than half of the villages have electricity. The distance to a weekly/periodic bazaar is around 2 km, indicating strong market access.

Table 4.1 Descriptive statistics of key variables for children 6–59 months

Variable	Obs	Mean	Std. dev	Min	Max
Anthropometric indicators for children aged 6–59 months					
Height-for-age (HAZ)	3,755	-1.72	1.45	-5.97	5.88
Stunted (HAZ < -2)	3,755	0.43	0.49	0.00	1.00
Weight-for-height (WHZ)	3,755	-0.82	1.22	-4.94	4.91
Wasted (WHZ < -2)	3,755	0.14	0.35	0.00	1.00
Household-level indicators					
Total livestock owned (Tropical livestock unit)	3,798	0.68	1.08	0.00	25.80
Owned milk-producing cow over the past 12 months (= 1, 0 otherwise)	3,798	0.14	0.35	0.00	1.00
Owned no milk-producing cow over the past 12 months (= 1, 0 otherwise)	3,798	0.08	0.27	0.00	1.00
Owned no milk-cow over the past 12 months (=1, 0 otherwise)	3,798	0.78	0.42	0.00	1.00
Owned buffalo/bullock over the past 12 months (= 1, 0 otherwise)	3,798	0.26	0.44	0.00	1.00
Owned goat/sheep over the past 12 months (= 1, 0 otherwise)	3,798	0.16	0.36	0.00	1.00
Owned poultry/duck over the past 12 months (= 1, 0 otherwise)	3,798	0.64	0.48	0.00	1.00
Owned/produced fish over the past 12 months (= 1, 0 otherwise)	3,798	0.29	0.45	0.00	1.00
Total cultivated land over the past 12 months (hectares)	3,798	0.22	0.46	0.00	9.62
Total value of household assets (US$ in 1000s)	3,798	3.09	73.16	0.01	106.39
Per capita monthly expenditure (US$), 7-day recall	3,798	32.86	77.83	7.06	4549.45
Age (in years) of mother	3,798	27.34	5.95	16.00	65.00
Mother has completed primary education (= 1, 0 otherwise)	3,798	0.51	0.50	0.00	1.00
Mother has completed secondary education (= 1, 0 otherwise)	3,798	0.05	0.21	0.00	1.00
Mother has completed post-secondary education (= 1, 0 otherwise)	3,798	0.03	0.17	0.00	1.00
Household head has completed primary education (= 1, 0 otherwise)[1]	3,798	0.34	0.47	0.00	1.00
Household head has completed secondary education (= 1, 0 otherwise)	3,798	0.08	0.27	0.00	1.00
Household head has completed post-secondary education (= 1, 0 otherwise)	3,798	0.04	0.19	0.00	1.00
Age (in years) of household head	3,798	39.00	12.94	19.00	90.00

Household size	3,798	5.30	1.98	2.00	21.00
No toilet (= 1, 0 otherwise)	3,798	0.03	0.16	0.00	1.00
Improved toilet (= 1, 0 otherwise)	3,798	0.31	0.46	0.00	1.00
Access to a water supply (= 1, 0 otherwise)	3,798	0.77	0.42	0.00	1.00
Male child (= 1, 0 otherwise)	3,798	0.51	0.50	0.00	1.00
Age in months	3,798	29.19	17.04	0.00	59.93
Household has taken loan from NGO (= 1, 0 otherwise)	3,798	0.49	0.50	0.00	1.00
Household has electricity (= 1, 0 otherwise)	3,798	0.52	0.50	0.00	1.00
Distance to health centre (km)	3,798	6.16	6.87	0.00	130.00
Distance to regular bazaar (km)	3,798	1.78	1.85	0.00	25.00

[1]The household head is the self-identified primary decision-maker (in most cases, male) in the sample household. Source: BIHS 2011, 2015 (Ahmed 2013, IFPRI 2016)

4.4.2 Linkages between dairy production, 24-hour milk consumption and child growth outcomes

Table 4.2 shows the percentage of children who consumed milk in the past 24 hours by age group for milk-producing (Group A) and no milk-producing (Group B) dairy cow ownership households, as well as by households without ownership of any type of dairy cow (Group C). The estimates suggest that milk-producing dairy cow ownership (Group A) is a strong predictor of milk consumption in the past 24 hours among pre-school children. Children from milk-producing households (Group A) consumed twice as much milk as children from households that did not produce milk (Group C). We also report consumption of other food products (meat, chicken, fish and eggs) across these three sub-samples (see Appendix Table 4.10). We find that a greater proportion of children from Group A consumed meat, chicken and eggs in the past 24 hours than children from Group B.

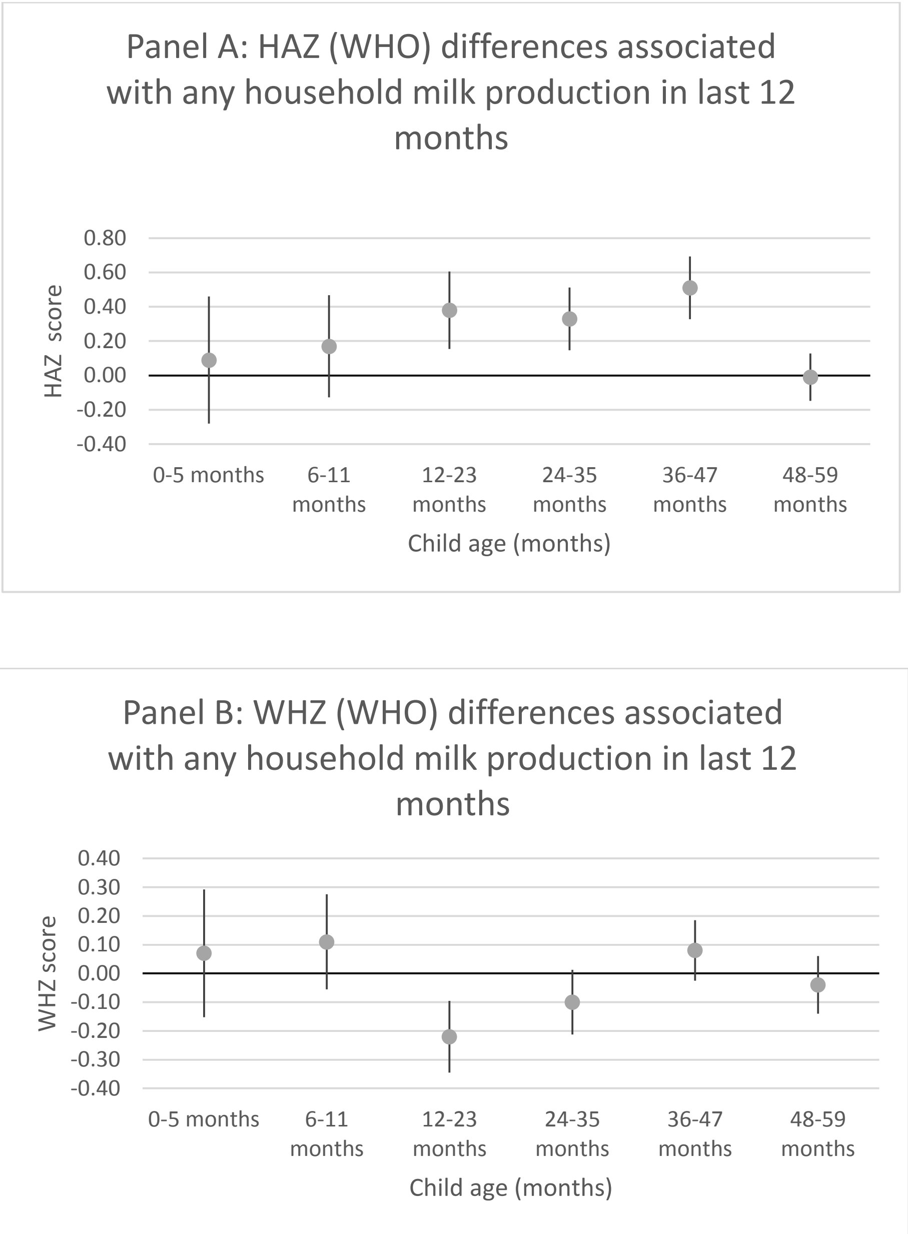
Table 4.2 Prevalence and levels of 24-hour recall of cow milk consumption by cow ownership and milk production status, with t-tests of differences in group means[1]

	Group (A) Owns cow, produced milk	Group (B) Owns cow, produced no milk	Group (C) Does not own cow
		Percentage of children consuming milk	
Children (6–23 months)	35.0%	19.6%***	18.5%***
Children (24–59 months)	38.7%	16.4%***	14.7%***
		Quantity of milk consumed (grams/person/day)	
Children (6–23 months)	56.4	27.7***	29.0***
Children (24–59 months)	53.9	21.2***	20.5***

[1] t-tests were conducted for the null hypothesis that the means of groups A and B were equal, and the means of groups A and C were equal. All hypotheses were rejected at the 1% level. Source: Authors' estimates from the BIHS 2011, 2015 (Ahmed 2013, IFPRI 2016)

Figure 4.1 reports the p-values of t-tests for differences in mean height-for-age (HAZ) and weight-for-height (WHZ) scores associated with household milk production in the past 12 months, by age-samples. We find that mean HAZ scores are higher for children living in milk-producing dairy cow ownership households compared to those for children living in households with no dairy cow.

Figure 4.1 T-tests for differences in mean HAZ (Panel A) and WHZ (Panel B) scores associated with household milk production in the past 12 months, for pre-school children



Notes: These figures report the results of t-tests for differences in means by age sub-samples. The one-sided hypothesis tests (90% confidence intervals) show that mean HAZ scores are higher for children living in milk-producing households. Source: Authors' estimates from the BIHS 2011, 2015 (Ahmed 2013, IFPRI 2016)

4.5 Regression results

Table 4.3 presents regression results of the linear and logistic models showing the relationship between livestock ownership, height-for-age (HAZ) and stunting. For children aged 6–23 months, milk-producing dairy cow ownership (Group A) raises HAZ by 0.49 standard deviations (SDs), being statistically significant at the 1% level. Notably, this coefficient is very close in magnitude to that derived by Rawlins et al.'s (2014) evaluation of the dairy cow program's impact in Rwanda (0.50), but substantially larger than the analogous coefficient from the Hoddinott, Headey and Dereje (2015) results from Ethiopia (0.21), which did not include information on annual milk production. Moreover, the coefficient on ownership of dairy cows that have not produced milk in the past 12 months (Group B) is not statistically significant in magnitude, and smaller than magnitude (at the 10% level) than the coefficient on ownership of milk-producing cows.

Column 2 reports marginal effect estimates from a logit model of stunting. The magnitude of the estimated impact in the case of milk-producing dairy cow ownership (Group A) is striking: milk-producing dairy cow ownership reduces the probability of stunting by 13.5 percentage points, and is statistically significant at the 1% level. By contrast, we find no significant effect of milk-producing dairy cow ownership for children aged 24–59 months. Amongst other variables, household expenditure, parental education and improved toilets often yield significant coefficients, particularly for the sample of older children (24–59 months). In particular, education of mother and household head at the post-secondary level has a commensurately large effect. Older children whose mothers have completed post-secondary education have a lower probability of stunting (28 percentage points) compared to older children whose mothers have no education.

Table 4.3 Association between HAZ scores and livestock ownership, by age groups 6–23 and 24–59 months

	(1)		(2)	
	HAZ 6–23 months	HAZ 24–59 months	Stunted 6–23 months	Stunted 24–59 months
Owns cow, produced milk (A)	0.490***	0.043	-0.135***	-0.035
	(0.166)	(0.105)	(0.052)	(0.038)
Owns cow, produced no milk (B)	0.144	0.097	-0.102*	-0.012
	(0.185)	(0.126)	(0.060)	(0.044)
Owns buffalo/bullock	0.021	-0.167**	0.032	0.073**
	(0.118)	(0.080)	(0.040)	(0.031)
Owns goat/sheep	0.014	-0.022	0.027	0.035
	(0.127)	(0.080)	(0.045)	(0.031)
Owns poultry/duck/other birds	0.002	0.075	-0.012	-0.027
	(0.104)	(0.061)	(0.031)	(0.022)
Owns/produces fish	0.184	-0.020	-0.043	0.008
	(0.121)	(0.071)	(0.034)	(0.027)
Total livestock owned (TLU)	-0.021	0.042	0.009	-0.016
	(0.028)	(0.038)	(0.015)	(0.015)
Log per capita monthly expenditure	0.151	0.216***	-0.119***	-0.103***
	(0.120)	(0.068)	(0.043)	(0.030)
Log value of household assets	0.073	0.063*	-0.017	-0.016
	(0.055)	(0.032)	(0.015)	(0.011)
Land area cultivated	-0.025	0.015	-0.013	0.006
	(0.100)	(0.060)	(0.038)	(0.026)
Access to electricity	0.063	-0.022	-0.011	0.011
	(0.111)	(0.063)	(0.035)	(0.023)
Mother has completed primary education	0.015	0.084	0.029	-0.071***
	(0.132)	(0.078)	(0.038)	(0.027)
Mother has completed secondary education	0.030	0.232	0.106	-0.090
	(0.229)	(0.160)	(0.072)	(0.065)
Mother has completed post-secondary education	0.140	0.553**	-0.049	-0.283***
	(0.318)	(0.219)	(0.098)	(0.089)
Household head has completed primary education	0.004	0.136**	0.027	-0.010
	(0.118)	(0.068)	(0.035)	(0.023)
Household head has completed secondary education	0.007	0.028	0.040	0.015
	(0.204)	(0.171)	(0.067)	(0.060)
Household head has completed post-secondary education	-0.101	0.702***	0.032	-0.175**
	(0.318)	(0.263)	(0.096)	(0.086)
Distance to regular bazaar (km)	-0.066***	-0.006	0.011	0.005
	(0.025)	(0.020)	(0.008)	(0.006)
Distance to health centre (km)	-0.002	-0.004	0.001	0.002
	(0.008)	(0.004)	(0.002)	(0.002)
Proportion of households with no toilet	-0.006	0.137	0.057	-0.018

Source of loan from NGO	-0.030	0.001	0.024	-0.002
	(0.088)	(0.057)	(0.029)	(0.020)
Access to water supply	0.237*	0.008	-0.012	-0.011
	(0.135)	(0.083)	(0.038)	(0.032)
Access to improved toilet	0.024	0.152**	-0.028	-0.056**
	(0.110)	(0.064)	(0.035)	(0.023)
Observations	1,124	2,254	1,124	2,254
R-squared	0.169	0.114	0.148	0.106
Pseudo R-squared			0.126	0.081
Wald tests (p-values):				
(A)>(B)	0.093	0.707	0.605	0.644

Notes: Standard errors are in parentheses, clustered at village level. ***p < 0.01, **p < 0.05, *p < 0.1. Controls included but not reported are child's sex, household size, maternal age, age of the household head, month-specific child age dummy variables, time dummies and district dummy variables. Source: BIHS 2011, 2015 (Ahmed 2013, IFPRI 2016)

In Table 4.4, we replicate the test used in Hoddinott, Headey and Dereje (2015) by collapsing Categories A and B, as shown in Table 4.3, into one variable: "household owns any type of dairy cow" using linear and logistic models. We find that for children 6–23 months, any type of dairy cow ownership raises HAZ by 0.36 SDs (significant at the 5% level) and reduces the likelihood of stunting by 12.3 percentage points (significant at the 1% level).

Table 4.4 Association between HAZ scores and livestock ownership, by age groups 6–23 and 24–59 months

	(1)		(2)	
	HAZ 6–23 months	HAZ 24–59 months	Stunted 6–23 months	Stunted 24–59 months
Owns any type of dairy cow[1]	0.363**	0.067	-0.123***	-0.024
	(0.144)	(0.090)	(0.046)	(0.032)
Owns buffalo/bullock	0.046	-0.168**	0.029	0.072**
	(0.118)	(0.080)	(0.040)	(0.031)
Owns goat/sheep	0.012	-0.019	0.027	0.036
	(0.127)	(0.080)	(0.045)	(0.031)
Owns poultry/duck/other birds	0.003	0.076	-0.012	-0.027
	(0.105)	(0.061)	(0.032)	(0.022)
Owns/produces fish	0.183	-0.019	-0.043	0.008
	(0.122)	(0.071)	(0.034)	(0.028)
Total livestock owned (TLU)	-0.016	0.039	0.009	-0.018
	(0.031)	(0.038)	(0.016)	(0.015)
Log per capita monthly expenditure	0.155	0.215***	-0.120***	-0.103***
	(0.121)	(0.069)	(0.044)	(0.030)
Log value of household assets	0.071	0.064*	-0.017	-0.016
	(0.055)	(0.032)	(0.015)	(0.011)
Land area cultivated	-0.021	0.014	-0.014	0.006
	(0.102)	(0.060)	(0.039)	(0.027)
Access to electricity	0.073	-0.022	-0.012	0.011
	(0.111)	(0.063)	(0.035)	(0.023)
Mother has completed primary education	0.012	0.085	0.029	-0.071***
	(0.133)	(0.077)	(0.038)	(0.027)
Mother has completed secondary education	0.022	0.232	0.106	-0.090
	(0.231)	(0.160)	(0.072)	(0.065)
Mother has completed post-secondary education	0.129	0.554**	-0.049	-0.283***
	(0.317)	(0.219)	(0.098)	(0.089)
Household head has completed primary education	0.009	0.135**	0.027	-0.010
	(0.118)	(0.068)	(0.035)	(0.023)
Household head has completed secondary education	0.013	0.026	0.040	0.014
	(0.206)	(0.171)	(0.068)	(0.060)

Household head has completed post-secondary education	-0.091	0.701***	0.031	-0.176**
	(0.319)	(0.263)	(0.096)	(0.086)
Distance to regular bazaar (km)	-0.066***	-0.006	0.011	0.005
	(0.025)	(0.020)	(0.008)	(0.006)
Distance to health centre (km)	-0.002	-0.003	0.001	0.002
	(0.007)	(0.004)	(0.002)	(0.002)
Proportion of households with no toilet	-0.001	0.136	0.057	-0.018
	(0.335)	(0.174)	(0.094)	(0.064)
Source of loan from NGO	-0.034	0.000	0.025	-0.002
	(0.088)	(0.057)	(0.029)	(0.020)
Access to water supply	0.247*	0.007	-0.012	-0.012
	(0.136)	(0.083)	(0.038)	(0.032)
Access to improved toilet	0.017	0.151**	-0.028	-0.056**
	(0.111)	(0.064)	(0.035)	(0.023)
Observations	1,124	2,254	1,122	2,252
R-squared	0.167	0.114		
Pseudo R-squared			0.116	0.081

Notes: [1] Households that own any type of dairy cow (produced milk or produced no milk). Standard errors are in parentheses, clustered at village level. ***p < 0.01, **p < 0.05, *p < 0.1. Controls included but not reported are child's sex, household size, maternal age, age of the household head, month-specific child age dummy variables, time dummies and district dummy variables. Source: BIHS 2011, 2015 (Ahmed 2013, IFPRI 2016)

Table 4.5 presents regression results of the linear and logistic models showing the relationship between livestock ownership and child weight, expressed in terms of Z-scores, disaggregated by age groups 6–23 and 24–59 months. For the age group 6–23 months, milk-producing dairy cow ownership (Group A) increases the probability of wasting by 16 percentage points, significant at the 1% level. This finding implies that milk-producing dairy cow ownership (Group A) has complex relationships with child nutrition, which go beyond the simple effect on linear growth. In addition, other socioeconomic indicators such as household expenditure and maternal education at the post-secondary level are significantly correlated with weight among younger and older children. However, a surprising result is the positive association between household head's post-secondary education and child weight. One explanation may be that children whose household heads have completed post-secondary education may have greater exposure to animals in or around the dwelling, which is linked to deterioration of hygienic conditions and increase in illnesses, and thereby leading to a perverse impact of milk-producing dairy cow ownership on wasting (George et al. 2015; Headey and Hirvonen 2016). Here, we can speculate that one of these explanations (or both) might be at play.

Table 4.5 Association between WHZ scores and livestock ownership, by age groups 6–23 and 24–59 months

	(1)		(2)	
	WHZ 6–23 months	WHZ 24–59 months	Wasted 6–23 months	Wasted 24–59 months
Owns cow, produced milk (A)	-0.209	-0.072	0.156***	0.013
	(0.136)	(0.099)	(0.050)	(0.031)
Owns cow, produced no milk (B)	-0.221	-0.089	0.050	-0.018
	(0.154)	(0.097)	(0.050)	(0.033)
Owns buffalo/bullock	-0.051	-0.026	0.068*	0.015
	(0.118)	(0.067)	(0.036)	(0.022)
Owns goat/sheep	-0.251**	-0.062	0.037	-0.001
	(0.103)	(0.077)	(0.031)	(0.024)
Owns poultry/duck/other birds	-0.033	-0.142***	-0.012	-0.013
	(0.098)	(0.054)	(0.028)	(0.016)
Owns/produces fish	-0.049	-0.011	0.014	0.009
	(0.092)	(0.062)	(0.030)	(0.019)
Total livestock owned (TLU)	0.021	-0.002	-0.052*	-0.000
	(0.046)	(0.041)	(0.027)	(0.011)
Log per capita monthly expenditure	0.280**	0.025	-0.087**	-0.004
	(0.111)	(0.055)	(0.034)	(0.018)
Log value of household assets	0.024	0.019	0.002	-0.006
	(0.046)	(0.031)	(0.015)	(0.010)
Land area cultivated	-0.056	0.039	0.013	-0.006
	(0.122)	(0.069)	(0.048)	(0.017)
Access to electricity	0.096	0.008	-0.035	0.010
	(0.105)	(0.057)	(0.027)	(0.016)
Mother has completed primary education	0.100	-0.032	-0.007	0.024
	(0.101)	(0.062)	(0.028)	(0.019)
Mother has completed secondary education	0.361*	0.186	-0.005	-0.088
	(0.210)	(0.130)	(0.068)	(0.059)
Mother has completed post-secondary education	0.001	0.427**	0.065	-0.045
	(0.277)	(0.199)	(0.078)	(0.064)
Household head has completed primary education	-0.099	0.060	0.006	-0.019
	(0.096)	(0.063)	(0.027)	(0.019)
Household head has completed secondary education	0.050	0.176	-0.083	-0.120*
	(0.182)	(0.125)	(0.065)	(0.062)
Household head completed post-secondary education	-0.095	-0.298	0.042	0.198***
	(0.279)	(0.184)	(0.092)	(0.071)
Distance to regular bazaar (km)	0.025	0.028**	-0.001	-0.005

	(0.025)	(0.012)	(0.007)	(0.005)
Distance to health centre (km)	0.002	-0.002	0.001	-0.000
	(0.007)	(0.004)	(0.002)	(0.001)
Proportion of households with no toilet	-0.270	-0.212	0.026	0.045
	(0.269)	(0.181)	(0.065)	(0.042)
Source of loan from NGO	-0.061	-0.028	0.032	0.007
	(0.087)	(0.049)	(0.023)	(0.016)
Access to water supply	-0.159	0.027	0.079**	0.033*
	(0.114)	(0.063)	(0.035)	(0.020)
Access to improved toilet	0.026	0.016	0.010	-0.022
	(0.101)	(0.062)	(0.027)	(0.021)
Observations	1,120	2,257	1,120	2,257
R-squared	0.123	0.080		
Pseudo R-squared			0.087	0.060
Wald tests (p-values):				
(A) > (B)	0.946	0.886	0.027	0.414

Notes: Standard errors are in parentheses, clustered at village level. ***p < 0.01, **p < 0.05, *p < 0.1. Controls included but not reported are child's sex, household size, maternal age, age of the household head, month-specific child age dummy variables, time dummies and district dummy variables. Source: BIHS 2011, 2015 (Ahmed 2013, IFPRI 2016)

In Table 4.6 we test the association between dairy cow ownership and child weight using linear and logistic models, including the variable "household owns any type of dairy cow". We find that cow ownership increases the likelihood of wasting by 10.3 percentage points and is statistically significant at the 5% level.

Table 4.6 Association between WHZ scores and livestock ownership, by age groups 6–23 and 24-59 months

	(1)		(2)	
	WHZ 6–23 months	WHZ 24–59 months	Wasted 6–23 months	Wasted 24–59 months
Owns any type of dairy cow[1]	-0.214*	-0.080	0.103**	-0.001
	(0.114)	(0.079)	(0.041)	(0.025)
Owns buffalo/bullock	-0.050	-0.026	0.065*	0.016
	(0.118)	(0.067)	(0.036)	(0.021)
Owns goat/sheep	-0.251**	-0.063	0.033	-0.003
	(0.103)	(0.076)	(0.031)	(0.024)
Owns poultry/duck/other birds	-0.033	-0.142***	-0.011	-0.014
	(0.098)	(0.054)	(0.028)	(0.016)
Owns/produces fish	-0.049	-0.011	0.011	0.008
	(0.092)	(0.062)	(0.030)	(0.019)

Total livestock owned (TLU)	0.021	-0.001	-0.038	0.002
	(0.046)	(0.041)	(0.023)	(0.011)
Log per capita monthly expenditure	0.280**	0.026	-0.086**	-0.004
	(0.111)	(0.055)	(0.034)	(0.018)
Log value of household assets	0.024	0.019	0.001	-0.006
	(0.046)	(0.031)	(0.015)	(0.010)
Land area cultivated	-0.056	0.039	0.014	-0.005
	(0.122)	(0.069)	(0.047)	(0.017)
Access to electricity	0.096	0.008	-0.032	0.010
	(0.105)	(0.057)	(0.027)	(0.016)
Mother has completed primary education	0.100	-0.032	-0.008	0.024
	(0.101)	(0.062)	(0.028)	(0.019)
Mother has completed secondary education	0.361*	0.187	-0.007	-0.088
	(0.209)	(0.130)	(0.068)	(0.059)
Mother has completed post-secondary education	0.001	0.426**	0.058	-0.046
	(0.276)	(0.199)	(0.079)	(0.064)
Household head has completed primary education	-0.098	0.060	0.008	-0.019
	(0.096)	(0.063)	(0.027)	(0.019)
Household head has completed secondary education	0.051	0.177	-0.080	-0.120*
	(0.182)	(0.125)	(0.067)	(0.062)
Household head completed post-secondary education	-0.095	-0.298	0.050	0.200***
	(0.278)	(0.185)	(0.093)	(0.071)
Distance to regular bazaar (km)	0.025	0.028**	-0.001	-0.005
	(0.025)	(0.012)	(0.007)	(0.005)
Distance to health centre (km)	0.002	-0.003	0.001	-0.000
	(0.007)	(0.004)	(0.002)	(0.001)
Proportion of households with no toilet	-0.270	-0.212	0.025	0.046
	(0.269)	(0.181)	(0.066)	(0.042)
Source of loan from NGO	-0.061	-0.028	0.030	0.007
	(0.086)	(0.049)	(0.023)	(0.016)
Access to water supply	-0.159	0.028	0.082**	0.034*
	(0.114)	(0.063)	(0.035)	(0.020)
Access to improved toilet	0.026	0.016	0.007	-0.021
	(0.101)	(0.062)	(0.027)	(0.020)
Observations	1,120	2,257	1,047	2,184
R-squared	0.123	0.080		
Pseudo R-squared			0.091	0.071

Notes: [1] Households that own any type of dairy cow (produced milk or produced no milk). Standard errors are in parentheses, clustered at village level. ***p < 0.01, **p < 0.05, *p < 0.1. Controls included but not reported are child's sex, household size, maternal age, age of the household head, month-specific child age dummy variables, time dummies and district dummy variables. Source: BIHS 2011, 2015 (Ahmed 2013, IFPRI 2016)

4.6 Extensions

In this section, we engage in a series of extensions designed to examine whether the results presented Section 4.5 stand up to alternative specifications and to a more confident causal interpretation.

Table 4.7 shows the relationship between dairy cow ownership and the likelihood of a child 6-59 months old consuming dairy in the last 24 hours, estimated using a linear probability model. Our outcome variable, children's consumption of dairy products in the last 24 hours, is defined as a dichotomous indicator. The results suggest that milk production increases the likelihood that milk was consumed by 13.9 percentage points.

Table 4.7 Association between livestock ownership and dairy consumption in the last 24 hours among children 6-59 months

	(1)
	Consumed dairy, last 24 hrs
Owns cow, produced milk (A)	0.139***
	(0.042)
Owns cow, produced no milk (B)	-0.019
	(0.036)
Owns buffalo/bullock	-0.015
	(0.022)
Owns goat/sheep	-0.021
	(0.021)
Owns poultry/duck/other birds	0.015
	(0.015)
Owns/produces fish	-0.022
	(0.019)
Total Livestock Units (TLU)	0.004
	(0.015)
District fixed effects?	Yes
Controls for age and gender?	Yes
All 15 socioeconomic controls?	Yes
Observations	3,352

R-squared	0.172
Wald tests (p-values):	
(A)>(B)	0.001***

Notes: These are least squares or linear probability estimates, with standard errors are in parentheses, clustered at village level. ***p<0.01, **p<0.05, *p<0.1. Source: Bangladesh Integrated Household Survey 2011, 2015

An alternative to modelling a dichotomous indicator of whether the household produced any milk is to specify the household's estimate of the quantity of milk produced in the past 12 months, which we measure as the log of litres per child (based on previous evidence that children are often given the major share of a household's milk supply in Bangladesh). OLS coefficient estimates for this indicator are reported in Table 4.8. This coefficient is significant in the 6–23 month bracket and insignificant in the 24–59 month bracket. The coefficients are imprecisely estimated, however, and perhaps suffer from attenuation bias related to the significant challenges that respondents have in accurately answering 12-month recall questions. Overall, though, the results are broadly consistent with the results from Table 4.3.

Table 4.8 OLS estimates of the association between HAZ and the log of milk production per child

	(1) 6–23 months	(2) 24–59 months
OLS estimates		
Log quantity of milk produced	0.084**	0.008
	(0.034)	(0.024)
Other livestock and TLUs?	Yes	Yes
Full set of socioeconomic controls?	Yes	Yes
Age & gender controls?	Yes	Yes
District fixed effect?	Yes	Yes
Observations	1,159	2,390
R-squared	0.192	0.124

Notes: Standard errors are in parentheses, clustered at village level. ***p < 0.01, **p < 0.05, *p < 0.1. Source: BIHS 2011, 2015 (Ahmed 2013, IFPRI 2016)

4.6.1 Controlling for income

Another possible concern is that household expenditure data is not effectively controlling for household income, which dairy sales may contribute to. While income is generally measured with more error than expenditure, Table 4.9 adds to the model total agricultural income earned by households in the past 12 months. The marginal effects associated with the ownership of milk-producing dairy cows are slightly lower when the regression is loaded with total agricultural income variable, though they are still statistically significant at the 5% level and large in magnitude.

Table 4.9 Association between HAZ scores and livestock ownership, by age group 6–23 months with controls for agricultural income

	HAZ	
	6–23 months	
Owns cow, produced milk (A)	0.490***	0.440**
	(0.166)	(0.183)
Owns cow, produced no milk (B)	0.144	0.050
	(0.185)	(0.205)
Owns buffalo/bullock	0.021	0.038
	(0.118)	(0.139)
Owns goat/sheep	0.014	0.045
	(0.127)	(0.128)
Owns poultry/duck/other birds	0.002	-0.010
	(0.104)	(0.111)
Owns/produces fish	0.184	0.148
	(0.121)	(0.125)
Full set of socioeconomic controls?	Yes	Yes
Age & gender controls?	Yes	Yes
District fixed effect?	Yes	Yes
Agricultural income control?	No	Yes
	1,124	2,254
Observations		
R-squared	0.169	0.114
Wald tests (p-values):		
(A) > (B)	0.093	0.033

Notes: Standard errors are in parentheses, clustered at village level. ***p < 0.01, **p < 0.05, *p < 0.1. See Table 4.3 for list of controls. Source: BIHS 2011, 2015 (Ahmed 2013, IFPRI 2016)

4.6.2 Exploring associations between dairy production and wasting

In developing countries one would typically expect increased milk consumption to be positively associated with weight gain, but we find a negative association between milk production and WHZ scores. What might explain this? Here we consider several possible answers.

One possibility is that dairy consumption produces strong impacts on linear growth, but has relatively little impact on body mass, or even reduces weight gain relative to substitute foods. In the BIHS data the correlation between HAZ and WHZ is negative (-0.17) and significant at the 1% level, and stunted children are 6 percent less likely to be wasted, and wasted children are 3 percent less likely be stunted. Arithmetically, a negative association between stunting and wasting is unsurprising: an increase in height improves HAZ scores but decreases WHZ scores if there is no commensurate improvement in weight. Previous studies have noted that South Asian populations may also be genetically or epigenetically prone to thinness (Nubé 2009)[20], so one conjecture is that the negative association between WHZ and milk consumption is context-specific. Still other studies from developed countries have found that dairy products, despite their fat content, inhibit weight gain through a variety of plausible biological mechanisms as well as appetite satiation (Teegarden 2005; Visioli and Strata 2014; Zemel 2004).

A related possibility is that households with a stable dairy milk supply choose to breastfeed less or commence weaning earlier. This is a partially testable hypothesis insofar as BIHS asks mothers whether they are currently breastfeeding. Figure 4.2 plots breastfeeding status by child

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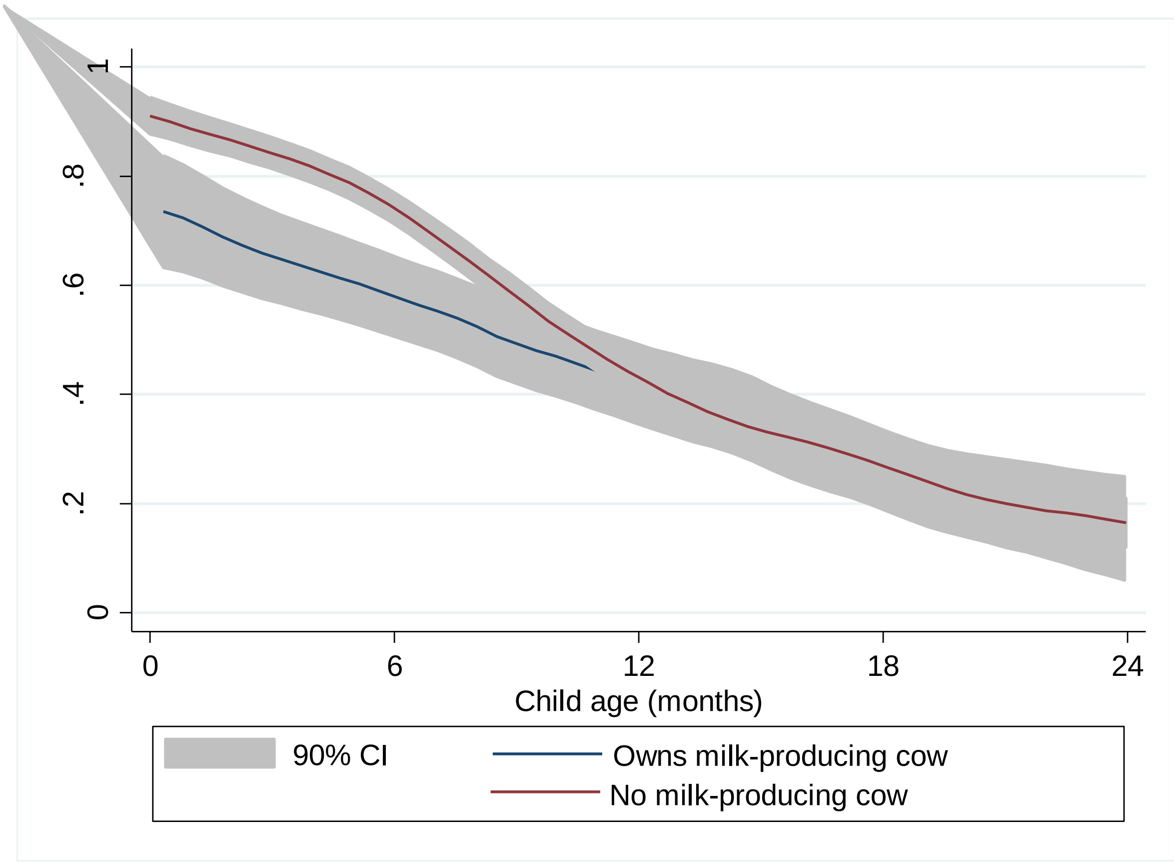
[20] Although few papers still argue that genetics are important (Nube 2007), the WHO Multi-Center Growth Reference Study has shown, through work in several countries, that ethnicity and genetics are less important than environmental factors associated with child growth (see http://www.who.int/childgrowth/mgrs/en/).

age for households where dairy milk was produced in the past 12 months, and those where it was not. The results show that from birth to around eight months of age dairy-producing households were less likely to breastfeed their children; after age eight months there is no significant difference in breastfeeding rates. This suggests that access to dairy milk may have a negative spillover on breastfeeding practices, since children 0–5 months are supposed to be exclusively breastfed.[21] Indeed, dairy milk is only recommended to be introduced at 12 months of age because of potentially harmful effects on the digestive system (Iannotti Muelhoff and McMahon 2013). However, it is less clear how reductions in breastfeeding translate into reduced weight gain. One possibility is that overall calorie intake (exclusive of breast milk) is much lower for children who are not breastfed early in life (Figure 4.3), but that conjecture is not testable with the data at hand. A further possibility, as noted above, is that dairy consumption inhibits weight gain.

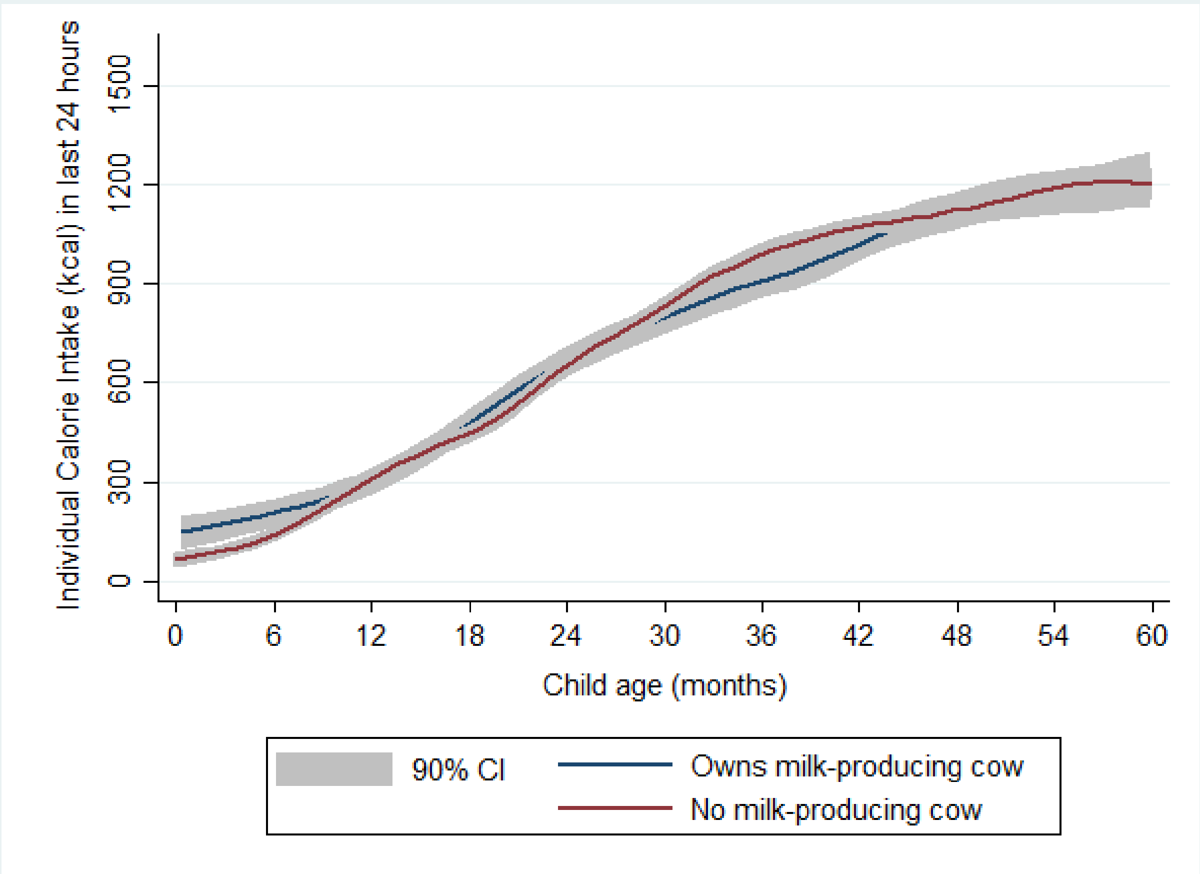
[21] Breastfeeding is not necessarily associated with linear growth unless non-breastmilk foods lead to a lot of diarrhoea or an overall reduction in calorie intake. The benefits of breastmilk are primarily about disease prevention. The concern would be that milk (improperly treated) causes diarrhoea or causes digestive problems since milk is not recommended for children below 12 months of age.

Figure 4.2 An lpoly graph of breastfeeding status by child age for households that have and have not produced dairy



Source: These are local polynomial smoothing estimates from BIHS 2011 and 2015 (Ahmed 2013, IFPRI 2016)

Figure 4.3 An lpoly graph of individual calorie intake (kcal) in past 24 hours by child age for households that have and have not produced dairy



Source: These are local polynomial smoothing estimates from BIHS 2011 and 2015 (Ahmed 2013, IFPRI 2016)

A third possibility is that dairy intake at young ages leads to increased rates of infection. The BIHS asks about infections in the past 4 weeks. In Table 4.10 we regress these indicators against the livestock indicators and the usual set of control variables. We find no association between dairy production and morbidity symptoms. This is perhaps not surprising since milk is generally boiled in South Asia – thereby largely eliminating harmful pathogens – and since parents would presumably discontinue feeding children products that produce observable infections.

Table 4.10 Disease incidence in the past 4 weeks as a function of livestock ownership, for children aged 6–23 months

	(1) Fever	(2) Diarrhoea	(3) Cough
Owns cow, produced milk (A)	-0.059	0.007	-0.017
	(0.042)	(0.032)	(0.043)
Owns cow, produced no milk (B)	0.047	-0.041	0.042
	(0.043)	(0.036)	(0.058)
Owns buffalo/bullock	-0.022	0.009	-0.062*
	(0.037)	(0.024)	(0.038)
Owns goat/sheep	-0.021	-0.008	-0.032
	(0.039)	(0.029)	(0.041)
Owns poultry/duck/other birds	0.028	0.020	-0.030
	(0.035)	(0.024)	(0.030)
Owns/produces fish	0.043	0.006	0.041
	(0.033)	(0.026)	(0.033)
Full set of socioeconomic controls?	Yes	Yes	Yes
Age & gender controls?	Yes	Yes	Yes
District fixed effect?	Yes	Yes	Yes
Observations	939	939	939
R-squared	0.113	0.156	0.154
Wald tests (p-values):			
(A)>(B)	0.014	0.113	0.156

Notes: Standard errors are in parentheses, clustered at village level. ***p < 0.01, **p < 0.05, *p < 0.1. See Table 4.3 for list of controls. Source: BIHS 2011, 2015 (Ahmed 2013, IFPRI 2016)

A final possibility is some form of reverse causality. In more-developed country settings researchers have investigated bidirectional relationships between breastfeeding/bottle-feeding status and child weight gain, because parents may accelerate or postpone weaning if they feel their child is experiencing slower than normal weight gain. In a large study of 17,046 Belorussian children the authors found that smaller size (especially weight for age) was strongly and statistically significantly associated with increased risks of subsequent weaning and of discontinuing exclusive breastfeeding (Kramer et al. 2011). In principle, it is possible that parents whose children are not gaining sufficient weight might focus more attention on producing dairy products, especially insofar as dairy is often considered an important infant food group. There is no clear means of testing this possibility with our existing data, however, since the interval between surveys is too long.

4.7 Conclusions

Consistent with biological evidence on the strong links between dairy consumption and child growth, recent economic research has found only inconsistent evidence of a positive association between cow ownership and nutrition, and only in East African samples. In this paper, we proposed a novel approach that distinguishes between lactating and non-lactating cows as a means of precluding the conventional endogeneity concern that cow-owning households are systematically different to non–cow-owning households. We show that children in households with lactating cows are twice as likely to have consumed milk in the past 24 hours, and likely to have consumed twice as much milk, when compared to households without any cows or with cows that are not lactating. We then show that ownership of a lactating cow has positive associations with child growth, but negative associations with weight gain. These findings have important implications for the existing literature on child nutrition.

First, our results clearly indicate that it is dairy milk production – not dairy cow ownership per se – that is significantly and positively associated with linear growth in young children. Indeed, previous work examining the association between cow ownership and milk production (Hoddinott, Headey and Dereje 2015; Azzarri et al. 2015; Rawlins et al. 2014; Mosites et al. 2015) appears to have underestimated the growth benefits of milk production, because at any given time a household's cow herd may not be producing milk. Thus, there is a difference between the average benefit of owning a cow at any given time (whether or not it is lactating), and the benefits of owning a cow that is currently lactating. More generally, these results point to the ongoing failures of milk markets in rural settings; even households that own dairy cows do not have children who consume milk consistently throughout their early life cycle.

In policy terms, our results corroborate findings from comprehensive reviews by Iannotti et al. (2013) and Hoppe et al. (2006) on the importance of cow's milk for linear growth, especially in low-income country settings where diets are generally monotonous and limiting in ASF intake. But our results are also highly age-specific and reaffirm the importance of the so-called 1,000-day window of opportunity, implying it is critical to promote milk consumption early in life (dairy products are generally recommended to be introduced at 12 months and not to substitute for breast milk), even if there are also benefits accruing to milk consumption later in life (see Shively and Sununtnasuk (2015) where they find some degree of substitution between a mother's education and the household's crop diversity). How best to promote dairy consumption is less certain.

Unusually, milk consumption in Bangladesh is very low by international standards (Headey and Hoddinott 2016). For instance, per capita milk production is less than half compared to India (Headey and Hoddinott 2016). This is likely because of very high population density and the resultant lack of animal feed for large animals, as well as value chain bottlenecks that may keep milk more expensive than is necessary. It may also be that cultural norms – historical unavailability of milk – have kept demand for milk relatively low. Clearly, increasing household ownership of dairy cows can have nutritional benefits (Rawlins et al. 2014), but this approach is also costly. In the long run the promotion of milk markets is essential, especially as populations urbanise and farming households specialise.

Our results provide a strong nutritional rationale for investing in dairy development and promoting dairy consumption for young children. In some cases, increasing dairy cow ownership may be the best practical means of increasing household access to dairy products. The latter result may stem from a complex association between breastfeeding, weight gain and linear growth, which warrants closer examination in future research.

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Appendix A: Additional descriptive statistics

Table 4.10 Consumption of meat, chicken, fish and eggs in past 24 hours, by cow ownership and milk production status, with t-tests of differences in group means, by age groups 6–23 and 24–59 months

	Group (A) Owns cow, produced milk	Group (B) Owns cow, produced no milk	Group (C) Does not own cow	T-tests for differences in means
Percentage of children consuming meat				-0.034** -0.022*
Children (6-23 months)	5.1	2.9	1.8	
Children (24-59 months)	6.1	1.6	4.7	
Percentage of children consuming chicken				-0.029 -0.025*
Children (6-23 months)	5.1	3.8	3.3	
Children (24-59 months)	9.9	5.7	6.7	
Percentage of children consuming fish				0.038 0.037
Children (6-23 months)	29.4	34.3	33.6	
Children (24-59 months)	61.0	65.8	65.5	
Percentage of children consuming eggs				-0.035 -0.031*
Children (6-23 months)	19.2	12.4	11.4	
Children (24-59 months)	16.3	14.0	15.1	
Quantity of meat consumed (grams/person/day)				
Children (6-23 months)	1.3	0.4	0.6	
Children (24-59 months)	3.6	1.0	3.2	
Quantity of chicken consumed (grams/person/day)				-1.708 -1.397
Children (6-23 months)	1.9	0.7	1.2	
Children (24-59 months)	6.5	4.5	4.5	
Quantity of fish consumed (grams/person/day)				2.181 2.025
Children (6-23 months)	3.7	5.7	6.5	
Children (24-59 months)	22.0	24.9	23.9	
Quantity of eggs consumed (grams/person/day)				-1.608 -1.031

Children (6-23 months)	6.4	4.5	3.6
Children (24-59 months)	5.3	3.6	5.0

[1] Milk-producing dairy cow ownership households are defined as those who own milk cow and produce milk. [2] Non-milk-producing dairy cow ownership households own milk cow but do not produce milk. [3] t-tests were conducted for the null hypothesis that the means of group A and B were equal, and the means of groups A and C were equal. Source: BIHS 2011, 2015 (Ahmed 2013, IFPRI 2016)

Chapter 5: Conclusion

This chapter reiterates the objectives of the thesis, summarizes its empirical results, draws out their implications, and lists areas where future research could build on this study.

The thesis has contributed to a better understanding of why dietary diversity is essential for improving child nutrition outcomes. It has done so by addressing three research questions: (1) What drives diversification of food supplies (DFS) at the country level? (2) What factors determine dietary diversity among pre-school children, according to Demographic and Health Survey (DHS) data? (3) What are the impacts of dairy production in particular on child nutritional outcomes in rural Bangladesh?

Unlike previous empirical research that has focused on the determinants of calorie consumption, Chapter 2 of this thesis explores through a cross-country analysis the economic, social and agro-ecological factors that drive DFS. The chapter's panel regressions reveal that besides economic growth, there are structural transformation indicators such as urbanisation and demographic change, as well as time-invariant agro-ecological characteristics that are significant contributors to improved nutrition.

A growing body of evidence has found that early childhood malnutrition occurs at about 6 months of age, due to a lack of consumption of nutrient-rich foods. Yet the causes of poor diets have not been thoroughly explored by nutritionists, who often stress their interventions on nutritional knowledge but under-emphasise the role of economic factors. Chapter 3 integrates both the nutrition and economic literatures in a single framework to examine the determinants of dietary diversity among pre-school children. Similar to findings in Chapter 2, the results in Chapter 3 include strong support for Bennett's law and underscore that urbanisation and infrastructure expansion contribute. In terms of geographical determinants, rainfall strongly predicts dietary diversity, a result that contrasts with that in Chapter 2 where rainfall is negatively associated with DFS. Also, despite Chapter 2 finding no effect of education on DFS, Chapter 3 uncovers enough evidence to suggest investing more in women's education would improve diets.

The effects of dietary diversity as a means of improving child nutrition outcomes are still debatable although a small literature using experimental approaches provides some evidence. Most of the research in low-income countries that have associated child growth to dairy cow ownership is largely focused on East Africa and is subject to several methodological limitations. Chapter 4 is one of the few studies that observes the benefits of dairy consumption for child growth in the context of rural Bangladesh, where dairy consumption is unusually low by international standards. The results reveal that milk production leads to higher consumption of milk products among young children, which in turn is strongly associated with linear growth of young children. This finding provides a strong justification for increasing access to dairy products among young children. There are also strong grounds for strengthening existing efforts to improve nutritional knowledge and appropriate feeding practices, given the apparent substitution between cow milk and breast milk. These complex relationships between breastfeeding, weight gain and linear growth should be further investigated.

The above findings provide a strong foundation for future research in other areas too. Empirical results from Chapter 2 demonstrate that there is a plenty of variation in DFS paths. For example, countries such as Vietnam have experienced dramatic increases in DFS but, in other countries including Bangladesh, dietary diversification has been slow. This may be because of agroecological constraints to diversification and the imperfect tradability of some highly nutritious foods. Future research should focus more on individual case studies to better understand the constraints to dietary diversification and policy options for accelerating diversification.

Several East Asian countries such as Vietnam and Thailand have been very successful in increasing dairy consumption. An additional research topic is to assess how Bangladesh might best pursue strategies and policies like Vietnam and Thailand to increase dairy consumption. Bangladesh is an especially important case given that almost half of its children are stunted and dairy intake is unusually very low by South Asian standards. With a very high population density and resultant lack of animal feed for large animals, Bangladesh has no clear comparative advantage in large-scale dairy production and partly relies on milk powder imports. Those imports are still heavily taxed with a tariff of 25%, and value chain bottlenecks inhibit both domestic production and domestic and international trade in dairy products. Interventions to develop those value chains are necessary to reduce the problems of perishability of dairy and other nutrient-rich foods (e.g. lack of cold storage, inadequate infrastructure).

Likewise, other supply-side constraints such as access to dairy markets in rural areas are still a problem in Bangladesh. Various studies have confirmed that market access matters for the dietary quality of rural households and individual household members. Increasing physical access to markets in Bangladesh would translate to better diets and would play an important role for dairy products that cannot be stored for long periods of time. Furthermore, market access can substitute for dairy consumption especially for rural households that are not engaged in milk production. It may also be that cultural norms – historical unavailability of milk – has kept demand for milk relatively low. Behavioural change communication strategies could be an effective way to tackle the demand-side constraints to improving children's consumption of dairy products.

Until now, however, limited research has evaluated how countries might best implement a strategy to increase the affordability of nutrient-rich foods, and what effect nutrition-sensitive food policies of that nature might have on diets and various nutrition outcomes. Nutrition-sensitive interventions could address these issues through modern technologies supporting agricultural practices to promote local production of nutrient-rich foods. Production diversity could be an important policy instrument as it could lead to expanded production of nutrient-rich foods and thus more affordable prices.

Finally, another area for future research is to focus on understanding the consequences of climate changes on production and dietary diversity. Chapter 3 finds a striking association between climate and dietary diversification. High rainfall strongly predicts dietary diversity, while cooler temperatures seem to be linked to increasing diversity. Future research could explore whether this association arises from strong impacts of climatic factors on production diversity, and could assess the influence of these factors on production and availability of nutrient-rich foods.

Overall, the findings of this thesis carry important implications for programs and policies across many sectors looking to increase consumption of nutrient-rich animal-sourced foods and to improve child dietary diversity and child nutritional status.

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