

Refrigeration and child growth: What is the connection?

Sebastian Martinez¹  | Juan M. Murguia² | Brisa Rejas² | Solis Winters¹ 

¹Office of Strategic Planning and Development Effectiveness, Inter-American Development Bank, Washington, DC, USA

²Division of Environment and Rural Development, Inter-American Development Bank, Washington, DC, USA

Correspondence

Sebastian Martinez, Office of Strategic Planning and Development Effectiveness, Inter-American Development Bank, 1300 New York Ave NW, Washington, DC 20577, USA. Email: sebmart@gmail.com

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Abstract

Child stunting in Latin America and the Caribbean (LAC) decreased from 22.9% in 1990 to 9.6% in 2017. While stunting rates in the region were falling, access to electricity and refrigeration were on the rise. Despite a large body of evidence surrounding the effects of refrigeration on food consumption, and separately of the importance of food consumption for child health and nutrition, surprisingly few studies explore the potential effects of refrigeration on child nutrition. We studied the relationship between refrigeration and child nutrition outcomes using rich panel data for 1298 low-income households with children younger than 12 months at baseline in El Alto, Bolivia. We estimated the effects of refrigerator ownership on diet and nutrition outcomes using a difference-in-difference approach. Owning a refrigerator was associated with increased food expenditures and improved child nutrition. We found evidence that households that acquired a refrigerator were more likely to buy food that requires refrigeration, and children in households that acquired refrigerators were 0.17 standard deviations taller for their age after 2 years. We also found that refrigeration was associated with a 0.26 standard deviation decline in BMI-for-age, an effect driven by increased height rather than lower weight. These results suggest that refrigeration may play a role in explaining reductions in undernutrition observed in low- and middle-income countries in recent decades.

KEYWORDS

child growth, food consumption, nutrition, obesity, overweight, refrigeration, stunting

1 | INTRODUCTION

Reducing childhood stunting (low height-for-age) is a global priority and a major development goal. The effects of stunting during the first 1000 days of life are largely irreversible. Stunting impairs cognitive and physical development and is associated with less schooling, poor academic performance, lower per-capita income and a greater likelihood of living in poverty (WHO & 1000 Days, 2014). Grantham-McGregor et al. (2007) estimate that the loss of income due to stunting is 19.8%. Moreover, stunting has large economic

consequences. A 1% loss in adult height is associated with a decrease of about 1.4% in economic productivity. Stunting has also been estimated to reduce a country's GDP up to 3% (The World Bank, 2006). Children who are stunted also face worse health outcomes, including greater susceptibility to infections and an increased risk for obesity, diabetes, cardiovascular disease and maternal mortality later in adulthood (WHO & 1000 Days, 2014).

Between 1990 and 2014, the prevalence of stunting in children under 5 decreased from 39.6% to 23.8% worldwide. Stunting in Latin America and the Caribbean followed the global trend, decreasing from

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22.9% in 1990 to 9.6% in 2017. The decline in Bolivia, which has one of the highest rates of undernutrition in the region, has been even steeper: In 1989, 44% of children were stunted, and by 2016, the prevalence decreased to 16.1% (UNICEF, WHO, & World Bank Group, 2015; Figure 1).

Many factors are likely associated with the decline in stunting in Latin America and the Caribbean. Between 1950 and 2010, the urban population of Latin America increased sevenfold, from 69 to 480 million. At the same time, there were vast social and economic improvements in the region, including increased income and education, investments in infrastructure, improved water, sanitation, and housing and greater access to health services (Inter-American Development Bank [IDB], 2005, 2014; The World Bank, 2019). The indigence index in Latin America decreased from 12% to 6% between 1990 and 2012, and, in the last 20 years, the Human Development Index has increased 10 percentage points (IDB, 2014). Alongside widespread economic growth, governments in the region invested in many programmes and policies to improve nutritional outcomes, including conditional cash transfer (CCT) programmes, health systems strengthening, nutrition supplementation, agricultural incentives and behaviour change interventions (Atun et al., 2015; Imdad, Yakoob, & Bhutta, 2011; Lassi, Das, Xahid, Imdad, & Bhutta, 2013; Leroy, Ruel, & Verhofstadt, 2009; Tirado et al., 2016).

While stunting rates in the region were falling, access to electricity and refrigeration were on the rise. In Bolivia, stunting declined 14 percentage points between 2005 and 2016, while over the same period, the percentage of households with refrigeration increased from 30.4 to 58.1 (Figure 2; Instituto Nacional de Estadísticas [INE], 2018).

This study explores the potential role of refrigeration in improving child nutritional outcomes. This research question is particularly relevant in low- and middle-income countries. Although refrigerator ownership is nearly universal in developed countries, it is still relatively low in developing regions: in Southeast Asia and China, only 65% of the population owns a refrigerator; in Africa, the Middle East and

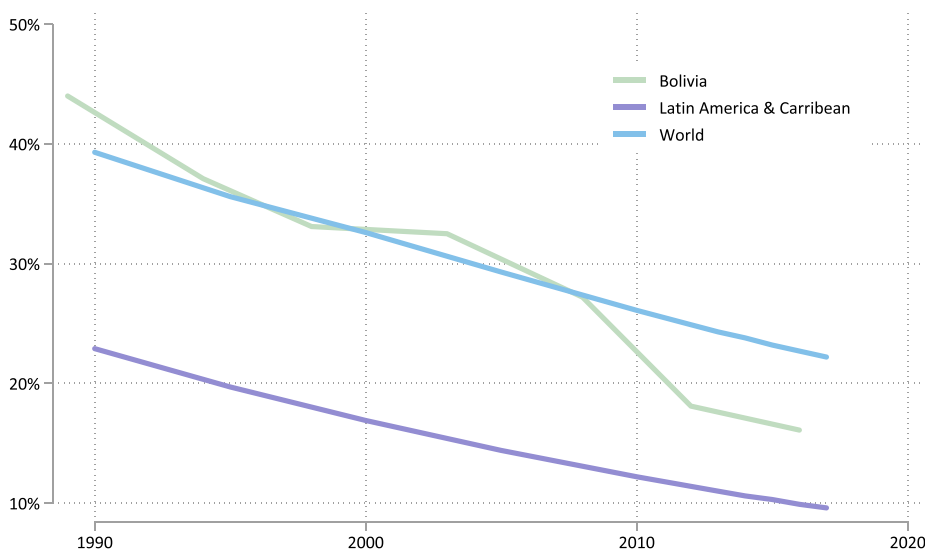
Key Messages

- We quasi-experimentally evaluate the impact of refrigeration on food consumption and child nutrition of households with children under 12 months old at baseline in a predominantly low-income and indigenous population in the city of El Alto, Bolivia.
- After controlling for time-invariant characteristics as well as changes in socio-economic status, refrigeration is associated with a significant increase in the purchase of more and/or higher quality food, including dairy, meat and fish.
- Acquiring a refrigerator is associated with a 0.17 standard deviation (SD) improvement in average height-for-age and has no significant association with average weight.

Eastern Europe, 80%; and in Latin America, 82% (Electrolux, 2019). Within these areas, there are large inequalities; for example, in Bolivia 69% of urban households own a refrigerator compared with 32% of rural households (INE, 2017).

1.1 | Refrigeration and nutrition

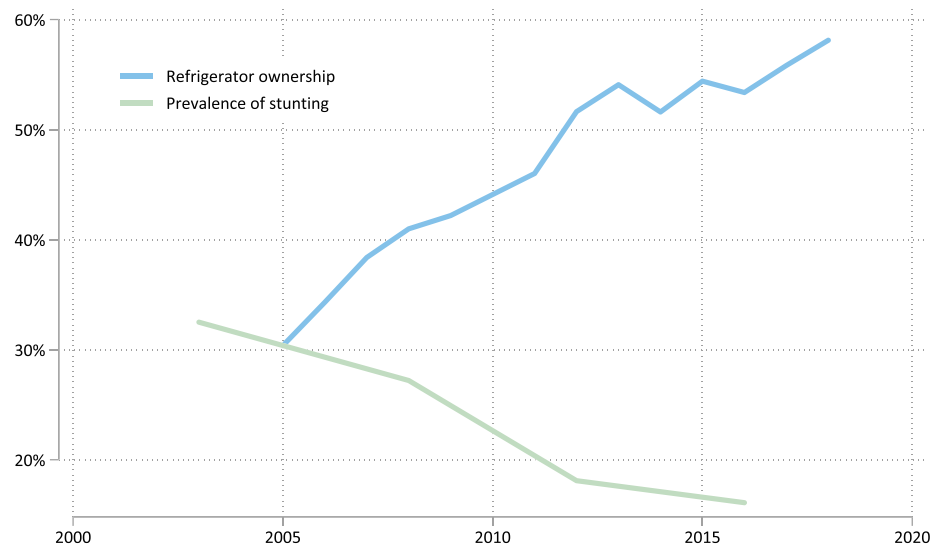
Refrigeration has the potential to affect child nutrition through multiple pathways. First, refrigeration prolongs the shelf-life of perishable foods, thereby affecting a household's decisions about what food to buy and consume. Because refrigeration reduces the risk of spoiling, food safety may be improved, and households may be willing to purchase greater quantities of food and/or higher quality products. Refrigeration may also affect transaction costs and allow for economies of scale when purchasing perishable foods, because items can be purchased less often and in bulk and could therefore reduce the per-



Source: UNICEF, WHO, World Bank: Joint child malnutrition estimates

FIGURE 1 Trends in stunting in children under five

FIGURE 2 Trends in refrigeration and stunting in Bolivia



Source: Instituto Nacional de Estadística: Encuesta de Hogares 2005-2018; UNICEF, WHO, World Bank: Joint child malnutrition estimates

unit cost of the food items after factoring in bulk purchase discounts, transportation costs and the opportunity cost of time for shopping.

The benefits of refrigeration in purchasing and storing perishable items may lead to an increase in their overall consumption. The relationship between refrigerator ownership and increased dietary diversity and reduced food insecurity has been established in the literature (Ballantine, Rousseau, & Venter, 2008; Faber, Schwabe, & Drimie, 2009). Some studies have also found an association between refrigerator ownership and increased consumption of perishable foods, including beef, dairy products, eggs, seafood and fruits (Barham, Cox, & Paz, 1996; Craig, Goodwin, & Grennes, 2004; Dong & Gould, 2007; Lyon & Durham, 1999).

Foods that require refrigeration are generally healthier than non-perishable items. These types of foods include important micro-nutrients and macronutrients such as vitamins, minerals, proteins and fibres that are essential for child growth and development. More specifically, the intake of animal source food, such as meat and milk, has been linked to increased growth (Choudhury & Headey, 2018; Neumann, Harris, & Rogers, 2002; Puentes et al., 2016). Vegetable and fruit consumption are inversely related to weight and obesity (Bradlee, Singer, Qureshi, & Moore, 2010). Furthermore, dietary diversity and food variety has been positively linked to height-for-age z scores and weight-for-age z scores, and low dietary diversity has been shown to be a predictor of stunting in children (Arimond & Ruel, 2004; Bhutta, 2008; Rah et al., 2010).

Despite evidence surrounding the effects of refrigeration on food consumption, and separately of the importance of food consumption for child health and nutrition, there are surprisingly few studies that look at the potential role of refrigeration on final health outcomes. One exception is De Souza (2017), the only study to our knowledge that looks at the relationship between refrigerator ownership and final nutrition outcomes. The study analysed possible correlates of stunting among 5783 Yemeni children between 6 and 59 months old and found that refrigerator ownership was associated with a 51% reduction in the probability of stunting. Related studies have found

associations between undernutrition and the ownership of other assets, yet causal attribution is complicated by potential confounders (Hong & Mishra, 2006; Linnemayr, Alderman, & Ka, 2008; Pongou, Ezzati, & Salomon, 2006).

2 | METHODS

2.1 | Data

We analysed panel data from a community nutrition programme in Bolivia that collected rich child nutrition, food consumption and household demographic and socio-economic survey data (Martinez et al., 2018). The survey was implemented in the eighth district of El Alto, a low-income, predominately indigenous population where all households have access to electricity, but there is substantial variation in refrigerator ownership. 2001 households with a pregnant woman or child under 12 months old were identified at baseline, and 14 households were recruited for the programme afterwards and included in the endline survey. Baseline data were collected between March and July 2014, and endline data were collected about 30 months later.

Of the 2001 households with baseline data, 1571 were reached for follow-up. Among these, 273 households had pregnant women and no children under 12 months old at baseline; therefore, child-level outcomes were unavailable. A balanced panel of the remaining 1298 households was used for analysis. Household-level data on food expenditures were measured longitudinally for the same households. To identify the effect of refrigeration on child-level outcomes, we created a balanced panel of children, which included anthropometric measures for the same children in each round. Eleven households had more than one eligible child, resulting in a panel of 1310 children.

The data include a rich set of variables on food expenditures and consumption which allowed us to study the mechanisms through which refrigeration may affect nutrition. Moreover, children were at a

critical stage of growth and development during the study period. Studies show that height-for-age z scores tend to decrease sharply during the first 24 months of life and then show fewer changes thereafter (Dewey & Begum, 2011). This trajectory in growth is seen among children in our data and suggests refrigeration could be particularly influential early in life (Figure 3).

2.2 | Outcome variables

Child nutrition was assessed using the following anthropometrics measures: (1) height-for-age z score, (2) weight-for-age z score, (3) weight-for-height z score and (4) BMI-for-age z score. Height and weight were measured using standardized methods (Martinez et al., 2018). Height was measured using a wood infantometer, and weight was measured using a SECA scale with a precision of ± 50 g; z scores were calculated from raw height and weight measures using the WHO Anthro Software in Stata. Calculations are based on WHO Child Growth Standards, which were developed using data collected in the WHO Multicentre Growth Reference Study, and vary by child age and gender (WHO, 2011).

Intermediate outcomes were measured at the household level. We analysed household's monthly per-capita food expenditures (expressed in bolivianos or Bs) in total and separately for five food categories: (1) dairy and eggs, (2) meat and fish, (3) vegetables, (4) fruit and (5) sweets, including cookies, sugar, honey, soda, juice, hot chocolate and other sweets/sugary foods. Child food consumption indicators were measured as follows:

- Diverse food categories consumed: number of food groups consumed in past 24 h \div total number of food groups. There are seven food groups defined by the WHO: (1) grains, roots and tubers; (2) legumes and nuts; (3) dairy products (milk, yogurt and cheese); (4) flesh foods (meat, fish, poultry and liver/organ meats); (5) eggs;

(6) vitamin A-rich fruits and vegetables; and (7) other fruits and vegetables (WHO et al., 2010).

- Refrigerated food consumed: number of refrigerated food groups consumed in past 24 h \div total number of refrigerated food groups. Refrigerated food groups include: (1) dark greens, (2) vitamin A-rich fruits, (3) other fruits and vegetables, (4) liver and organs, (5) meat, (6) fish and (7) dairy products.
- Non-perishable food consumed: number of non-perishable food groups consumed in past 24 h \div total number of non-perishable food groups. Non-perishable food groups include: (1) rice, bread, crackers and corn; (2) potatoes, yucca and flours; (3) beans, lentils and chickpeas; and (4) chocolates, candies, cakes and sugary foods.

All household-level indicators were computed using self-reported data on food expenditures and consumption.

2.3 | Refrigerator ownership

Refrigerator ownership is a binary variable equal to 1 if a household reported ownership of a working refrigerator, and 0 otherwise. Table 1 shows refrigerator ownership at baseline and endline for the 1298 households in our balanced panel. Most households (875) never had a refrigerator, and only 153 households had a refrigerator at baseline and endline (always refrigerator group). One hundred ninety-two households acquired a refrigerator after baseline, and 78 households

TABLE 1 Refrigerator ownership

Endline	Baseline		Total
	No refrigerator	Refrigerator	
No refrigerator	875	78	953
Refrigerator	192	153	345
Total	1067	231	1298

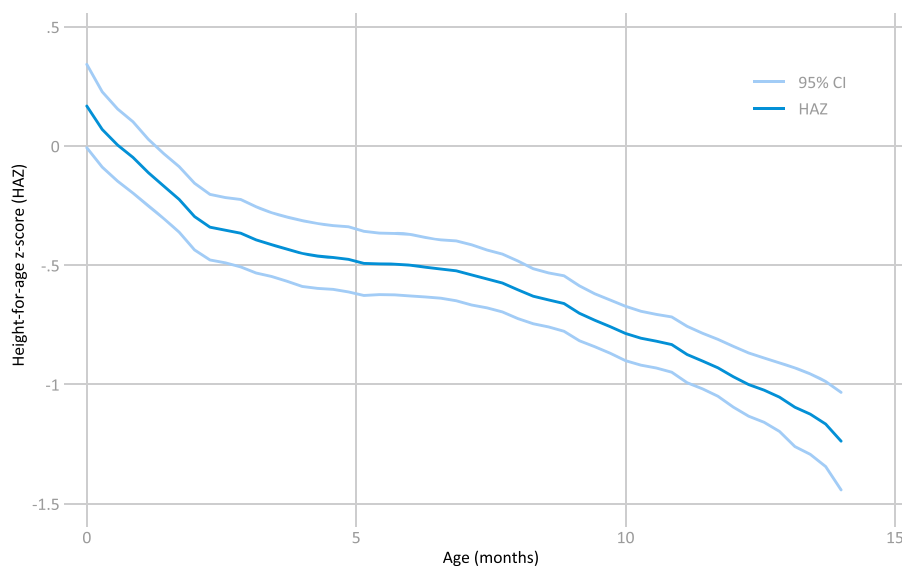


FIGURE 3 Child growth trajectory

who had a refrigerator at baseline 'lost' refrigeration between rounds. Two of the households that lost refrigeration indicated that the refrigerator was no longer working at endline, and eight others changed addresses. The reasons for why the remaining households may have lost refrigeration are unknown.

Using the self-reported refrigerator ownership variable, we construct two separate 'treatment' dummy variables equal to 1 at endline for households that acquire or lose a refrigerator between rounds, respectively. Households that acquire a refrigerator (i.e., adopters) are those that reported no refrigerator ownership at baseline and reported a positive refrigerator ownership status at endline (refrigerator ownership changes from 0 to 1). Households that lose a refrigerator include all households that reported a refrigerator at baseline and no refrigerator at endline (refrigerator ownership changes from 1 to 0). The 'control' group includes households that maintained the same refrigerator ownership status between rounds, that is, households that never had a refrigerator or always had a refrigerator over the observation period.

A map of all 1298 households categorized by refrigeration group is presented in Figure 4. The geographic location of households by refrigerator ownership appears evenly dispersed, suggesting geography did not play a significant role in a household's decision to own a refrigerator.

2.4 | Statistical analysis

Panel data provided a unique opportunity to control for potential time-invariant confounders when analysing the association between refrigeration and child nutrition or household food expenditures and consumption. However, acquisition or loss of a refrigerator is unlikely to be random, and there may have been other time-varying factors that drove both the acquisition (or loss) of a refrigerator and changes in child nutrition or household food expenditures, such as changes in household income and wealth. To account for these differences, we rely on detailed socio-economic measures collected at baseline and endline.

We estimated the effects of refrigerator ownership on nutrition outcomes and food expenditures using a difference-in-difference approach. For nutritional outcomes measured at the child level, we included child fixed effects to control for constant unobserved heterogeneity between children, including birthweight, exclusive breastfeeding and other baseline characteristics that may affect children's growth trajectories. The difference-in-difference specification is as follows:

$$Y_{iht} = \beta_1 * acquiredfridge_h + \beta_2 * lostfridge_h + age_{it} + \alpha_i + \lambda_t + \epsilon_{iht}, \quad (1)$$

where Y_{iht} is the observed outcome for child i in household h at time t , $acquiredfridge_h$ is a dummy variable equal to 1 if household h acquired a refrigerator at time $t = 1$ and 0 otherwise, $lostfridge_h$ is a dummy variable equal to 1 if household h lost a refrigerator at time $t = 1$ and 0 otherwise, age_{it} is a child's age in days and is included to

account for differences in age at baseline and endline measurement, α_i are child fixed effects, λ_t are time fixed effects and ϵ_{iht} is the standard error, which is clustered at the household level to account for correlation in outcomes between children in the same household.

For each nutritional outcome, we present two additional regression estimates including household-level time-varying controls, X_{ht} , for number of household members at time t , employment status of the head of household at time t , change of address at time $t = 1$ and a measure of either income or wealth, as follows:

$$Y_{iht} = \beta_1 * acquiredfridge_h + \beta_2 * lostfridge_h + age_{it} + X_{ht} + \alpha_i + \lambda_t + \epsilon_{iht}. \quad (2)$$

For outcomes measured at the household level such as food expenditure and consumption, we include only one observation per household and period, and change the fixed effect to the household level, thus controlling for time-invariant household characteristics. Specifically, we estimate the following models:

$$Y_{ht} = \beta_1 * acquiredfridge_h + \beta_2 * lostfridge_h + \alpha_h + \lambda_t + \epsilon_{ht}, \quad (3)$$

$$Y_{ht} = \beta_1 * acquiredfridge_h + \beta_2 * lostfridge_h + X_{ht} + \alpha_h + \lambda_t + \epsilon_{ht}. \quad (4)$$

Similar to the child-level estimates, we present two regression estimates of model 4, first controlling for income and separately controlling for wealth as two separate measures of household socioeconomic status.

2.5 | Ethical considerations

The survey questions were approved by the ethical review board of the National Bioethics Committee in Bolivia prior to the start of the programme and informed consent was obtained from caregivers. We analyse de-identified public access baseline and follow-up data.

3 | RESULTS

3.1 | Study population

Baseline characteristics are presented in Table 2. Most household heads were male (94%), indigenous (84%) and relatively young (33 years old). They had 10 years of education and an employment rate of 93%. Most were married or in a domestic partnership (93%) and few had health insurance (14%). The average household had 5 members with 2 children under 12 years old.

At baseline, households earned an average monthly per-capita income of 646 bolivianos (about \$93 USD). Most households had a bathroom or latrine (86%), but very few had sewerage connections (<1%). Almost all (>99%) households had electricity and a gas or electric stove, and a majority had cell phones, televisions and radios (98%, 97% and 83%, respectively). On the other hand, only 18% had refrigeration, 13% had computers and 25% had cars.

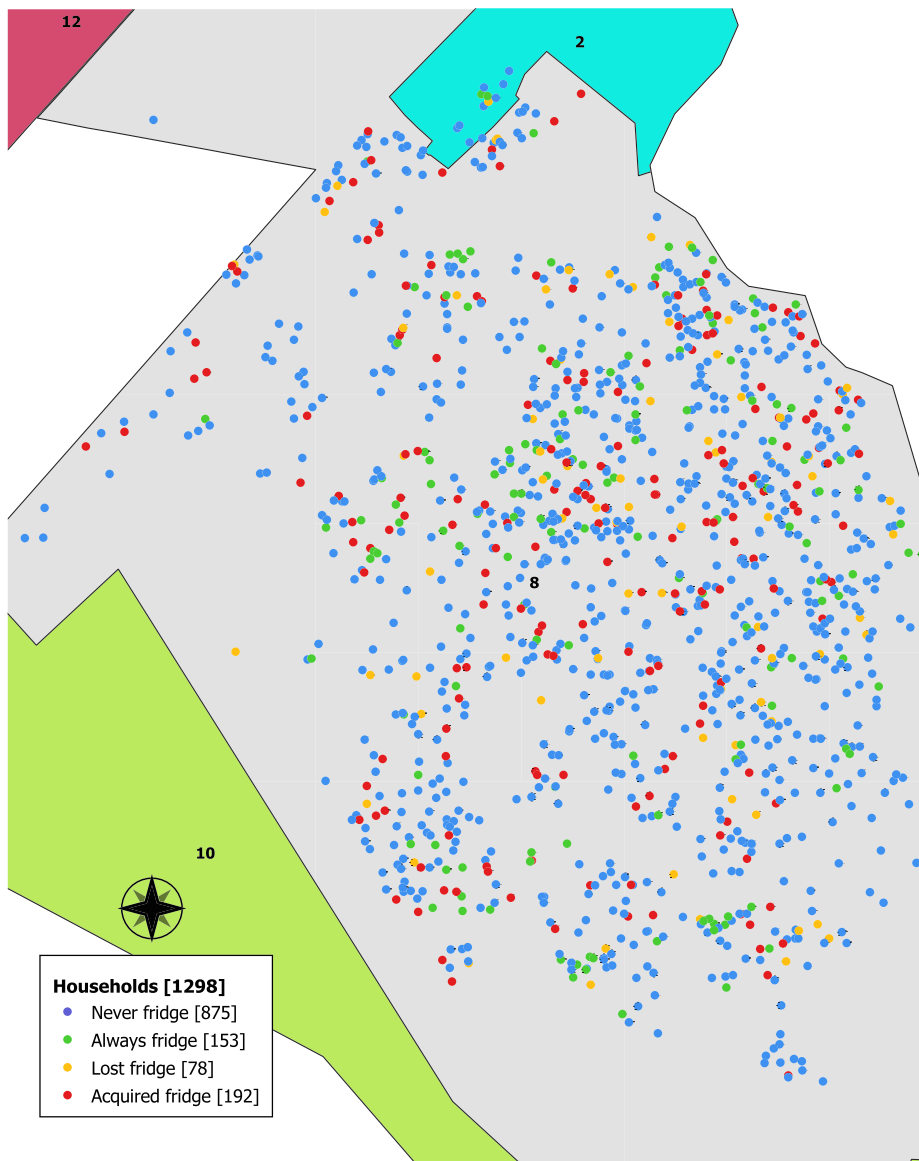


FIGURE 4 Study households, by refrigeration group

The panel of 1310 children had an average age of 6.5 months at baseline. About 10% of children were stunted, 3% were underweight, and 7% were overweight or obese; 14% had mild or moderate anaemia.

3.2 | Balance

To test for balance at baseline, we compared demographic, socio-economic and health-related characteristics between households who acquired or lost refrigeration and those that never had a refrigerator and always had a refrigerator. There are significant differences in numerous characteristics between the four groups (Table 3). The difference-in-difference strategy controls for time-invariant baseline differences. As discussed above, we included additional controls for key time-varying confounders in the regression models. In addition, we ran a series of validity checks to verify that our results can be

reasonably attributed to refrigeration rather than underlying differences between groups. A detailed description of balance is presented in Appendix S1.

3.3 | Children's health and nutrition

The primary interest of this study was to determine the association between refrigeration and children's anthropometric outcomes (Table 4). We found that acquiring refrigeration is associated with a positive and significant increase in height-for-age of 0.17 standard deviations (SDs). Additionally, we found a significant decrease in weight-for-height of around 0.26 SD and in BMI-for-age of 0.26 SD. There were no significant effects on weight-for-age, indicating that the impacts on weight-for-height and BMI-for-age are likely operating through an increase in height, rather than a reduction in weight. Moreover, children in this study had a below average

TABLE 2 Baseline characteristics

	Full sample		Acquired fridge		Lost fridge		Never fridge		Always fridge		
	n	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Panel A. Household demographics											
Household head											
Male = 1	1298	0.935	(0.25)	0.969	(0.17)	0.962	(0.19)	0.921	(0.27)	0.961	(0.19)
Age (years)	1298	33.105	(9.75)	33.422	(10.01)	32.885	(9.26)	32.680	(9.49)	35.248	(10.86)
Indigenous = 1	1298	0.841	(0.37)	0.818	(0.39)	0.872	(0.34)	0.847	(0.36)	0.824	(0.38)
Married or in partnership = 1	1298	0.931	(0.25)	0.943	(0.23)	0.949	(0.22)	0.925	(0.26)	0.941	(0.24)
Education (years)	1298	10.082	(3.56)	10.745	(3.23)	10.782	(3.38)	9.739	(3.49)	10.850	(4.17)
Works = 1	1298	0.935	(0.25)	0.953	(0.21)	0.936	(0.25)	0.933	(0.25)	0.922	(0.27)
Health insurance = 1	1298	0.138	(0.34)	0.198	(0.40)	0.167	(0.38)	0.097	(0.30)	0.281	(0.45)
Child											
Age (months)	1310	6.456	(4.04)	6.649	(4.14)	6.797	(4.17)	6.375	(4.00)	6.503	(4.06)
Male = 1	1310	0.505	(0.50)	0.546	(0.50)	0.443	(0.50)	0.501	(0.50)	0.503	(0.50)
Household composition											
Number of members	1298	5.012	(1.78)	4.755	(1.79)	4.923	(1.67)	5.094	(1.80)	4.908	(1.69)
Number of members per bedroom	1298	4.140	(1.95)	3.749	(1.63)	3.892	(1.42)	4.360	(2.05)	3.504	(1.67)
Males 0–5 years old (%)	1298	0.174	(0.15)	0.188	(0.17)	0.173	(0.15)	0.174	(0.15)	0.162	(0.15)
Males 6–18 years old (%)	1298	0.089	(0.13)	0.075	(0.12)	0.112	(0.14)	0.091	(0.13)	0.080	(0.13)
Males 19–49 years old (%)	1298	0.216	(0.09)	0.232	(0.09)	0.211	(0.09)	0.210	(0.09)	0.234	(0.09)
Males 50 years or older (%)	1298	0.010	(0.04)	0.012	(0.05)	0.011	(0.04)	0.009	(0.04)	0.014	(0.05)
Females 0–5 years old (%)	1298	0.174	(0.16)	0.154	(0.15)	0.165	(0.15)	0.179	(0.16)	0.172	(0.15)
Females 6–18 years old (%)	1298	0.104	(0.14)	0.094	(0.14)	0.098	(0.14)	0.110	(0.14)	0.089	(0.13)
Females 19–49 years old (%)	1298	0.223	(0.09)	0.235	(0.09)	0.222	(0.07)	0.218	(0.09)	0.239	(0.09)
Females 50 years or older (%)	1298	0.010	(0.04)	0.011	(0.04)	0.008	(0.03)	0.009	(0.04)	0.012	(0.05)
Panel B. Socio-economic Characteristics											
Income											
Monthly per-capita income (Bs) ^a	1298	646.612	(813.65)	758.715	(1299.83)	840.082	(1517.23)	577.832	(566.17)	800.653	(656.07)
Household Assets											
Wealth index	1298	0.033	(0.99)	0.177	(0.98)	0.268	(0.82)	-0.126	(0.94)	0.638	(1.03)
Bathroom = 1	1298	0.860	(0.35)	0.839	(0.37)	0.910	(0.29)	0.851	(0.36)	0.908	(0.29)
Sewer connection = 1	1298	0.004	(0.06)	0.005	(0.07)	0.000	(0.00)	0.003	(0.06)	0.007	(0.08)
Electric or gas stove = 1	1298	0.995	(0.07)	0.990	(0.10)	0.987	(0.11)	0.998	(0.05)	0.993	(0.08)
Electricity = 1	1298	0.998	(0.05)	1.000	(0.00)	1.000	(0.00)	0.997	(0.06)	1.000	(0.00)

(Continues)

TABLE 2 (Continued)

	Full sample		Acquired fridge		Lost fridge		Never fridge		Always fridge		
	n	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Landline = 1	1298	0.031	(0.17)	0.047	(0.21)	0.064	(0.25)	0.019	(0.14)	0.059	(0.24)
Cell phone = 1	1298	0.978	(0.15)	0.984	(0.12)	0.974	(0.16)	0.975	(0.16)	0.993	(0.08)
Radio = 1	1298	0.828	(0.38)	0.896	(0.31)	0.949	(0.22)	0.782	(0.41)	0.948	(0.22)
Television = 1	1298	0.969	(0.17)	0.964	(0.19)	0.962	(0.19)	0.966	(0.18)	1.000	(0.00)
Computer = 1	1298	0.129	(0.34)	0.125	(0.33)	0.205	(0.41)	0.088	(0.28)	0.333	(0.47)
Car = 1	1298	0.255	(0.44)	0.229	(0.42)	0.295	(0.46)	0.230	(0.42)	0.412	(0.49)
Electric pump = 1	1298	0.003	(0.06)	0.000	(0.00)	0.013	(0.11)	0.002	(0.05)	0.007	(0.08)
Air conditioning = 1	1298	0.000	(0.00)	0.000	(0.00)	0.000	(0.00)	0.000	(0.00)	0.000	(0.00)
Panel C. Food expenditures, diet and nutrition outcomes											
Monthly per-capita food expenditures (Bs) ^a											
Total food expenditures	1298	313.915	(178.82)	309.594	(134.25)	349.070	(206.57)	301.805	(178.75)	370.672	(200.30)
Expenditures on dairy and eggs	1298	39.507	(42.25)	38.903	(35.51)	48.212	(45.77)	37.540	(44.48)	47.078	(33.02)
Expenditures on meat and fish	1298	82.499	(58.39)	89.651	(58.61)	94.089	(77.52)	76.143	(52.06)	103.969	(72.89)
Expenditures on fruits	1298	21.600	(16.38)	22.499	(18.44)	22.902	(12.90)	20.296	(14.64)	27.267	(22.37)
Expenditures on vegetables	1298	30.753	(20.07)	31.460	(16.40)	32.167	(28.67)	29.430	(17.61)	36.707	(29.21)
Expenditures on sweets and sugary beverages	1298	43.687	(93.49)	39.484	(43.53)	52.978	(120.86)	43.004	(99.25)	48.129	(89.83)
Food consumption											
Minimum dietary diversity = 1	729	0.764	(0.42)	0.755	(0.43)	0.755	(0.43)	0.761	(0.43)	0.800	(0.40)
Diverse food consumed (%)	729	0.630	(0.23)	0.625	(0.25)	0.606	(0.24)	0.627	(0.23)	0.664	(0.24)
Refrigerated food consumed (%)	729	0.356	(0.17)	0.349	(0.18)	0.350	(0.17)	0.351	(0.16)	0.397	(0.18)
Non-perishable food consumed (%)	729	0.585	(0.25)	0.552	(0.27)	0.566	(0.26)	0.595	(0.24)	0.582	(0.24)
Child nutrition											
Height (cm)	1278	64.712	(7.23)	65.140	(7.36)	65.417	(7.45)	64.461	(7.21)	65.256	(7.04)
Weight (kg)	1279	7.353	(1.90)	7.556	(1.96)	7.549	(1.94)	7.263	(1.89)	7.513	(1.90)
BMI	1278	17.205	(2.03)	17.460	(2.13)	17.269	(1.64)	17.127	(2.04)	17.295	(2.03)
Height-for-age z score	1277	-0.539	(1.20)	-0.515	(1.09)	-0.470	(1.18)	-0.575	(1.24)	-0.394	(1.15)
Weight-for-age z score	1235	0.017	(1.08)	0.134	(1.08)	0.159	(0.83)	-0.035	(1.10)	0.093	(1.03)
Weight-for-height z score	1229	0.498	(1.19)	0.693	(1.21)	0.584	(0.98)	0.454	(1.21)	0.464	(1.15)
BMI-for-age z score	1233	0.463	(1.18)	0.638	(1.16)	0.576	(0.90)	0.415	(1.22)	0.462	(1.13)
Stunted = 1	1277	0.101	(0.30)	0.085	(0.28)	0.104	(0.31)	0.111	(0.31)	0.060	(0.24)
Underweight = 1	1235	0.032	(0.18)	0.027	(0.16)	0.000	(0.00)	0.041	(0.20)	0.007	(0.08)
Wasted = 1	1229	0.028	(0.17)	0.016	(0.13)	0.014	(0.12)	0.035	(0.18)	0.014	(0.12)

TABLE 2 (Continued)

	Full sample		Acquired fridge		Lost fridge		Never fridge		Always fridge		
	n	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Overweight = 1	1233	0.074	(0.26)	0.109	(0.31)	0.027	(0.16)	0.072	(0.26)	0.063	(0.24)
Haemoglobin level (g/dl) = 1	931	12.678	(1.48)	12.822	(1.41)	12.540	(1.29)	12.630	(1.45)	12.839	(1.73)
Mild anaemia = 1	931	0.100	(0.30)	0.119	(0.32)	0.105	(0.31)	0.096	(0.29)	0.096	(0.30)
Moderate anaemia = 1	931	0.038	(0.19)	0.015	(0.12)	0.018	(0.13)	0.045	(0.21)	0.035	(0.18)
Severe anaemia = 1	931	0.000	(0.00)	0.000	(0.00)	0.000	(0.00)	0.000	(0.00)	0.000	(0.00)

*1 USD = 6.9098 bolivianos.

height-for-age (-0.52 SD) and an above average weight-for-height and BMI-for-age (0.66 and 0.61 SD, respectively), suggesting that refrigeration could play a role in improving children's height and reducing overweight.

On the other hand, losing refrigeration is associated with a negative but statistically insignificant change in height. The magnitude of the estimated coefficient on height-for-age (-0.2 SD) is similar to the coefficient on acquiring refrigeration, which suggests that losing refrigeration may play an equally important role in constraining gains in height relative to children with no change in refrigeration status. Losing a refrigerator was also associated with a significant decrease of about 0.25 SD on weight-for-age, an effect size considerably larger than for acquiring refrigeration. There were no significant effects of losing refrigeration on weight-for-height or BMI-for-age. These results suggest not only that acquiring refrigeration can improve nutritional outcomes but also that losing refrigeration may lead to undesired effects on a child's nutritional status.

Associations between refrigeration and raw anthropometric measurements and nutrition subcategories can be found in Appendix S2, along with additional analyses looking at heterogeneous effects and associations with other nutrition outcomes such as anaemia and diarrhoea.

3.4 | Food expenditures and consumption

Changes in household's food composition patterns are a plausible pathway for refrigeration to affect children's anthropometric outcomes. To test this hypothesis, we looked at the effects of refrigeration on intermediate outcomes related to household food expenditures and consumption.

Table 5 shows the effects of acquiring and losing refrigeration on monthly per-capita food expenditures. The effect of acquiring a refrigerator on total monthly food expenditures was about 80 bolivianos (11.658 USD) per capita. Furthermore, acquiring refrigeration was associated with an increase of about 36 bolivianos (5.21 USD) per capita on monthly dairy and egg expenditures. There were no significant changes in meat and fish, fruit, vegetables or sweets expenditures. There were also no effects of losing refrigeration on total food expenditures or on any individual category. Inverse-hyperbolic-sine transformed expenditures are presented in Appendix S3 (Table S6).

The associations between refrigerator ownership and food consumption outcomes are also presented in Appendix S3. No significant effects were found on the proportion of diverse, refrigerated, or non-perishable food groups consumed (Table S7).

3.5 | Validity checks

We ran several validity checks to verify that our findings can reasonably be attributed to refrigeration rather than underlying differences between groups. Estimates within the four refrigeration subgroups (acquired fridge, lost fridge, never fridge and always fridge) are

TABLE 3 Balance

	Acquired fridge vs. never fridge	Acquired fridge vs. always fridge	Lost fridge vs. never fridge	Lost fridge vs. always fridge
Panel A. Household demographics				
Household head				
Male = 1	0.048***	0.008	0.040*	0.001
Age (years)	0.742	-1.826	0.205	-2.364*
Indigenous = 1	-0.029	-0.006	0.025	0.048
Married or in partnership = 1	0.018	0.002	0.024	0.008
Education (years)	1.005***	-0.105	1.043***	-0.068
Works = 1	0.021	0.032	0.003	0.014
Health insurance = 1	0.101***	-0.083*	0.070	-0.114**
Child				
Age (months)	0.274	0.146	0.422	0.294
Male = 1	0.045	0.043	-0.058	-0.060
Household composition				
Number of members	-0.339**	-0.153	-0.171	0.015
Number of members per bedroom	-0.611***	0.245	-0.468***	0.388*
Males 0-5 years old (%)	0.014	0.026	-0.001	0.011
Males 6-18 years old (%)	-0.016*	-0.005	0.021	0.032*
Males 19-49 years old (%)	0.022***	-0.002	0.002	-0.022*
Males 50 years or older (%)	0.003	-0.002	0.002	-0.003
Females 0-5 years old (%)	-0.026**	-0.018	-0.015	-0.007
Females 6-18 years old (%)	-0.016	0.005	-0.011	0.010
Females 19-49 years old (%)	0.017**	-0.003	0.004	-0.017
Females 50 years or older (%)	0.001	-0.001	-0.002	-0.004
Panel B. Socio-economic characteristics				
Income				
Monthly per-capita income (Bs) ^a	180.884*	-41.938	262.250	39.429
Household Assets				
Wealth index	0.303***	-0.460***	0.394***	-0.370***
Bathroom = 1	-0.013	-0.070**	0.059*	0.002
Sewer connection = 1	0.002	-0.001	-0.003*	-0.007
Electric or gas stove = 1	-0.008	-0.004	-0.011	-0.006
Electricity = 1	0.003*	0.000	0.003*	0.000
Landline = 1	0.027*	-0.012	0.045	0.005
Cell phone = 1	0.010	-0.009	-0.000	-0.019
Radio = 1	0.114***	-0.052*	0.167***	0.001
Television = 1	-0.002	-0.036***	-0.004	-0.038*
Computer = 1	0.037	-0.208***	0.117**	-0.128**
Car = 1	-0.001	-0.183***	0.065	-0.117*
Electric pump = 1	-0.002	-0.007	0.011	0.006
Air conditioning = 1	0.000	0.000	0.000	0.000
Panel C. Food expenditures, diet and nutrition outcomes				
Monthly per-capita food expenditures (Bs)^a				
Total food expenditures	7.789	-61.077***	47.265**	-21.602
Expenditures on dairy and eggs	1.363	-8.175**	10.672**	1.134
Expenditures on meat and fish	13.508***	-14.318**	17.946**	-9.880

TABLE 3 (Continued)

	Acquired fridge vs. never fridge	Acquired fridge vs. always fridge	Lost fridge vs. never fridge	Lost fridge vs. always fridge
Expenditures on fruits	2.203	-4.768**	2.606*	-4.364*
Expenditures on vegetables	2.030	-5.246**	2.736	-4.540
Expenditures on sweets and sugary beverages	-3.519	-8.645	9.974	4.849
Food consumption				
Minimum dietary diversity = 1	-0.006	-0.045	-0.006	-0.045
Diverse food consumed (%)	-0.002	-0.039	-0.021	-0.057
Refrigerated food consumed (%)	-0.001	-0.047*	-0.001	-0.047
Non-perishable food consumed (%)	-0.043	-0.030	-0.029	-0.016
Child nutrition				
Height (cm)	0.678	-0.116	0.956	0.161
Weight (kg)	0.294*	0.043	0.287	0.036
BMI	0.333**	0.166	0.142	-0.026
Height-for-age z score	0.060	-0.121	0.105	-0.076
Weight-for-age z score	0.169*	0.041	0.194*	0.066
Weight-for-height z score	0.239**	0.228*	0.130	0.120
BMI-for-age z score	0.222**	0.176	0.161	0.114
Stunted = 1	-0.027	0.025	-0.008	0.044
Underweight = 1	-0.014	0.020	-0.041***	-0.007
Wasted = 1	-0.019*	0.002	-0.021	-0.000
Overweight = 1	0.037	0.046	-0.045**	-0.035
Haemoglobin level (g/dl) = 1	0.192	-0.017	-0.090	-0.299
Mild anaemia = 1	0.023	0.022	0.009	0.009
Moderate anaemia = 1	-0.030**	-0.020	-0.027	-0.018
Severe anaemia = 1	0.000	0.000	0.000	0.000

^a1 USD = 6.9098 bolivianos.

* $P < 0.1$.

** $P < 0.05$.

*** $P < 0.01$.

presented in Appendix S4, and additional validity checks are presented in Appendix S5. Together, these validity checks support the finding that refrigeration may play a role in improving child nutrition, rather than results being driven by other unobserved time-varying factors that may have changed simultaneously in households that acquired or lost refrigeration.

4 | DISCUSSION

Our study adds to a limited body of evidence on the relationship between refrigeration and improved nutritional outcomes for young children. We estimated the effects of refrigerator ownership on diet and nutrition outcomes using a difference-in-difference approach for a panel of 1298 households in El Alto, Bolivia. Our results suggest that acquiring refrigeration led to a 0.17 SD increase in height-for-age which translates into a 1.2-cm average increase in height over roughly

30 months. We also estimate that acquiring a refrigerator is associated with reductions of 0.26 SD in weight-for-age and of 0.26 SD in BMI-for-age, which appear to be driven by increased height rather than changes in weight.

These results are consistent with population characteristics. Households were generally food secure: the baseline rate of wasting (weight-for-height $< 2SD$), which is associated with acute starvation, was less than 3%. The population did, however, exhibit poor nutritional conditions: 10% of children at baseline were stunted (height-for-age $< 2SD$), which is associated with chronic malnutrition, and 20% were at endline. Additionally, 7% were overweight or obese (BMI-for-age $> 2SD$) at baseline, which is linked to high sugar and fat intake (WHO, 2018). Another 24% were at risk for overweight (BMI-for-age $> 1SD$) at baseline and 32% were at endline. The null effect of refrigeration on weight is important, given that obesity has nearly tripled worldwide since 1975 and has become a major public health concern in Latin

TABLE 4 Anthropometrics

	(1)	(2)	(3)	Baseline mean
Height-for-age z score				
β1: Acquired fridge = 1	0.174** (0.080)	0.177** (0.081)	0.167** (0.082)	-0.52
β2: Lost fridge = 1	-0.201 (0.125)	-0.192 (0.126)	-0.200 (0.126)	-0.47
Observations	2558	2544	2543	
Number of children	1309	1309	1309	
Weight-for-age z score				
β1: Acquired fridge = 1	-0.049 (0.088)	-0.046 (0.088)	-0.062 (0.088)	0.13
β2: Lost fridge = 1	-0.248** (0.107)	-0.258** (0.105)	-0.240** (0.106)	0.16
Observations	2494	2481	2480	
Number of children	1306	1306	1305	
Weight-for-height z score				
β1: Acquired fridge = 1	-0.262** (0.106)	-0.259** (0.108)	-0.269** (0.108)	0.69
β2: Lost fridge = 1	-0.077 (0.151)	-0.101 (0.150)	-0.076 (0.152)	0.58
Observations	2486	2473	2472	
Number of children	1304	1304	1303	
BMI-for-age z score				
β1: Acquired fridge = 1	-0.260** (0.104)	-0.257** (0.105)	-0.271** (0.106)	0.64
β2: Lost fridge = 1	-0.071 (0.147)	-0.093 (0.145)	-0.067 (0.147)	0.58
Observations	2489	2476	2475	
Number of children	1305	1305	1304	
Time, Child FE	Yes	Yes	Yes	
Child age	Yes	Yes	Yes	
Employment, HH size, change of address		Yes	Yes	
Income		Yes		
Wealth			Yes	

Note: Standard errors, clustered at the household level, are in parentheses. Separate regression models, which include two dummy variables for households that acquired and lost refrigerators, respectively, were run for each of the outcomes.

**P < 0.05.

America, where childhood obesity rates are among the highest in the world, with one in five children under 20 years old either overweight or obese (Caballero, Vorkoper, Anand, & Rivera, 2017; WHO, 2018).

Our findings suggest that the pathway through which refrigeration improved child height was related to increased expenditures on food quality or quantity rather than the diversity of items. We found that households that acquired refrigeration spent more on food overall than households that did not. They spent more on dairy products and eggs, which require refrigeration and have been linked to child growth. No significant effects were found on dietary diversity; however, the population under study had high baseline measures of diversity, so effects were likely driven by changes in food composition at the intensive (amount and quality) rather than extensive (yes/no) margins, especially in regards to products where increased food expenditures were observed. Unfortunately, our dataset lacks information on the quality and quantity of items

consumed directly by children, so we were unable to test child-specific food consumption.

Our study presents various limitations. First, changes in refrigerator ownership were not random. Although our analysis controls for time-invariant characteristics as well as time-varying characteristics such as income and wealth, we cannot experimentally rule out all unobserved confounders. Nevertheless, several placebo and validity tests support our findings. Furthermore, our data do not include measures of child-level food consumption, so although our analysis of household-level food expenditures indicated that households increased expenditures on dairy, we cannot say whether children's diets were improving through changes in the amounts, quality or both. In addition, 78 households lost refrigeration between baseline and endline, and although there are reasonable explanations for 10 of those households, the reasons for losing a refrigerator in the remaining 68 are unclear. 703 households (35% of the original population) were also excluded from the analysis due to attrition or missing

TABLE 5 Monthly per-capita food expenditures (Bs)

	(1)	(2)	(3)	Baseline mean
Total food expenditures				
β1: Acquired fridge = 1	82.409** (35.186)	77.891** (35.316)	77.163** (35.476)	309.6
β2: Lost fridge = 1	-26.266 (52.871)	-14.639 (52.971)	-16.325 (53.288)	349.1
Expenditures on dairy and eggs				
β1: Acquired fridge = 1	37.178* (19.464)	36.110* (19.712)	35.941* (19.779)	38.90
β2: Lost fridge = 1	-9.803 (29.248)	-10.229 (29.566)	-10.431 (29.710)	48.21
Expenditures on meat and fish				
β1: Acquired fridge = 1	15.660 (9.663)	15.533 (9.694)	15.682 (9.733)	89.65
β2: Lost fridge = 1	-10.233 (14.520)	-5.901 (14.541)	-6.069 (14.620)	94.09
Expenditures on vegetables				
β1: Acquired fridge = 1	-7.412 (19.499)	-9.350 (19.723)	-9.639 (19.795)	31.46
β2: Lost fridge = 1	-13.982 (29.299)	-11.871 (29.583)	-13.081 (29.734)	32.17
Expenditures on fruits				
β1: Acquired fridge = 1	0.234 (2.300)	0.136 (2.296)	0.260 (2.304)	22.50
β2: Lost fridge = 1	-2.939 (3.455)	-2.703 (3.444)	-2.686 (3.460)	22.90
Expenditures on sweets and sugary beverages				
β1: Acquired fridge = 1	11.618 (7.735)	11.699 (7.781)	11.170 (7.814)	39.48
β2: Lost fridge = 1	-5.997 (11.623)	-3.534 (11.671)	-3.799 (11.737)	52.98
Observations	2592	2578	2577	
Number of households	1298	1298	1298	
Time, Household FE	Yes	Yes	Yes	
Employment, HH size, change of address		Yes	Yes	
Income		Yes		
Wealth			Yes	

Note: 1 USD = 6.9098 bolivianos. Standard errors are in parentheses. Separate regression models, which include two dummy variables for households that acquired and lost refrigerators, respectively, were run for each of the outcomes.

* $P < 0.1$.

** $P < 0.05$.

data; however, there was no evidence of systematic differences in characteristics between these households and the analysis sample.

The study context of El Alto, Bolivia, has some unique characteristics: it is located at a high altitude (13,620 feet above sea level) with a fairly low average annual temperature of 45.0°F, and most of the population is Aymara, one of the largest indigenous nations among the 36 officially recognized in Bolivia. Given the effect of refrigeration on nutrition outcomes is driven by its effect on food consumption, these patterns may vary with differences in food availability, cultural and ethnic consumption preferences and climate conditions that may affect food perishability. El Alto has lower average temperatures and humidity relative to most other cities in Bolivia, thus limiting the relative importance of refrigeration for food perishability. In this context, the results presented in this study may be conservative estimates of the potential benefits of refrigeration.

Despite these limitations, the results of this study open a promising line of inquiry regarding the potential connection between refrigeration and improved nutrition outcomes observed in developing

countries in recent years. In regards to improving children's height-for-age, our regression estimates suggest that acquiring refrigeration is equivalent to obtaining a 3520 Bs increase in monthly per-capita income (approximately \$509 USD). That is a 4.6-fold increase relative to the baseline mean of 759 Bs for households that acquired refrigeration. Given the value of a basic refrigerator in El Alto runs between \$200 and \$400 USD and refrigerators often last for over 10 years, the cost of expanding refrigeration is much lower than the increase in income associated with a commensurate change in height. Moreover, an effect size of 0.17 SD on height-for-age is comparable with effect sizes attributed to well-known, large-scale CCT programmes in Latin America (Leroy et al., 2008; Maluccio & Flores, 2005; Rivera, Stores-Alvarez, Habicht, Shamah, & Villalpando, 2004). For example, Familia en Acción in Colombia found a significant increase in height-for-age z score of 0.16 SD in children 0–24 months old (Leroy et al., 2009). Providing a refrigerator may also be a cheaper alternative to these CCT programmes. The monthly transfer per family for PROGRESA was typically between \$32.5–\$41.3 USD in urban areas

and \$25 USD in rural areas. With exposure periods of 24 and 18 months, respectively, the total cost was between \$780–\$991 USD in urban areas and approximately \$450 USD in rural areas (Leroy et al., 2008; Rivera et al., 2004). In Nicaragua, over a 24-month period, the actual average transfer was \$272 USD per year or about \$544 in total (Maluccio & Flores, 2005). Monthly transfers in Colombia's Familia en Acción varied by family, but the minimum total cost over the 12-month intervention period for families with children under 5 was \$180 USD (Attanasio, Battistin, Fitzsimons, Mesnard, & Vera-Hernández, 2005; Attanasio & Mesnard, 2006).

Although further research, particularly from randomized control trials, is needed to confirm our findings among different populations, the results found in this paper suggest that expanding refrigeration coverage could be a cost-effective approach for improving child nutrition and growth and provides compelling evidence to continue exploring its role in low- and middle-income countries where its adoption is still low. Furthermore, future studies could test the interaction effects of refrigeration with income transfer, complementary feeding, nutrition supplementation or other complementary behaviour change interventions that provide mothers and caregivers the means, knowledge and skills to improve children's diets and nutritional outcomes.

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CONFLICTS OF INTEREST

All authors were employed by the Inter-American Development Bank at the time of the study's conception and implementation and had a role in study design, data collection, data analysis, data interpretation or writing of the report. All authors had full access to all the data and final responsibility to submit to publication. We declared no competing interests in the results of the study. All opinions in this paper are those of the authors and do not necessarily represent the views of the Government of Bolivia or the Inter-American Development Bank, its Executive Directors or the governments they represent.

CONTRIBUTIONS

SM and JM conceived and designed the study. SM, JM, BR and SW wrote the paper. SM, JM, BR and SW discussed, critically revised and

approved the study protocol. SM and JM are responsible for the organization and conduct of the study. SM and JM supervised the study. SM and SW are responsible for the statistical analysis. SW contributed to data analysis. SM, JM, BR and SW drafted the first version of the report. SM, JM, BR and SW elaborated, discussed and approved the final version of the paper for publication.

ORCID

Sebastian Martinez  <https://orcid.org/0000-0002-7651-6674>

Solis Winters  <https://orcid.org/0000-0002-3269-4495>

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of this article.

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