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The Influence of Household Refrigerator Ownership on Diets in Vietnam

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ABSTRACT

Refrigerator ownership accompanies socio-economic development, with the potential to change human diets. Household refrigerator ownership in Vietnam has increased from 13% to 59% between 2004-2014. This study estimates changes in food consumption and diet linkages with household refrigerator ownership in Vietnam, while controlling for socioeconomic variables. We use a two-step instrumental variable regression model on two panels of the Vietnam Household Living Standards Survey covering 2004-2014. Our study finds refrigerator ownership to be significantly associated with decreases in per-capita calorie intake over both periods. Refrigerator ownership may be connected with households substituting lower-nutrient foods with higher ones, with substantial decreases in starchy staple food consumption connected with refrigerator ownership in both panels. For both periods, refrigerator ownership is significantly connected with increased dairy consumption, potentially reflecting the refrigerator increasing a household's ability to store dairy products.

1. Introduction

Vietnam has experienced tremendous economic growth over the past thirty years as a result of the government's *Đổi Mới* policy promoting market liberalization. GDP growth has averaged 6.42% between the beginning of this program in 1986 and 2017, with annual per capita GDP growth averaging 5.04% (The World Bank, 2018). This growth has been attained in part through infrastructure development throughout the country. For example, household electrification has increased from less than 50% in 1993 to including nearly all households in 2014 (World Wildlife Fund, 2016).

As a country develops, dietary shifts towards lower amounts of starchy staple foods and greater quantities of protein-rich and higher-fat foods have been demonstrated (Umberger et al., 2020, Rupa et al., 2019, Thang and Popkin, 2004). While this linkage is well-established, the specific mechanisms enabling these shifts are understudied, including the presence of refrigeration. This study assesses the relationship between household refrigerator ownership (as an indicator for development in the country) and the consumption of food types in Vietnam, filling part of this research gap.

Refrigeration plays a transformative role in food system development, and is interconnected with changes in what foods are consumed and can be supplied (Heard and Miller, 2016). The presence of refrigeration is connected with diets containing more perishable food items (Garnett, 2007), with a connection to increased meat consumption explicitly noted in China's development (Garnett & Wilkes, 2014). Perishable foods have the potential to improve health outcomes in developing countries (International Organization for the Development of Refrigeration, 2009), but the availability of refrigeration in conjunction with income increases may also promote diets which increase obesity and related health burdens (Popkin, 2001). The relationship between refrigeration, diet, and development has been addressed in the academic literature either largely qualitatively (Garnett, 2011, 2007; Parfitt et al., 2010) or modeled more-abstractly, carrying an assumption of dietary convergence reflecting diets in Western countries (Heard and Miller, 2019).

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Refrigerator ownership is tied to income, with sufficiently high household income being a necessary precursor for purchasing a refrigerator. Income increases have been empirically connected with decreased starchy staple food consumption and increases in fruit, vegetable, meat, dairy, and refined grain consumption; with the degree of these shifts dependent on the relative cost of these food types (Godfray et al., 2018). Due to the technological and logistical requirements of supplying perishable foods, shifts towards their consumption is in part enabled by refrigeration as a technology, and in part enabled by income used to purchase these products and a refrigerator. The extent to which diet shifts with development are attributable to refrigeration, wealth, and/or the interaction between these factors is relatively unassessed in the academic literature (Heard and Miller, 2016).

The unbroken refrigerated supply chain, or "cold chain," provides the capacity to robustly supply perishable foods, and its presence is a characteristic of a developed, industrialized food system (Parfitt et al., 2010). Cold chain services have developed in Vietnam in recent years due to an increase in international investment and an increase in the presence of supermarkets, with sales from modern grocery retailers growing from 30.9 trillion VND in 2011 to 69.2 trillion VND in 2015 (Euromonitor, 2017). The cold chain also plays a key role in agricultural development and in the transition towards Vietnam becoming an agricultural product exporter (Arita and Dyck, 2014). Despite these changes, cold chain development in Vietnam still faces several challenges including the need for improved training at the professional and farmer levels, a lack of supporting information technology, and high costs of installation and operation (Gligor et al., 2018). While development of cold chain services is gaining traction, the introduction of refrigerators enables the integration of households to the value chain; with this analysis assessing the influence of household refrigerator ownership on diet.

The presence, forms, and effects of refrigeration and the cold chain are influenced by intrinsic, direct, and external factors as described by Heard and Miller (2016). These factors include the specific elements outlined in Fig. 1, ranging from the food environment to its effect on consumer behavior, and resulting dietary outcomes (including nutrition, health, and social impacts). These elements are also influenced by demographics, socio-economics, cultural and the natural environment, all of which are also connected with the presence of refrigeration. This analysis examines refrigeration's effect on dietary outcomes, a process influenced by consumer behavior, the food environment, demographics, social, economic and cultural drivers. These elements are shaped by the natural environment, technology and infrastructure present, both of which are also connected to the presence of refrigeration. This analysis connects with the multifaceted elements determining dietary outcomes and situates them in the broader systems context surrounding the cold chain, refrigeration, and food system development.

The expected influence of refrigerator ownership on diet can be summarized in two hypotheses. First, household refrigerator ownership is hypothesized to have a positive and statistically significant relationship with the consumption of the more-perishable food types assessed: flesh foods (meat and fish), eggs, vegetables, fruits, and dairy. Second, refrigeration is hypothesized to have a negative and statistically significant relationship with the consumption of the less-perishable foods studied: starchy staple foods, nuts and seeds, and pulses.

These hypotheses are investigated through the empirical analysis of causal linkages between refrigerator ownership and household nutrition. First, the chosen estimation strategy must consider that refrigerator ownershipis likely notnot the only variable influencing a household's consumption of different food types. Socio-economic variables including income, household

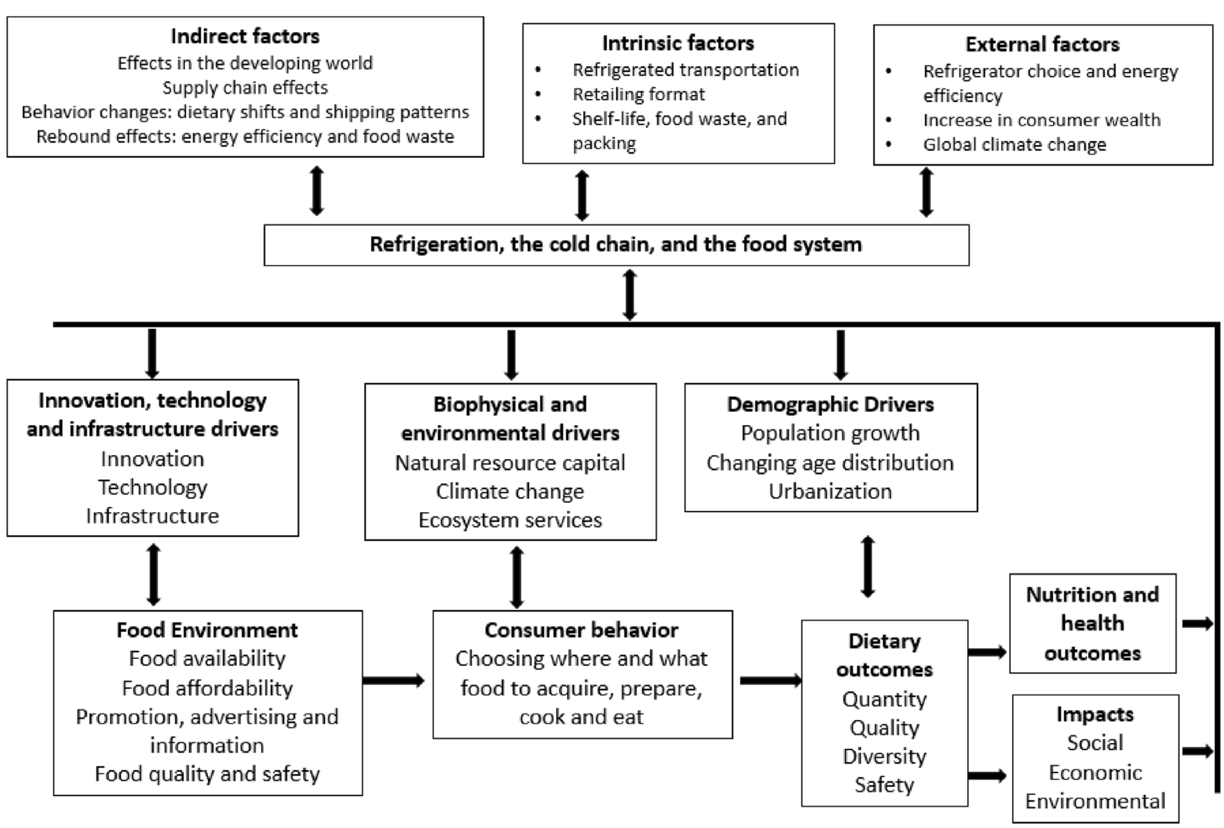

Fig. 1. Framework of linkages between household refrigerator ownership on the quality and diversity of diets in Vietnam. Authors' adaptation from FAO's HLPE (2017) and Heard and Miller (2016).

location, education level, and household size (among others) can be expected to affect food consumption. Variables accounting for these elements are included in the estimated regression model as control variables. Second, the availability of panel data on Vietnamese household consumption allows for an explicit treatment of unobserved individual heterogeneity by adding individual fixed effects to the estimated regression model (Stock and Watson, 2015). Unobserved individual heterogeneity can be a source of endogeneity to the explanatory variable of interest, i.e. owning a refrigerator. This variable can be correlated with individual, non-time-varying factors that are not observed and that also influence diet. The introduction of individual fixed effects makes it possible to control for this source of endogeneity of owning refrigerator. Third, the issue other potential sources of endogeneity of owning a refrigerator, due to reverse causality between nutritional outcome and owning refrigerator or some unobserved time-varying factors impacting these two variables, is addressed using an instrumental variable approach, namely control function approach (Wooldridge, 2015).

The proposed estimation strategy is implemented using data from Vietnamese Household Living Standard Survey, or VHLSS, over the 2004-2014 period. Consumption data are converted into energy intakes and normalized using per capita calorie intakes, allowing comparison between households. Nutritional outcomes under consideration include a dietary diversity measure, total per capita calorie intake, per capita calorie intakes for major food items, and the ratio between the shares of calories coming from food items with high nutrient intake and food items with low nutrient intake. This empirical analysis provides a snapshot of the causal effect of owning refrigerator on nutritional diet seen from different angles.

The paper is organized as follows. First, the estimation strategy is detailed, followed by a description of the VHLSS data, and then a description of our results and findings.

1.1. Estimation strategy

The influence of refrigerator ownership for Vietnamese households is investigated through regression of nutritional outcome for household i at period t, or Y_{it}, on refrigerator ownership, or X_{it}, and a vector of control variables, or Z_{it}:

$$Y_{it} = \alpha_i + \beta X_{it} + \gamma' Z_{it} + \varepsilon_{it}, \quad i = 1, \ldots, N, \quad T = 1, \ldots, T \qquad (1)$$

Household i fixed effect, or α_i, controls for potential unobserved time-invariant household heterogeneity. ε_{it} is the classical random term capturing the effect of unobserved time-variant variables. Estimating the influence of household refrigerator ownership on diet requires addressing issues of endogeneity of household ownership. The specific estimation strategy undertaken is depicted in Fig. 2, and described as follows.

The treatment of endogeneity of refrigerator ownership in Eq. (1) requires special attention as the endogenous explanatory variable is binary: owning a refrigerator, or not owning one. Eq. (1) is typically referred to as a dummy endogenous variable model (Heckman, 1978). As discussed in Wooldridge (2010), instrumental variables techniques must be adapted to deal with dummy endogenous explanatory variable issue. Let W_{it} denote a vector of instrumental variables. The estimation strategy consists then of a two-step IV method:

First step: Estimate a binary response model Prob $(X_{it} = 1 | Z_{it}, W_{it} = G(Z_{it}, W_{it}; \delta)$ by maximum likelihood (for instance, a fixed-effect logit model).

Second step: Estimate Eq. (1) by IV regression using instruments $\hat{G_{it}}$ and Z_{it} where $\hat{G_{it}}$ denotes fitted probability of owning a refrigerator for household i at time t obtained in first step.

Implementation of this two-step estimation procedure using panel data raises various issues. In the first step, different estimation strategies have been proposed to deal with the estimation of fixed-effect logit model. One possible strategy is maximum likelihood estimation with a dummy variable for each household. It is well known that estimation of parameters of usual fixed effects models with a small number of observations per fixed effect suffers from the incidental parameters problem (Neyman and Scott, 1948). Estimates of fixed effects values have no intrinsic interest, but their presence may prevent the consistent estimation ofparameters of interest, in this case, β in Eq. (1). Even increasing the number of time periods T does not necessary solve the incidental parameters bias because fixed effects estimators are asymptotically biased even if T grows at the same rate as N (Hahn

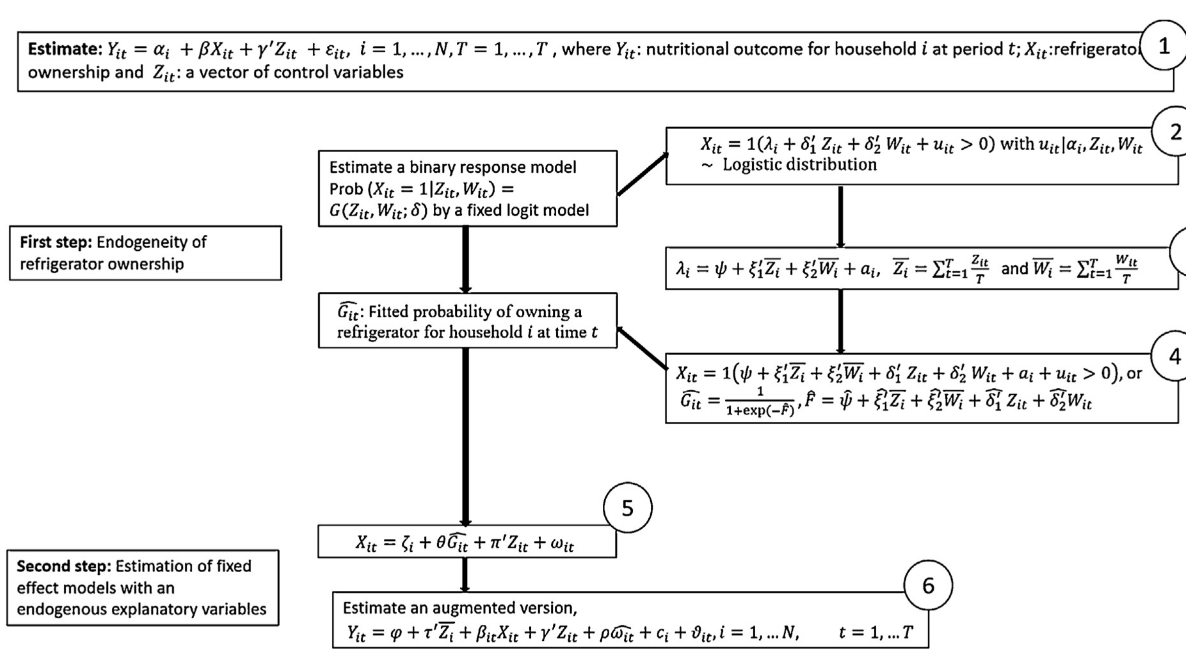

Fig. 2. Visual depiction of the two-step estimation strategy employed to estimate the influence of household refrigerator ownership on dietary outcomes.

and Newey, 2004). A conditional logit estimator has been proposed as an alternative to the previous estimation strategy (see Andersen, 1970; Chamberlain, 1980). The main drawback of a conditional logit estimator is that it does not provide estimates of the fixed effects that is needed to compute fitted probabilities.

The alternative estimation strategy we follow is inspired by correlated random effects panel data models recently surveyed in Wooldridge (2019). Considering the fixed-effect logit model

$$X_{it} = 1\left(\lambda_i + \delta_1^{'}\ Z_{it} + \delta_2^{'}\ W_{it} + u_{it} > 0\right) \text{ with } u_{it}|\lambda_i,\ Z_{it},\ W_{it} \sim \text{Logistic distribution} \quad (2)$$

as proposed by Mundlak (1978), potential correlation between unobserved household heterogeneity, as captured by fixed effect λ_i, and regressors in model (2) can be written as

$$\lambda_i = \psi + \xi_1^{'}\overline{Z_i} + \xi_2^{'}\overline{W_i} + a_i \quad (3)$$

Where $\overline{Z_i}$ and $\overline{W_i}$ denote time-averaged values of Z_{it} and W_{it}, i.e. $\overline{Z_i} = \sum_{t=1}^{T}\frac{Z_{it}}{T}$ and $\overline{W_i} = \sum_{t=1}^{T}\frac{W_{it}}{T}$ and, conditionally to $(Z_{it},\ X_{it})$, a_i is purely random and distributed with a zero mean. By including the vector of time-averaged explanatory variables, i.e. Z_{it} and W_{it}, time-invariant unobserved heterogeneity can be controlled as with fixed effects, but without encountering the incidental parameters problem that affects fixed effects model estimation. Eq. (2) can be written as

$$X_{it} = 1\left(\psi + \xi_1^{'}\overline{Z_i} + \xi_2^{'}\overline{W_i} + \delta_1^{'}\ Z_{it} + \delta_2^{'}\ W_{it} + a_i + u_{it} > 0\right) \quad (4)$$

and estimated using classical random effect panel data estimator. As a byproduct, computation of fitted probabilities is not marred by the need to estimate fixed effects, i.e.

$$\log\frac{G_{it}}{1-G_{it}} = \psi + \xi_1^{'}\overline{Z_i} + \xi_2^{'}\overline{W_i} + \delta_1^{'}Z_{it} + \delta_2^{'}W_{it} + a_i + u_{it}$$

and

$$\hat{G_{it}} = \frac{1}{1+\exp(-\widehat{F})},\ \textit{where}\ \widehat{F} = \hat{\psi} + \hat{\xi_1^{'}}\overline{Z_i} + \hat{\xi_2^{'}}\overline{W_i} + \hat{\delta_1^{'}}Z_{it} + \hat{\delta_2^{'}}W_{it}$$

Where $\hat{\psi},\ \hat{\xi_1^{'}},\ \hat{\xi_2^{'}},\ \hat{\delta_1^{'}},\ \hat{\delta_2^{'}}$ denote estimated values of $\psi,\ \xi_1^{'},\ \xi_2^{'},\ \delta_1^{'}\ ,\ \delta_2^{'}$ from Eq. (4).

In the second step, we turn to classical estimation of fixed effects models with an endogenous explanatory variable. Recently, Wooldridge (2015) proposed to deal with this estimation issue using a control function approach. The estimation strategy we have chosen combines a control function approach with a correlated random effect one. As explained above, this last approach controls for time-invariant unobserved heterogeneity as with fixed effects, but without encountering the incidental parameters problem, that affects fixed effect model estimation. Second, this approach can be easily combined with a control function approach, which addresses the potential endogeneity of refrigerator ownership. The control function approach is inherently an instrumental variables method. Its implementation assumes the availability of variables that do not appear in the equation to be estimated (i.e. excluded instrumental variables), and that explain the variation of the endogenous explanatory variable. The exogenous variation induced by excluded instrumental variables provides separate variation in the residuals obtained from a reduced form, which serve as control functions. By adding appropriate control functions, which are estimated in a first stage, the endogenous explanatory variable becomes appropriately exogenous in a second-stage equation. Accordingly, the control function approach enables testing the endogeneity of the explanatory variable by using a simple Hausman (1978) test. This test first can be corrected from having estimation errors coming from first-stage estimation of control functions using bootstrap techniques, and then can be easily made robust to heteroskedasticity and serial correlation in a panel data setting.

Our estimation strategy proceeds thus in two steps:

Estimate a linear probability model where X_{it} is regressed on $\hat{G_{it}}$ and Z_{it} or

$$X_{it} = \zeta_i + \theta\hat{G_{it}} + \pi^{'}Z_{it} + \omega_{it} \quad (5)$$

Compute the estimated residuals, or $\hat{\omega_{it}} =\ X_{it} - \hat{X_{it}},\ i = 1,\ldots N$ and $t = 1,\ \ldots T$, where $\hat{X_{it}}$ denotes predicted value of X_{it}.

Estimate an augmented version of Eq. (1), i.e.

$$Y_{it} = \varphi + \tau^{'}\overline{Z_i} + \beta_{it}X_{it} + \gamma^{'}Z_{it} + \rho\hat{\omega_{it}} + c_i + \vartheta_{it},\ i = 1,\ldots N,\ t = 1,\ \ldots T \quad (6)$$

Where time-averaged explanatory variables $\overline{Z_i}$ and the random term c_i come from Mundlak's modeling of fixed effect α_i, as above, and ρ measures the correlation between the residuals of Eqs. (1) and (5). Put differently, $\varepsilon_{it} =\ \rho\omega_{it} + \vartheta_{it}$ with ϑ_{it} purely random with zero mean. Testing endogeneity of X_{it} is now equivalent to testing nullity of ρ using a robust t-statistics. [1]

2. Data

2.1. The Vietnam Household Living Standards Survey (VHLSS)

This study uses the Vietnam Household Living Standards Survey (VHLSS), conducted by the General Statistics Office of Vietnam (GSO) every two years since 2002. This multi-purpose survey has been conducted in approximately 9,000 Vietnamese households. Our analysis uses the six most recent VHLSS waves: 2004 to 2014. VHLSS is a rotating panel design with 50% rotation of households. While the VHLSS 2004-2006-2008 master sample design has a-two-stage estimation approach from enumeration areas (EAs) of the 1999 Population and Housing Census of Vietnam, the master sample of VHLSS since 2010 was based on the 2009 Population and Housing Census of Vietnam. Due to these sample designs, it enables us to make two panel datasets from 2004 to 2014: between the years 2004, 2006 and 2008 and between the years 2010, 2012 and 2014 (detailed information in Appendix A).

2.2. Nutrition outcome

The VHLSS survey collects recall responses on household food consumption. This study uses various nutrition outcome indicators.

A diet diversity score (DDS) is calculated based on a count of consuming nine food groups at household level. The nine food groups are starchy staple foods, nuts and seeds, pulses, flesh foods, eggs, vegetables, fruit, dairy, and others.[2] This score is recommended for validated indicators of dietary diversity (Food and Agriculture Organization of the United Nations, 2016; World Health Organization, 2008). A higher DDS reflects a diet consisting of a greater variety of foods. Dietary diversity measures positively correlate with nutrient adequacy for individuals in both developing and developed countries (Ruel, 2003). However, the relationship between dietary diversity and food system development remains a research gap. A full table of the food types aggregated into the categories is available in Table B-1, Appendix B.

Household calorie intake expressed in kcal per day and per

[1] Estimation strategy was implemented using plm and pglm packages in R.

[2] A full table of the food items aggregated into the food groups is given in Table B-1, Appendix B.

adult equivalent for each food groups in DDS are calculated from total per capita calorie intake (PCCI). Household food consumption quantity (in Kg) is normalized into daily intake values and converted into household calories by using a calorie conversion table constructed by Vietnam National Institute of Nutrition (National Institute of Nutrition, 2013). Then, per capita calorie intake is computed as per adult equivalent calorie intake as employed by Aguiar and Hurst (2013) and Trinh et al. (2018). Per capita calorie of food types are disaggregated from per capita calorie intake. The authors refer the reader to (Zezza et al., 2017) for a useful discussion of the relative advantages and disadvantages of household expenditure surveys for measuring food consumption. While the dietary recall period employed by the VHLSS survey exceeds that of typically recommended by nutritionists, it is the most-granular household dietary data available which can be coupled with measures of household refrigeration in Vietnam. These recall periods are fairly lengthy, and introduce uncertainty into the data. As found by, Gertler et al. (2017), the longer the time period between food consumption and when the household is surveyed results in households being more likely to forget to report consumed foods and more likely to report items not actually consumed. An additional limitation is that shorter survey lists often result in consumption estimates lower than those obtained with longer lists (Pradhan, 2017). These limitations are unavoidable for this survey population, but results should be interpreted in a way which acknowledges this source of error and uncertainty introduced into the data through the survey design.

An aggregate ratio is also used to measure diet adequacy. Food groups are combined into two categories: low nutrient intake (starchy staple foods) and high nutrient intake (all other food groups). For each household, share of calorie intake coming from low nutrient (resp. high nutrient) food items, denoted by S_l (resp. S_h) is computed. Nutritional outcome is the log ratio of the two shares, i.e. $\log\frac{S_h}{S_l}$. Since $S_h = 1 - S_l$, then $\log\frac{S_h}{1-S_h}$ and the log ratio can be interpreted as log odds ratio.

2.3. Refrigerator Ownership in Vietnam

The VHLSS survey records ownership of nearly 40 durable goods for households, including refrigerator ownership. The refrigerator ownership in Vietnam is coded “Yes” if household owns a refrigerator and “No” if households does not own any refrigerators. Refrigerator ownership in Vietnam has increased recently and is robustly present in Vietnam (Table C-1, Appendix C.).

2.4. Instrumental variable

To establish the direct effect of refrigerator ownership on food consumption, we employ an instrumental variable: whether the household is receiving electricity for lighting from the national electric grid. Two criteria must be met by instrumental variables. First, they must be relevant, i.e. correlated with the endogenous explanatory variable (owning a refrigerator). The chosen variable is an appropriate instrument for refrigerator ownership as it requires reliable household electricity, much as a refrigerator does. Second, the chosen instrumental variables must be considered as exogenous. If a household is using the national electricity grid for lighting, this necessarily means that the household is living in a community with access to national grid electricity, and is using it for a very basic need: lighting. Access to a stable supply of electricity is necessary for refrigerator operation, and the household receiving electricity from the national grid establishes that refrigerator ownership is possible for the household, therefore serving as an effective instrument.

2.5. Other variables

Following many papers in the literature on diets using VHLSS, other socio-economic household variables are considered. To measure income, we use (monthly) per capita expenditure (PCE),

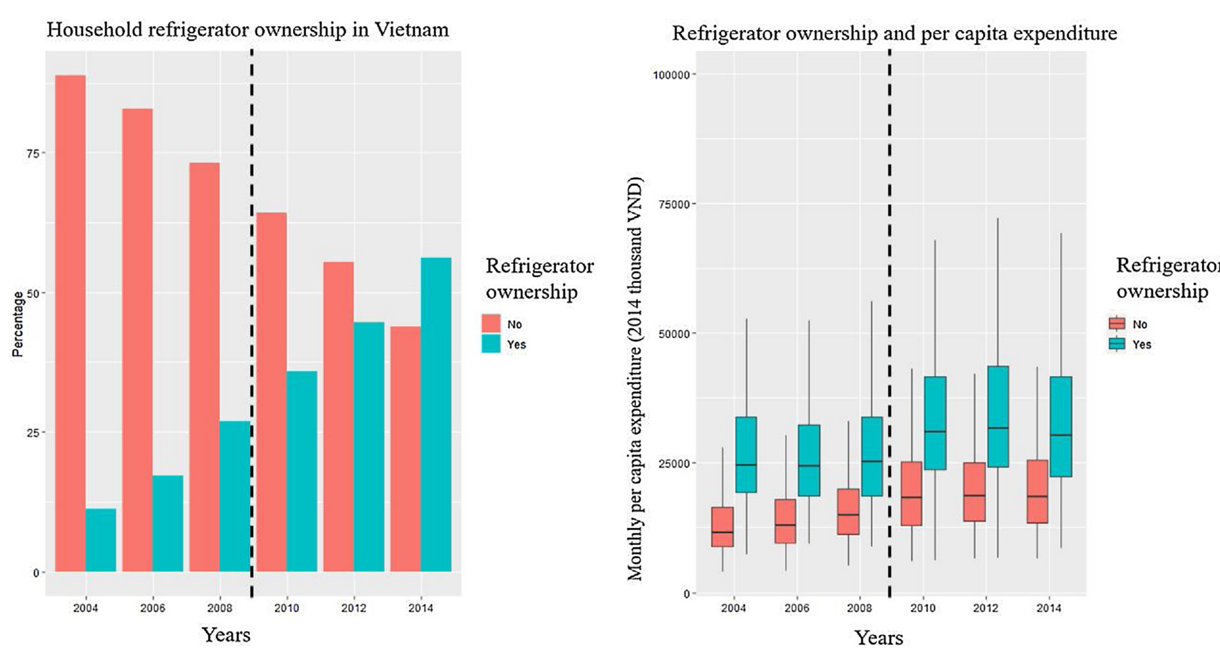

Fig. 3. Vietnamese refrigerator ownership and average per capita expenditure (PCE) over 2004-2014 as recorded by the Vietnam Household Living Standards Survey. The right plot boxes encompass the 25th and 75th percentile values of PCE per year, with the black lines extending to the extreme high and low values recorded. The horizontal black lines in the boxes indicate the median PCE value for each group per year.

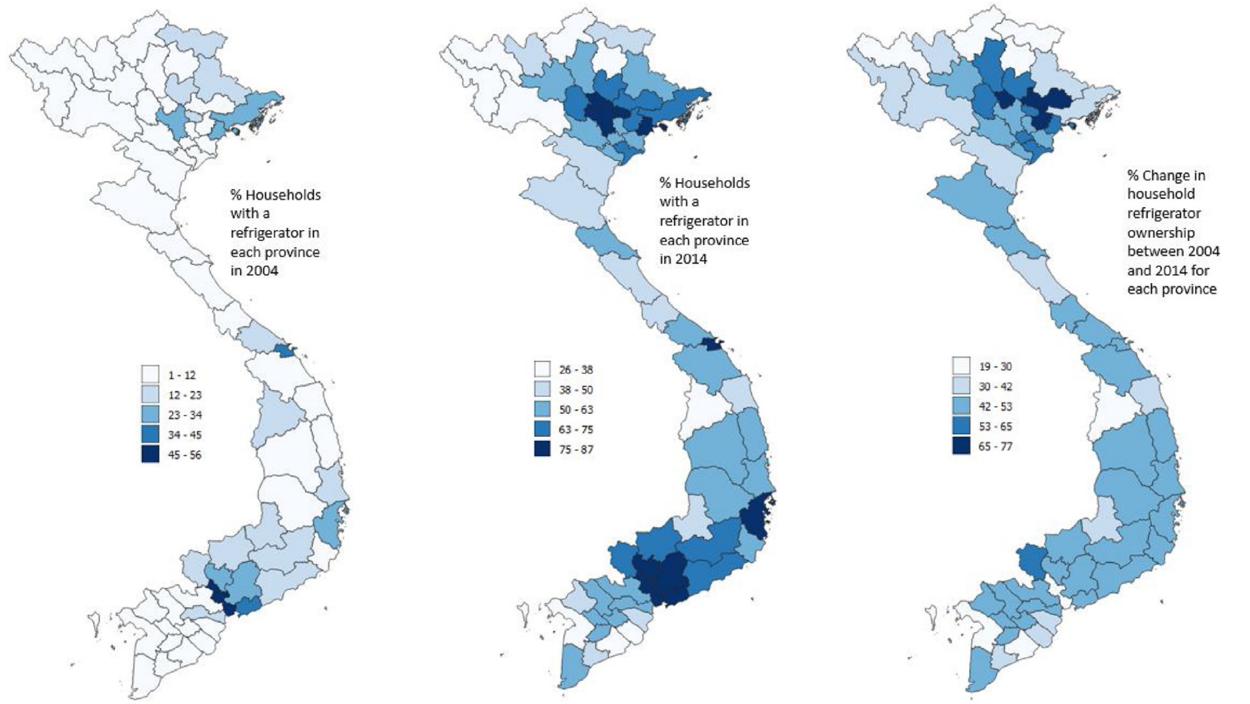

Fig. 4. Percentage of households reporting ownership of a refrigerator in the Vietnam Household Living Standards Survey. Data from the 2004 survey wave is displayed in the left-most map, 2014 data in the middle, and the percentage change between these survey waves on the right.

which has been widely employed as an appropriate proxy (Baulch and Masset, 2003; Minot et al., 2006; Trinh et al., 2018). Per capita expenditure serves as a useful income proxy as it avoids the issues of underreported income (Deaton, 1997) and income volatility (Bhalotra and Attfield, 1998). An overall income measure is studied in this analysis as it affects a household's ability to purchase both food and durable goods such as a refrigerator. This study normalizes PCE to 2014 thousand VND.[3]

The VHLSS data also contains information about sources of food consumption: including purchased goods, home-produced food, and food received in-kind. The proportion of food consumed that was purchased is the proportion of food consumed that was purchased over the total quantity of consumed food.

Control variables include URBAN: dummy variable equals 1 if the household is located in an urban area, equals 0 if not; AREA: the region where the household is located, including Red River Delta, Midlands Northern Mountains, Northern Central Coast, Central Highlands, South East, Mekong River Delta; Household size (HSIZE): less or equal to two members, three members, four members, five members, equal or more than six members; the proportion of household children under 15 years old in family; KINH: ethnicity equals 1 if the head of the household belongs to the major ethnic group of the country (Kinh for Vietnam), equal to 0 otherwise; EDUCH: the highest education level of household head, including three levels: below and equal primary school, secondary school, university; SEX: of household head, male or female; WA: if the household is located in a house with access to clean water or not. Table D-1 summarizes the main characteristics of all the variables from 2004-2014 which includes two panel data (Appendix D).

[3] Inflation rate from (The World Bank 2019).

3. Results

3.1. Increasing Refrigerator Ownership in Vietnam

Trends of Vietnamese refrigerator ownership and its relationship to average per capita expenditure over the study period are displayed in Fig. 3.

Household refrigeration has increased notably during the time period observed, with 2014 being the first year when more surveyed households owned refrigerators than did not. Average household PCE is higher among refrigerator-owning households than those households that do not own a refrigerator. However, PCE increases by 84% among both categories of households over the study period of 2004-2014.

Refrigerator ownership over the study period by province is displayed in Fig. 4. The largest growth (65-77%) in household refrigerator ownership between 2004-2014 is seen in the provinces surrounding Vietnam capital city, Hanoi, with moderate growth experienced elsewhere in the country.

Data on household refrigerator ownership in developing nations is sparse. However, for comparison, Vietnamese refrigerator ownership percentages in both 2010 and 2014 were lower than those recorded for China in both rural and urban regions (97% urban and 45% rural ownership in China compared with 60% and 28% for Vietnam in 2010; 92% urban and 78% rural Chinese ownership in 2014 compared with 80% and 51% for Vietnam) (National Bureau of Statistics of China, 2019). Additionally, using data from (USDA Economic Research Service, n.d.), Vietnamese household refrigerator ownership is recorded as larger than that for India in 2002, 2006, and 2008, and below that for Indonesia for 2002 and 2006, but exceeding Indonesian ownership rates in 2008.

Households which do not own a refrigerator consume a higher share food from their own production than households who do own a refrigerator, as illustrated in Fig. 5.

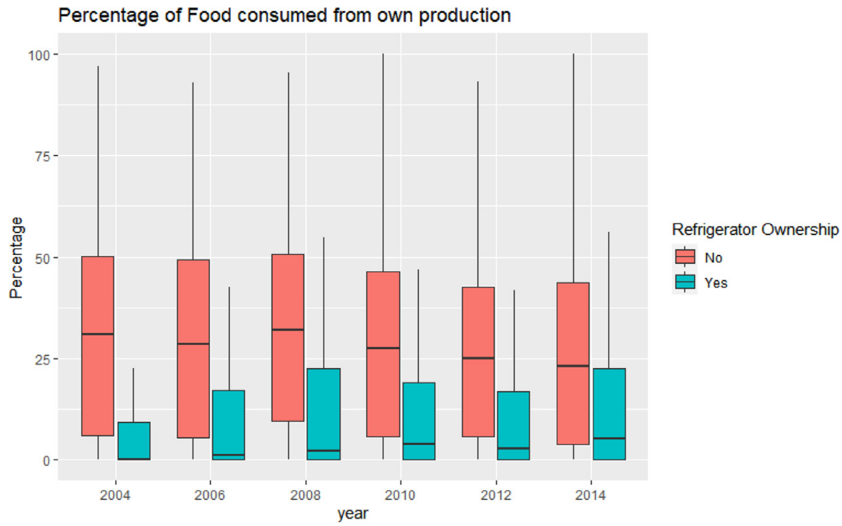

Fig. 5. Boxplots of proportions of food consumed from a household's own production.. Proportions are of the food when characterized into monetary values, and displayed for households with or without refrigerators.

The average household in the highest income quintile purchases 92% of their food over the observed years, compared with 58% for households in the lowest quintile. An average lowest quintile household produces 42% of their food consumed over the observed years, compared with 7% for an average household in the highest income quintile.

3.2. Vietnamese Dietary Change from 2004 to 2014

Changes in food consumption by Vietnamese households over the study period are displayed in Fig. 6. Starchy staple food consumption decreases 16% over the time period observed, while flesh food consumption rises 38%. Calories from "other" sources rise 98% between 2004-2014, capturing changes in calories from non-major food sources including sugars, alcohol, lard, cooking oil, among others. These food groups have the largest average consumption in kcal, with averages for the other foods examined (nuts and seeds, pulses, eggs, vegetables, fruit, and dairy) remaining below 125 kcal/day over the observation period. Average consumption by food groups and by year are in Table D-2 (Appendix D).

3.3. Household Refrigerator Ownership and Diet

Dietary Diversity Scores and theirrelationship to refrigerator ownership across time is presented in Fig. 7. There is a higher proportion of food group consumed for refrigerator-owning households across all observation periods, as compared to households that do not own refrigerators, as can be seen in shifted lines in Fig. 7 from left figure to right figure. In addition, among households owning refrigerator, there is a higher proportion of households consuming food from 5-to-8 groups in the period 2010-2014 than the period 2004-2008. However, there is an inverse trend for all households who consume up to 8 or 9 food groups. The difference may come from sample design[4] and may include increases in the consumption of the "other" food group over the observation period, as well as the influence of VHLSS food categories remaining fixed over the years, despite new foods being increasingly introduced in Vietnam through import or general increases in availability.

Percentage of consumption of low nutrient food items among households owning a refrigerator has been consistently smaller across time, compared to those not owning a refrigerator (Fig. 8; left panel). However, low nutrient food is still the predominant source for households in Vietnam: 70-75% for households not owning a refrigerator and 50-55% for households owning a refrigerator. The log ratio of share of hight nutrient over share of low nutrient food consumed, i.e $\log\frac{S_h}{S_l}$, shows an opposite effect, households owning a refrigerator showed a higher log ratio value than those that do not (Fig. 8; right panel). Interestingly, the log ratio gradually increased from 2004 to 2014, showing increased calories sourced from high nutrient foods and potential substitution between high nutrient calories and low nutrient ones.

3.3.1. Effect of refrigerator ownership on diet

The estimation strategy presented in section 2 is implemented using the two distinct panel data sets to assess the causal link between nutritional outcomes and refrigerator ownership. Table 1 shows estimation results of fixed logit model using the Mundlak (1978) correlated random error approach, only focusing on the chosen instrumental variable (the estimated values of all other coefficients are displayed in Table E-1). The instrumental variable, households using national grid electricity for main lighting, showed a significantly positive relationship with household refrigerator ownership in both panels (p-value <0.05 in the panel 2004-2008 and p-value <0.0001 in the panel 2010-2014). In addition, likelihood ratio test (LRT) confirms that the parameter associated to the instrument cannot be assumed to be equal to zero. Therefore, classical rank condition for instrumental variables is satisfied. Then, we conclude that the chosen instrument variables perform well for both panels 2004-2008 and 2010-2014.

In order to rule out correlation between the instruments and the error term, a regression examining the exogeneity of the instrument is run with the outcome on the endogenous explanatory variable and a vector of control variables (Dang et al. 2020, Wooldridge 2013). We find the correlation between the endogenous explanatory variable and the omitted factors captured by this regression's residuals to be very small, indicating that this variable is an acceptable instrument. Results of this test are displayed along with results from the full IV regression in Appendix E.

[4] The recall period as 12 months in VHLSS before 2010 and as 30 days in VHLSS since 2010.

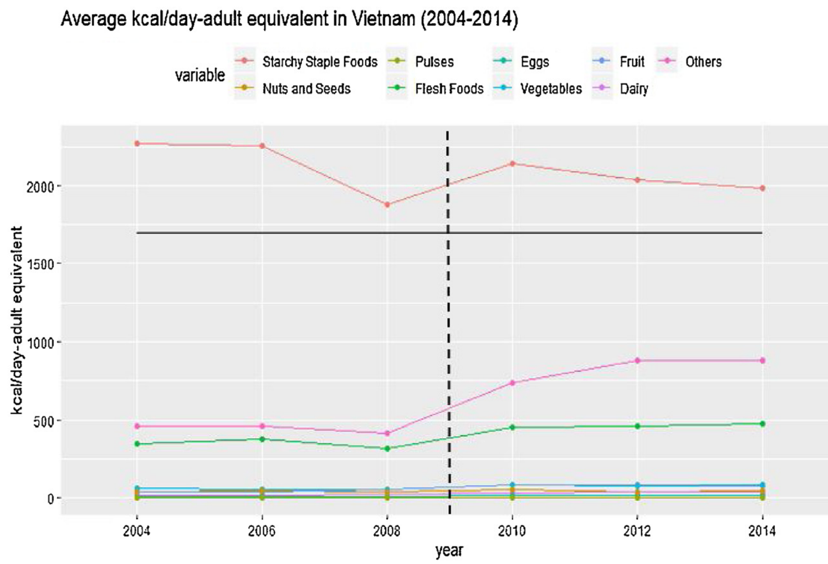

Fig. 6. Average household kcal/day per adult equivalent of food types examined as measured by the VHLSS between 2004 and 2014. A black line is defined at 1700 Kcal/Per Adult Equivalent to better-display the changes in consumption of Starchy Staple Foods in conjunction with other food categories. Results are obtained from two rotating panel in this period.

We then calculated the fitted probability of owning a refrigerator for household, denoted $\hat{G}_{it}$, and estimated the linear probability model expressing refrigerator ownership as a function of $\hat{G}_{it}$, and a vector of control variables. The estimated coefficient associated with estimated probability on the panel 2004-2008 is 0.537, with a p-value < 0.01, and the estimated coefficient on the later panel is 0.798 with a p-value < 0.01 (full estimation results are displayed in Table E-2). The residuals of this linear probability model are denoted as $\hat{\omega}$.

Finally, we estimated the augmented version of Eq. (1) (i.e. Eq. (6)), for the different nutrition outcomes, results of which are presented in Tables 2 and 3. Table 2 shows the impact of refrigerator ownership on per capita calorie intake (PCCI on the ratio between share of food from high nutrient groups and share from low nutrient food groups, and diet diversity score (DDS)). Table 3 shows the impact of owning refrigerator on per-capita calorie intake provided by different food groups. As shown in the estimation strategy section, there is potential endogeneity of

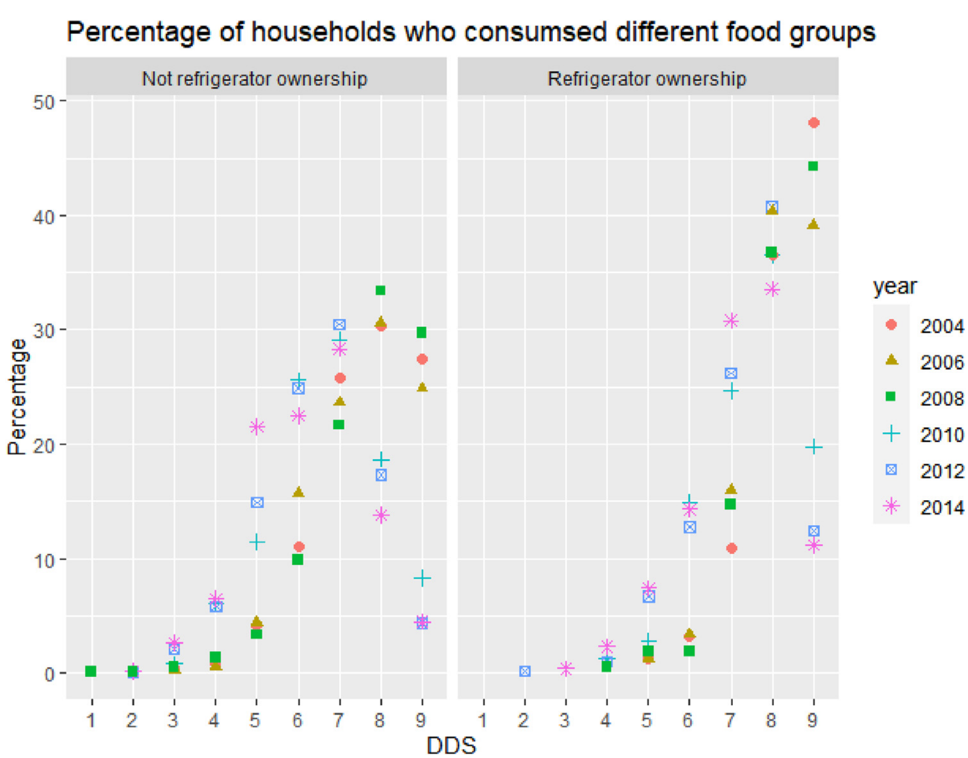

Fig. 7. Proportion of households consume different number of food group Dietary Diversity Scores (DDS, out of a maximum of 9) by year and refrigerator ownership status in VHLSS data (2004-2014).

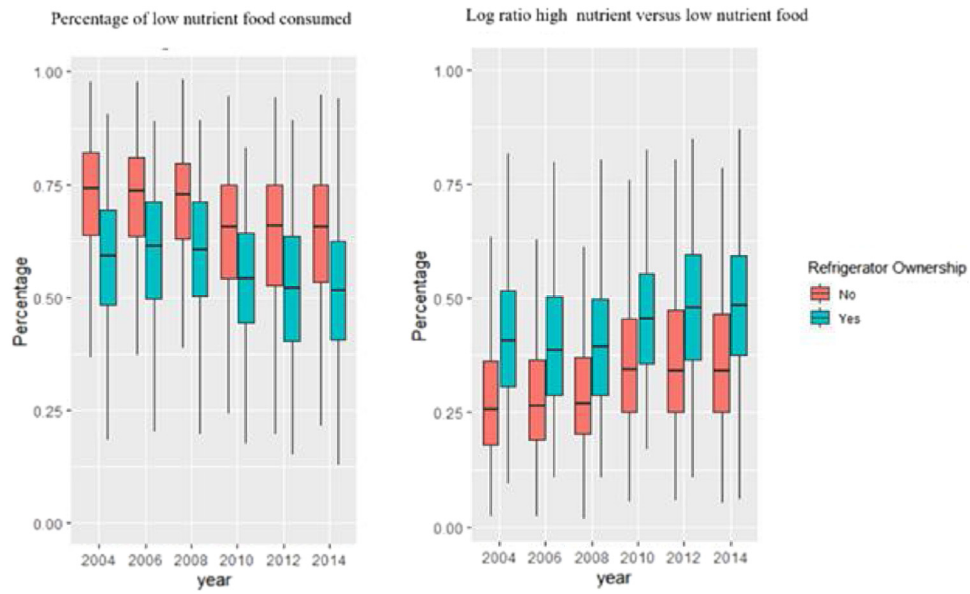

Fig. 8. The left plot displays the percentage of food consumption from low nutrient food types (the starchy staple foods category), and the right plot displays the log ratio of share of hight nutrient over share of low nutrient food consumsed, sorted by refrigerator ownership status in VHLSS (2004-2014).

Table 1
Estimation results of fixed effects logit model.

	Panel 2004-2006-2008 Coef	Panel 2010 - 2012 – 2014 Coef
Households use national grid electricity for main lighting	1.671*(0.874)	4.800 ***(1.309)
The likelihood ratio test (LRT) of the nullity of the coefficients associated with instrument	= 4.737 with p-value < 0.01	= 32.353 with p-value < 0.01

Note: *, **, and ***mean significant at 10%, and 5%, and 1% respectively. Robust standard errors are in parenthesis.

refrigerator ownership on nutrition outcomes and this issue is taken into account with inclusion of the estimated values of residuals of the linear probability model, i.e $\hat{\omega}$. Coefficient associated to $\hat{\omega}$ are significant in most of regressions in Tables 2 and 3, showing the endogeneity of owning a refrigerator. Through the use of controls, the estimated values of the effect of refrigerator ownership on the different nutrition outcomes do not suffer from any bias due to endogeneity of refrigerator ownership.

If a household owns a refrigerator, per capita calorie intake decreases significantly by 1051.65 Kcal per day per adult-

Table 2
Second step estimation results for PCCI, log(high nutrient/low nutrient) and DDS.

		Per capita calorie intake		log(highnutrient/lownutrient)		DDS	
		Panel 2004-2008	Panel 2010 – 2014	Panel 2004-2008	Panel 2010-2014	Panel 2004-2008	Panel 2010-2014
	(Intercept)	2565.066 ***	2813.269 ***	−2.471 ***	−1.901 ***	1.698 ***	1.561 ***
	Owning Refrigerator	−1051.647 ***	−386.926 **	−0.819 ***	−0.084	−0.272 ***	0.059
	The residuals of the linear probability model, $\hat{\omega}$	827.608 ***	332.577 *	0.861 ***	0.131	0.293 ***	−0.037
	Per capita expenditure (2014 thousand VND)	0.016 ***	0.026 ***	0.000 ***	0.000 ***	0.000 ***	0.000 **
	Proportion of food consumed from purchases	−90.843	−75.890	1.412 ***	0.920 ***	0.079	0.021
	Proportion of household children under 15	316.617 **	469.427 **	−0.254 **	−0.107	0.013	0.140 *
	Household in urban site	149.286 ***	188.757 ***	0.190 ***	0.084 ***	0.028	0.023
	Clean water for cooking indicator	−22.546	−50.009	−0.021	0.115 ***	0.013	0.003
Household size (ref: less than 3 members)	**Three members**	339.368 ***	330.813 ***	0.004	−0.079 **	0.054 **	0.020
	Four members	443.697 ***	422.342 ***	0.011	−0.08 **	0.092 ***	0.045 *
	Five members	439.859 ***	413.74 ***	0.015	−0.124 ***	0.116 ***	0.074 ***
	More than five members	364.486 ***	351.525 ***	−0.032	−0.169 ***	0.138 ***	0.082 ***
	Kinh (majority)	−72.061 **	43.864	0.175 ***	0.12 ***	0.067 ***	0.097 ***
	Female	−11.017	−6.585	0.075 ***	0.092 ***	0.014	0.02
Education levels (ref: below primary)	**Secondary/High school**	26.686	40.218	0.069 ***	0.032	0.027 **	0.011
	University	−127.467	44.614	0.042	0.012	0.056	−0.005

Note: *, **, and ***mean significant at 10%, 5%, and 1% respectively. Robust standard errors are in parenthesis.

Table 3
Second step estimation results for each food groups.

		Panel 2004-2008							
		Starchy Staple Foods	Dairy	Eggs	Flesh foods	Fruit	Nuts and Seeds	Pulses	Vegetables
	(Intercept)	2502.067 ***	−6.125	1.071	−8.553	4.517	38.893 ***	0.439	37.299 ***
	Owning Refrigerator	−648.04 ***	42.665 ***	−7.13 **	−335.015 ***	−53.5 ***	−71.275 ***	−3.068 **	−51.954 ***
	The residuals of the linear probability model, $\hat{\omega}$	479.59 ***	−32.409 **	7.300 ***	313.062 ***	55.212 ***	70.204 ***	3.467 **	48.803 ***
	Per capita expenditure (2014 thousand VND)	0.001	0.000 **	0.000 **	0.006 ***	0.001 ***	0.001 ***	0.000 ***	0.001 ***
	Proportion of food consumed from purchases	−848.256 ***	−3.665	3.835 **	217.149 ***	−10.612	11.698	0.452	13.098 *
	Proportion of household children under 15	329.008 ***	28.75 ***	2.495	94.539 ***	−22.877 **	4.213	1.668 *	16.881 **
	Household in urban site	−5.070	−1.241	1.523 ***	40.622 ***	1.124	7.253 **	0.335	5.243 **
	Clean water for cooking indicator	8.731	0.650	−0.090	−11.555 **	4.089 **	−3.969 **	−0.113	2.794 **
Household size (ref: less than 3 members)	**Three members**	248.336 ***	−2.473	−0.039	41.904 ***	−6.007 *	0.683	0.971 ***	0.836
	Four members	332.499 ***	−4.936 *	−0.145	57.638 ***	−8.384 ***	5.13	0.695 **	−1.636
	Five members	349.773 ***	−5.884 *	−0.857	49.55 ***	−9.487 ***	5.294	0.747 **	−5.884 *
	More than five members	328.884 ***	−5.974	−1.565 *	40.11 ***	−10 **	1.568	0.827 **	−13.411 ***
	Kinh (majority)	−138.227 ***	0.468	−0.432	−19.019 **	−0.618	3.002	−0.255	−3.347
	Female	−40.921 *	3.799 **	−0.028	0.874	0.120	4.997 **	0.043	2.068
Education levels (ref: below primary)	**Secondary/High school**	0.840	−2.848 *	1.573 ***	21.915 ***	−0.280	16.657 ***	−0.029	5.161 ***
	University	−29.468	−1.543	−0.742	6.306	−4.406	13.81 **	0.083	3.888
	Adj. R-Squared	0.260	0.111	0.081	0.225	0.078	0.076	0.008	0.058
		Panel 2010-2014							
		Starchy Staple Foods	Dairy	Eggs	Flesh foods	Fruit	Nuts and Seeds	Pulses	Vegetables
	(Intercept)	2744.176 ***	−30.759 ***	12.587 ***	221.028 ***	20.127 *	62.551 ***	1.682 **	98.025 ***
	Owning Refrigerator	−127.416	36.771 ***	−0.324	−17.808	−7.918	−11.801	1.494	−0.608
	$\hat{\omega}$	53.068	−33.737 ***	0.435	50.080	5.775	12.907	−1.369	−1.944
	Per capita expenditure (2014 thousand VND)	0.005 ***	0.001 ***	0.000 ***	0.006 ***	0.000	0.000 ***	0.000 ***	0.000
	Proportion of food consumed from purchases	−804.497 ***	12.686	−2.65	64.962 **	7.369	−0.513	−1.044	−4.308
	Proportion of household children under 15	404.094 ***	94.209 ***	9.833 ***	88.524 **	23.203	−3.514	2.71 **	14.728
	Household in urban site	14.644	3.250	2.488 ***	14.84 *	5.941	9.578 ***	0.165	12.473 ***
	Clean water for cooking indicator	−129.444 ***	−1.466	−0.252	1.988	1.776	−1.112	0.308	−3.916 *
Household size (ref: less than 3 members)	**Three members**	282.64 ***	−0.106	−0.674	16.579	−19.609 ***	−2.053	−0.240	−15.951 ***
	Four members	332.805 ***	−4.263	−2.48 ***	7.722	−25.138 ***	3.341	0.082	−28.062 ***
	Five members	359.506 ***	−0.321	−3.918 ***	−10.426	−31.801 ***	2.528	−0.250	−36.328 ***
	More than five members	362.91 ***	1.984	−5.120 ***	−19.316	−32.896 ***	−0.636	−0.232	−47.58 ***
	Kinh (majority)	−39.868	3.701	1.841 ***	−6.267	9.553 **	−0.084	−0.676 **	5.426 *
	Female	−66.894 ***	11.022 ***	1.515 ***	−2.158	7.888 **	5.215 **	−0.414	1.061
Education levels (ref: below primary)	**Secondary/High school**	−0.367	−7.672 ***	2.658 ***	24.391 ***	−9.592 **	17.695 ***	0.141	3.987
	University	−27.732	−1.577	1.625	22.516	−9.678	16.136 ***	−0.093	1.292
	Adj. R-Squared	0.239	0.135	0.083	0.241	0.091	0.063	0.011	0.072

Note: *,**, and ***mean significant at 10%, 5%, and 1% respectively. Robust standard errors are in parenthesis.

equivalent in the first panel while only by 386.93 Kcal in the second panel. For the log ratio of food from high and low nutrient groups, the coefficient is negative and significantly different from zero in 2004-2008 period. This would indicate that a household owning a refrigerator has substituted food groups with low nutrient intake (increase in the denominator) to food groups with high nutrient intake (decrease in numerator). No such effect of owning refrigerator appears in the second panel. Finally, there is a positive effect from owning refrigerator on diet diversity score in the first panel while owning refrigerator leads to a slight decrease in diet diversity score from 2010 to 2014. Household refrigerator ownership before 2010 dramatically decreased total per capita calories from food groups with high nutrient intake while, in the next period, households decreased per capita calorie intake.

We then go on to disaggregate total calorie intake from different food groups (see Table 3). The decrease in overall per capita calorie intake, shown in Table 2, mainly comes from the decrease in starchy staple foods – a low nutrient source of calories. Refrigerator ownership leads to a significant decrease in calories obtained from starchy staple foods by 648.04 Kcal in the first panel, and by 127.42 Kcal in the second panel. Interestingly, refrigerator ownership is associated with a statistically significant decrease in flesh food consumption in the first panel of 335.02 Kcal. In both panels, refrigerator ownership appears to facilitate the greater consumption of dairy products, with statistically significant increases in both panels (42.66 Kcal and 36.77 Kcal, respectively). For the first panel refrigerator ownership implies a statistically significant decrease in fruit, vegetable, and nuts and seeds consumption.

4. Discussion

At a basic level, the purpose of a refrigerator is to increase the capacity to store perishable foods. Household refrigerator ownership significantly decreases per capita calorie decreases by 1051.65 Kcal/day/adult-equivalent in the first panel and by 386.93 Kcal/day/adult-equivalent in the second panel, at a statistically significant level. Refrigerator ownership is implied to have resulted in the household substituting low nutrient food items with higher-nutrient ones, with substantial decreases in starchy staple food consumption connected with refrigerator ownership over both time periods. In both the panels, refrigerator ownership results in an increase in dairy consumption, potentially reflecting the refrigerator increasing a household's ability to store dairy products.

Refrigerator ownership in Vietnam increased over the time period studied, as did per capita expenditure and other developmental indicators. Income is connected to both the ability to own a refrigerator and dietary shifts. Owning a refrigerator is a technological pre-condition to support diets with perishable foods. While the causal linkages between refrigerator ownership and diet shifts have been identified when controlling for income, refrigerator ownership is unlikely to occur wholly independently of wealth increases. As such, refrigerator ownership influences diet, but is concurrently a necessary enabler for the influence of wealth.

Refrigerator ownership and income growth are occurring within the context of grocery retail development in Vietnam. The growth in supermarket retailing in Asia has been associated with refrigerator ownership in addition to income growth, urbanization, and other elements of development (Shepherd, 2005). Retail development typically results in more centralized food provision, realized in its fullest form as groceries of all types sold in a supermarket or hypermarket. This process of "de-fragmentation" in retail is characterized as occurring first for dry goods, then later for fresher foods (Reardon et al., 2003). Vietnamese retail sales through "modern" grocery retailers grew by 11% in 2017, though the quantity of these stores are still vastly outnumbered by traditional retailers (Vo and Francic, 2017) and with 77%–99% of food expenditures by urban consumers still occurring at traditional outlets (The Centre for Global Food and Resources, 2018a). Supermarket shopping in Vietnam is stratified by income, with lower-income consumers found to be purchasing less from supermarkets, and more from a diversity of outlets (both formal and informal), considering factors including accessibility, the ability to purchase on credit, and prices (Figuié and Moustier, 2009). Supermarket purchasing has been found to be highly income-elastic, with income playing a stronger role in influencing fruit and vegetables purchases at a supermarket than price or supermarket penetration in Vietnam (Mergenthaler et al., 2009).

Interestingly, this analysis does not find a link between refrigerator ownership and increases flesh foods consumption, with the first panel finding a statistically significant decrease. Notable increases in meat consumption in Vietnam have been recorded (Heller et al., 2019) and has been characterized as part of the "meatification" of the Vietnamese food system (Hansen, 2018), though it appears that household refrigeration does not play a role in this transformation. Hansen (2018) does ascribe increasing meat consumption resulting from broader systemic changes in the food system: encompassing the intensification of production systems, addition of more meat to traditional meals, changes in consumption patterns for food, as well as the role of meat as a socio-economic status symbol.

In health outcomes, a trend towards higher body mass index values for children connected with increased household food expenditures at supermarkets may be emerging (The Centre for Global Food and Resources, 2018b), which in the context of Vietnam may lead to a situation where parts of the population are overweight, with other portions of the population undernourished (Khan and Ha, 2008).

The availability of refrigerators has implications for nutrition and sustainability outcomes. Concurrent and pressing challenges from malnutrition and health burdens, climate change and environmental pressures, in addition to socio-economic and cultural inequities motivate a broader consideration of diet in the context of sustainability. The interdependencies between these considerations motivate the concept of a sustainable diet (Johnston et al., 2014). Analyses of these interconnected relationships in Vietnam is an essential task for future research. Integrated metrics assessing these dimensions of dietary transitions provides an opportunity to assess the multi-faceted elements of sustainable diets (Jones et al., 2016).

There are particular research gaps related to refrigeration's effects on nutrition and food system development (Heard and Miller, 2016). Topics explored in this analysis but still in need of further study include both the influence of refrigeration and wealth in isolation, as well as their interactions and interdependencies. Additionally, the cultural practices of food storage, and whether certain foods such as eggs, fruits, and vegetables are stores in refrigerators in some food contexts will influence the role that household refrigerator ownership has in determining dietary outcomes. Research addressing the relationship between refrigeration and infrastructure such as the electricity grid and transportation networks is also needed. Finally, culture and tradition must not be overlooked when assessing diet shifts, development, and the use of technology. The practice of shopping for fruits and vegetables on a regular basis from informal vendors (Maruyama and Trung, 2007; The Centre for Global Food and Resources, 2018a) may explain the lack of a statistically significant casual linkages between refrigeration and fruits and vegetables. This study's findings provide some insights into refrigerator ownership's connection with diet, but this topic remains in need of continuing research.

Declaration of Competing Interest

The authors report no declarations of interest.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.ehb.2020.100930.

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