Food Prices and Cognitive Development in the United States: Evidence from the 1850–1930 Data

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Abstract: This paper investigates the impact of food prices on children's cognitive development by exploiting historical price and census data in the mid to late 19th century and early 20th century United States. I explicitly model the relationships among food prices, nutrition, and cognitive development for both non-farm and farm households and use the model to motivate my empirical strategy. My empirical results confirm that there exist statistically significant differences between the two types of households in terms of the partial effects of food prices on children's cognitive development. Using the preferred specification of this paper, I find that on average, a 1% increase in food price level reduces children's probability of literacy by 0.44% for non-farm households and 0.37% for farm households; the average food price effect for farm households is 5/6 of that for non-farm households, after controlling for nonfood prices, household wages, demographic characteristics, household environments, and agricultural production inputs. These results send an important message to policymakers who want to address childhood nutrition and cognitive skill issues in developing countries—policy prescriptions need to take the population composition into consideration.

Key words: food prices, cognitive development, historical censuses

JEL codes: D13, N31, Q11

1 Introduction

A number of studies on the micro and meso levels suggest that exposure to malnutrition during childhood has detrimental effects on cognitive ability and later-life socioeconomic outcomes. Evidence is strong in observational and experimental settings, as well as in developed and developing countries (Glewwe, Jacoby, and King, 2001; Alderman, Hoddinott, and Kinsey, 2006; Chen and Zhou, 2007; Maluccio et al., 2009; Hoddinott et al., 2013; Ampaabeng and Tan, 2013). On the macro level, Baten, Crayen, and Voth (2014) used historical censuses in conjunction with food price data to examine the impact of food availability on cognitive ability and occupational outcomes in industrializing Britain, 1780–1850. Their empirical evidence supports the hypothesis that food shortages during the Napoleonic wars caused numeracy to decline, which was then translated into occupations that yielded lower income. Their study implies that the economic costs associated with childhood malnutrition could be substantial.

Policy-wise, the transaction costs of identifying families with children who are stricken by malnutrition are high, making it difficult to provide them with access to large-scale intervention programs. For this reason, it is tempting for economists and policy analysts to recommend a "cost-effective" policy that simply stabilizes food prices at a certain level. Nevertheless, policymakers may be cautious of the complicated welfare implications of food prices in the context of nutrition and cognitive development. They may want to take into account the distinct food price effects faced by agricultural and urban households. This is particularly pertinent in developing countries, where much of the labor force is still in the agricultural sector, and nutrition shortages during childhood are mostly likely to occur due to the high proportion of low-income families in those countries.

By exploiting historical food price and census data in the mid to late 19th century and early 20th century United States, this paper investigates the impact of food prices on children's cognitive development. In particular, the sample period I choose concerns farm-related households in the economy—whereas today there are only less than 1 percent of the U.S. labor force working in agriculture, the representation was much higher during mid to late 19th century and early 20th century, ranging from 64 percent to 21 percent (Spielmaker, 2014).

Unlike Baten, Crayen, and Voth (2014), who took food prices only as an indicator of food availability, I draw upon economic theory to motivate the subsequent empirical exercises. By explicitly modeling the relationships among food prices, nutrition, and cognitive development for both non-farm and farm households, this paper clarifies the food price effects as well as delivers better interpretations of the estimates to policymakers who want to address childhood nutrition and cognitive skill issues in developing countries.

As a preview, my empirical results confirm that there exist statistically significant differences between farm and non-farm households in terms of the partial effects of food prices on children's cognitive development. Using the preferred specification of this paper, I find that on average, a 1% increase in food price level reduces children's probability of literacy by 0.44% for non-farm households and 0.37% for farm households. The average food price effect for farm households is 5/6 of that for non-farm households, after controlling for nonfood prices, household wages, demographic characteristics, household environments, and agricultural production inputs.

The organization of the rest of this paper is as follows. Section 2 presents the economic model and the empirically testable implications from the model. Section 3 deals with the empirical strategy: the econometric model, measurement issues, and estimation methods. Section 4 describes the data and summary statistics. Section 5 discusses my results and their limitations. Section 6 concludes.

2 The Model

I provide a simple model to characterize a representative household's decision-making process in the context of developing children's cognitive skills. Suppose there are two individuals in the household: one parent or adult (denoted by p) and one child (denoted by k). The household consumes two goods: food and nonfood. The household's utility function is given by

$$u = u\left(c_f^p, c_f^k, l^p, c_{nf}^p, c_{nf}^k, d^k\right),$$

where c_f^p and c_f^k are respectively, the adult's and the child's consumption of food; l^p is the adult's leisure; c_{nf}^p and c_{nf}^k are respectively, the adult's and the child's consumption of nonfood; d^k is the child's cognitive development.

Following the cognitive skill production literature (López Bóo, 2009), I model the production of cognitive development as a continuously differentiable function $d(\cdot)$, such that

$$d^k = \delta\left(e\left(c_f^k\right), z\right) = d\left(c_f^k, z\right),$$

where z is an exogenous vector of the child's demographic characteristics and household environments. Note that the biological process $e(\cdot)$ that converts the child's food consumption into nutrients necessary for cognitive development is embedded in the cognitive development production function.

Let p_f and p_{nf} be, respectively, prices of food and nonfood; let w^p be the adult's market wage; let T be the endowment of human time per decision period, assumed to be identical in every household. I follow the classical approach of modeling household agricultural production by assuming that production and consumption decisions are separable (Singh, Squire, and Strauss, 1986). The household has an agricultural production function for the food item, given by

$$Q = q(L, a),$$

where L is total labor input, and a is a vector of other inputs such as land and livestock. Notice that the household will hire additional labor if $L > T - l^p$.

The following technical assumptions are maintained throughout the rest of this paper for tractability. (Subscripts on u, d, and q denote partial derivatives.)

Assumption 1. *The utility function is twice continuously differentiable with $u_v > 0$ and $u_{vv} < 0$ for each component $v \in \left\{c_f^p, c_f^k, l^p, c_{nf}^p, c_{nf}^k, d^k\right\}$, and exhibits weak separability among c_f^p, l^p, c_{nf}^p, c_{nf}^k and $\left\{c_f^k, d^k\right\}$.*

Assumption 2. *The cognitive development production function d is twice continuously differentiable with $d_{c_f^k} > 0$ and $d_{c_f^k c_f^k} < 0$.*

Assumption 3. *The agricultural production function is twice continuously differentiable with $q_v > 0$ and $q_{vv} < 0$ for each component $v \in \{L, a\}$.*

The household makes agricultural production and household consumption decisions in separate steps. Given the quantities of other inputs, the household first solves

$$\max_{L} \qquad p_f q\left(L, a\right) - w^p L.$$

For an interior solution L^* to the production problem, the first order condition is

$$q_L\left(L^*, a\right) = \frac{w^p}{p_f} \implies L^* = L\left(\frac{w^p}{p_f}, a\right).$$

Thus, L^* is independent of the household's labor supply, consumption, and hence cognitive development decisions. Now, define the farm profit as

$$\pi^* = \pi\left(p_f, w^p, L^*, a\right) = p_f q\left(L^*, a\right) - w^p L^*.$$

Notice that if the household is of the non-farm type, then $\pi^* \equiv 0$. The household then solves

$$\begin{aligned}
\max_{c_f^p, c_f^k, l^p, c_{nf}^p, c_{nf}^k, d^k} \qquad & u\left(c_f^p, c_f^k, l^p, c_{nf}^p, c_{nf}^k, d^k\right), \\
\text{s.t.} \qquad & d^k = d\left(c_f^k, z\right), \\
& p_f\left(c_f^p + c_f^k\right) + w^p l^p + p_{nf}\left(c_{nf}^p + c_{nf}^k\right) = w^p T + \pi^*,
\end{aligned}$$

where the second constraint is the Beckerian full-income constraint.

The Lagrangian for the household's utility maximization problem is

$$\mathcal{L} = u\left(c_f^p, c_f^k, c_{nf}^p, c_{nf}^k, l^p, d^k\right) + \lambda\left[d\left(c_f^k, z\right) - d^k\right] + \mu\left[w^p T + \pi^* - p_f\left(c_f^p + c_f^k\right) - w^p l^p - p_{nf}\left(c_{nf}^p + c_{nf}^k\right)\right],$$

where λ and μ are Lagrange multipliers. For an interior solution $\left(c_f^{p*}, c_f^{k*}, l^{p*}, c_{nf}^{p*}, c_{nf}^{k*}, d^{k*}\right)$ to the above problem, the first-order conditions are

$$u_{c_f^p}\left(c_f^{p*}\right) = \mu p_f, \tag{1}$$

$$u_{c_f^k}\left(c_f^{k*}\right) + \lambda d_{c_f^k}\left(c_f^{k*}, z\right) = \mu p_f, \tag{2}$$

$$u_{l^p}\left(l^{p*}\right) = \mu w^p, \tag{3}$$

$$u_{c_{nf}^p}\left(c_{nf}^{p*}\right) = \mu p_{nf}, \tag{4}$$

$$u_{c_{nf}^k}\left(c_{nf}^{k*}\right) = \mu p_{nf}, \tag{5}$$

$$u_{d^k}\left(d^{k*}\right) = \lambda, \tag{6}$$

$$d^{k*} = d\left(c_f^{k*}, z\right), \tag{7}$$

$$p_f\left(c_f^{p*} + c_f^{k*}\right) + w^p l^{p*} + p_{nf}\left(c_{nf}^{p*} + c_{nf}^{k*}\right) = w^p T + \pi^*. \tag{8}$$

Equations (1) and (2) imply

$$u_{c_f^p}\left(c_f^{p*}\right) = u_{c_f^k}\left(c_f^{k*}\right) + \lambda d_{c_f^k}\left(c_f^{k*}, z\right). \tag{9}$$

Equations (1), (3), (4), and (5) imply

$$u_{l^p}\left(l^{p*}\right) = \frac{w^p}{p_f} u_{c_f^p}\left(c_f^{p*}\right) \implies l^{p*} = u_{l^p}^{-1}\left(\frac{w^p}{p_f} u_{c_f^p}\left(c_f^{p*}\right)\right), \tag{10}$$

$$u_{c_{nf}^p}\left(c_{nf}^{p*}\right) = \frac{p_{nf}}{p_f} u_{c_f^p}\left(c_f^{p*}\right) \implies c_{nf}^{p*} = u_{c_{nf}^p}^{-1}\left(\frac{p_{nf}}{p_f} u_{c_f^p}\left(c_f^{p*}\right)\right), \tag{11}$$

$$u_{c_{nf}^k}\left(c_{nf}^{k*}\right) = \frac{p_{nf}}{p_f} u_{c_f^p}\left(c_f^{p*}\right) \implies c_{nf}^{k*} = u_{c_{nf}^k}^{-1}\left(\frac{p_{nf}}{p_f} u_{c_f^p}\left(c_f^{p*}\right)\right). \tag{12}$$

Equations (6), (7), and (9) imply

$$u_{c_f^p}\left(c_f^{p*}\right) = u_{c_f^k}\left(c_f^{k*}\right) + u_{d^k}\left(d\left(c_f^{k*}, z\right)\right) d_{c_f^k}\left(c_f^{k*}, z\right) \tag{13}$$

$$\implies c_f^{p*} = u_{c_f^p}^{-1}\left(u_{c_f^k}\left(c_f^{k*}\right) + u_{d^k}\left(d\left(c_f^{k*}, z\right)\right) d_{c_f^k}\left(c_f^{k*}, z\right)\right). \tag{14}$$

Equations (8), (10), (11), and (12) imply

$$p_f\left(c_f^{p*} + c_f^{k*}\right) + w^p u_{l^p}^{-1}\left(\frac{w^p}{p_f} u_{c_f^p}\left(c_f^{p*}\right)\right) + p_{nf}\left[u_{c_{nf}^p}^{-1}\left(\frac{p_{nf}}{p_f} u_{c_f^p}\left(c_f^{p*}\right)\right) + u_{c_{nf}^k}^{-1}\left(\frac{p_{nf}}{p_f} u_{c_f^p}\left(c_f^{p*}\right)\right)\right] = w^p T + \pi^*. \tag{15}$$

Equations (13), (14), and (15) imply

$$\begin{aligned}
&\left[u_{c_f^p}^{-1}\left(u_{c_f^k}\left(c_f^{k*}\right) + u_{d^k}\left(d\left(c_f^{k*}, z\right)\right) d_{c_f^k}\left(c_f^{k*}, z\right)\right) + c_f^{k*}\right] \\
&\quad + \frac{w^p}{p_f}\left[u_{l^p}^{-1}\left(\frac{w^p}{p_f}\left[u_{c_f^k}\left(c_f^{k*}\right) + u_{d^k}\left(d\left(c_f^{k*}, z\right)\right) d_{c_f^k}\left(c_f^{k*}, z\right)\right]\right)\right] \\
&\quad + \frac{p_{nf}}{p_f}\left[u_{c_{nf}^p}^{-1}\left(\frac{p_{nf}}{p_f}\left[u_{c_f^k}\left(c_f^{k*}\right) + u_{d^k}\left(d\left(c_f^{k*}, z\right)\right) d_{c_f^k}\left(c_f^{k*}, z\right)\right]\right)\right] \\
&\quad + \frac{p_{nf}}{p_f}\left[u_{c_{nf}^k}^{-1}\left(\frac{p_{nf}}{p_f}\left[u_{c_f^k}\left(c_f^{k*}\right) + u_{d^k}\left(d\left(c_f^{k*}, z\right)\right) d_{c_f^k}\left(c_f^{k*}, z\right)\right]\right)\right] \\
&\qquad = \frac{w^p}{p_f} T + \frac{\pi^*}{p_f}.
\end{aligned}$$

Thus, c_f^{k*} is implicitly defined in the following form, after normalizing $T = 1$:

$$c_f^{k*} = c_f^k\left(\frac{w^p}{p_f}, \frac{p_{nf}}{p_f}, \frac{\pi^*}{p_f}, z\right)$$

$$\implies d^{k*} = d\left(c_f^{k*}, z\right) = d^k\left(\frac{w^p}{p_f}, \frac{p_{nf}}{p_f}, \frac{\pi^*}{p_f}, z\right), \tag{16}$$

as long as local invertibility is satisfied. The impact of a food price change on the child's cognitive development is summarized in the following comparative statics:

Proposition 1. *If the household is a non-farm household (i.e. $\pi^* = 0$), then the partial effect of a food price change on the child's cognitive development is negative.*

Proof. Suppose not, so $\partial d^{k*}/\partial p_f \geq 0$, then $\partial c_f^{k*}/\partial p_f \geq 0$. Notice that there exists adult-child food consumption tracking, i.e. $\partial c_f^{p*}/\partial c_f^{k*} > 0$ by Equation (14), which is implied from the monotonicity properties stated in Assumptions 1 and 2. This implies that Equation (15) will be violated, which is a contradiction. □

Proposition 2. *If the household is a farm household (i.e. $\pi^* > 0$), then the partial effect of a food price change on the child's cognitive development is less negative than what would have been if the household is of the non-farm type. In fact, the direction of this effect could be negative, zero, or positive.*

Proof. Let $\eta < 0$ be the partial effect of a food price change on the child's cognitive development for the non-farm household. Differentiating Equation (16) with respect to p_f yields

$$\frac{\partial d^{k*}}{\partial p_f} = \underbrace{\frac{\partial d^k}{\partial \left(w^p/p_f\right)} \frac{\partial \left(w^p/p_f\right)}{\partial p_f} + \frac{\partial d^k}{\partial \left(p_{nf}/p_f\right)} \frac{\partial \left(p_{nf}/p_f\right)}{\partial p_f}}_{=\eta} + \underbrace{\frac{\partial d^k}{\partial \left(\pi^*/p_f\right)}}_{>0} \underbrace{\frac{\partial \left(\pi^*/p_f\right)}{\partial p_f}}_{>0}.$$

To see that the last part is positive, note that

$$\begin{aligned}\frac{\partial \left(\pi^*/p_f\right)}{\partial p_f} &= \frac{\partial q}{\partial L} \frac{\partial L}{\partial \left(w^p/p_f\right)} \frac{\partial \left(w^p/p_f\right)}{\partial p_f} - \frac{\partial \left(w^p/p_f\right)}{\partial p_f} L\left(\frac{w^p}{p_f}, a\right) - \frac{w^p}{p_f} \frac{\partial L}{\partial \left(w^p/p_f\right)} \frac{\partial \left(w^p/p_f\right)}{\partial p_f} \\ &= \underbrace{\frac{\partial \left(w^p/p_f\right)}{\partial p_f}}_{<0} \underbrace{\left[\frac{\partial L}{\partial \left(w^p/p_f\right)} \underbrace{\left(\frac{\partial q}{\partial L} - \frac{w^p}{p_f}\right)}_{=0} - \underbrace{L\left(\frac{w^p}{p_f}, a\right)}_{>0} \right]}_{<0},\end{aligned}$$

using the fact that $\frac{\pi^*}{p_f} = q\left(L^*, a\right) - \frac{w^p}{p_f} L^* = q\left(L\left(\frac{w^p}{p_f}, a\right), a\right) - \frac{w^p}{p_f} L\left(\frac{w^p}{p_f}, a\right)$. □

3 The Empirical Strategy

This section links my economic model to empirical evidence. Let d^* denote the empirically measurable outcome of cognitive development. I assume that the variables of interest follow a linear additive relationship:

$$d^* = (\beta_0 + \beta_1 s) + (\beta_2 + \beta_3 s) \ln p_f + (\beta_4 + \beta_5 s) \ln w^p + (\beta_6 + \beta_7 s) \ln p_{nf} + z' \beta_z + a' \beta_a + \varepsilon,$$

where s is an indicator of childhood farm status, with $s = 1$ for farm households, and $s = 0$ otherwise. For flexibility and ease of interpretation, I have applied the natural log transformation to every continuous variable. Here, the β's are coefficients to be estimated, and ε denotes some probabilistic error attached to the functional relationship. The covariates z' and a' may also include interaction terms with s. Given my propositions in the previous section, I propose the following testable hypotheses associated with the econometric model: (1) $\beta_2 < 0$; and (2) $\beta_3 > 0$. Note that by restricting $\beta_2 = -\beta_4 - \beta_6$ and $\beta_3 = -\beta_5 - \beta_7$, the above equation can be represented by relative prices only:

$$d^* = (\beta_0 + \beta_1 s) + (\beta_4 + \beta_5 s) \ln\left(\frac{w^p}{p_f}\right) + (\beta_6 + \beta_7 s) \ln\left(\frac{p_{nf}}{p_f}\right) + z'\beta_z + a'\beta_a + \varepsilon,$$

which is in line with my economic model implications.

Following the literature, I assume that cognitive skills are solidified by the first decade after birth, and remain stable throughout adult life (Heckman, 2013; Ampaabeng and Tan, 2013). More specifically, let $d^*_{i,t+\tau}$ be the outcome of cognitive development for individual i born in decade t; $d^*_{i,t+\tau}$ is measured only after the individual enters his/her second decade of life, i.e. during decade $t + \tau$, for $\tau = 1, 2, \ldots$; the relationship of interest is summarized as

$$d^*_{i,t+\tau} = x'_{i,t}\beta + \varepsilon_{i,t+\tau}, \tag{17}$$

where $x'_{i,t}$ is a vector with the first element equal to unity; $x'_{i,t}$ is measured during decade t, i.e. before individual i reaches the age of ten. Since direct measures of $d^*_{i,t+\tau}$ are usually not available in historical data, my goal is to show that some other approaches can be used to estimate the above coefficients.

A'Hearn, Baten, and Crayen (2009) and Baten, Crayen, and Voth (2014) considered age heaping as a proxy for one specific but important aspect of cognitive development, namely numeracy. Age heaping means that a person tends to round his/her age to the nearest 10 or 5, presumably because he/she is not numerate enough to infer his/her true age from year-related information. However, A'Hearn, Delfino, and Nuvolari (2016) have recently shown that age heaping is "most plausibly interpreted as a broad indicator of cultural and institutional modernization rather than a measure of cognitive skills". Thus, I take a more conservative approach by utilizing the information on literacy, which is available in the U.S. census data. While literacy may be affected by both childhood cognitive development and education quality, it is nevertheless a good proxy for cognitive skills (Kerckhoff, Raudenbush, and Glennie, 2001; Maddox, 2009).

Literacy is a binary variable that indicates a person's ability to both read and write. Let $d_{i,t+\tau} = 1$ if individual i born in decade t is literate in decade $t + \tau$, and $d_{i,t+\tau} = 0$ otherwise. A person is literate if he/she reaches a certain threshold level in terms of cognitive development.

Without loss of generality, I assume this threshold to be zero. Consequently, I observe $d_{i,t+\tau} = 1$ (literate) if and only if $d^*_{i,t+\tau} > 0$, and $d_{i,t+\tau} = 0$ (not literate) otherwise. Therefore, the conditional distribution

$$\begin{aligned}
\Pr\left(d_{i,t+\tau} = 1 \mid x'_{i,t}\right) &= \Pr\left(d^*_{i,t+\tau} > 0 \mid x'_{i,t}\right) \\
&= \Pr\left(x'_{i,t}\beta + \varepsilon_{i,t+\tau} > 0 \mid x'_{i,t}\right) \\
&= \Pr\left(-\varepsilon_{i,t+\tau} \leq x'_{i,t}\beta \mid x'_{i,t}\right) \\
&= F\left(x'_{i,t}\beta\right),
\end{aligned}$$

where $F(\cdot)$ denotes the cumulative distribution function of $-\varepsilon_{i,t+\tau}$.

Depending on the binary outcome model of interest, F can be a standard logistic distribution, a standard normal distribution, or some other distributions. As a result, I can get consistent estimates for β by maximum likelihood techniques. Alternatively, I can estimate β from the regression function

$$d_{i,t+\tau} = x'_{i,t}\beta + \varepsilon_{i,t+\tau},$$

which provides the best linear approximation to the conditional distribution/expectation above. This is the very popular linear probability model, which is inconsistent in terms of estimates, but has otherwise desirable properties such as protection against arbitrary forms of heteroskedasticity (Angrist and Pischke, 2008).

4 The Data

The empirical part of this paper relies on three sources of data. The first source is the published figures of the United States Censuses (1850, 1860, 1870, and 1880) in relation to agriculture, made available by the Integrated Public Use Microdata Series National Historical Geographic Information System (IPUMS-NHGIS) project (Minnesota Population Center, 2016). The second source is the seven linked representative samples (1850/1880, 1860/1880, 1870/1880, 1880/1900, 1880/1910, 1880/1920, and 1880/1930) provided by the IPUMS-USA project (Ruggles et al., 2015), also hosted at the Minnesota Population Center. The linked dataset is derived from the 1% samples of the 1850 to 1930 United States Censuses. The third source is the price data from one of the publications of the National Bureau of Economic Research (NBER).

Each linked observation in the dataset contains information from two censuses. Based on the information reported in the earlier census, I first identify individuals by census year, household number, and person number in the household. I then organize individuals by birth decade and household farm status in the first decade of life. The IPUMS-USA records three categories of household farm status: no answer, non-farm, and farm. The number of individuals/households without any answer is very small, so I exclude them from the analysis. The birth decade information is derived from birth year. Since there is no available birth year information in the earlier census, I calculate the birth year for each record by subtracting the earlier age from the corresponding census year.

By definition, household farm status in the first decade of life is observable for people whose ages were between 0 and 9 in the earlier census, so only these individuals are counted in my sample (except when other household members' information is adopted to construct variables related to demographic characteristics and household environments). I also exclude those observations that are missing literacy in the later census from the rest of the empirical analysis. Table 1 shows the relationship among census years, birth decades, and age groups implied from the earlier census.

Table 1: Relationship among census years, birth decades, and (implied) age groups

Census years	Birth decades			
	1841–1850	1851–1860	1861–1870	1871–1880
1850	0–9			
1860		0–9		
1870			0–9	
1880	30–39	20–29	10–19	0–9
1890				
1900				20–29
1910				30–39
1920				40–49
1930				50–59
N	3239	8864	29979	39387

My outcome variable ($d_{i,t+\tau}$) is based upon the reported literacy in the later census. This is in accordance with the aforementioned assumption that cognitive development is measured only after a child enters his/her second decade of life. The IPUMS-USA project subdivides literacy into four categories: (1) no, illiterate (cannot read nor write); (2) cannot read, can write; (3) cannot write, can read; and (4) yes, literate (reads and writes). However, data on categories (2) and (3) are not available in the 1930 census. Therefore, I let $d_{i,t+\tau} = 0$ if an individual belongs to the first three categories, and $d_{i,t+\tau} = 1$ if he/she belongs to the last category.

The household wage level during a sample individual's childhood is computed by summing up the wages of all members of the household where that individual resides in the earlier census. Specifically, for every earner in each related household, I use the wage data compatible with his/her occupation, as recorded in the occupational income score variable[1], from the linked samples. The IPUMS-USA reports the values of this variable in hundreds of 1950 dollars, so I convert them back into dollar amounts in corresponding census years according to the overall price level (CPI) estimate table disseminated by the Federal Reserve Bank of Minneapolis[2]. Since an occupational income score of zero is assigned to unpaid family workers (e.g. stay-at-home parents) in the dataset, I assume that the services they produce are consumed immediately, and that the household decisions and the budget constraints are not affected.

The NBER food and nonfood price levels are from the work by Hoover (1960). I take the 1851–1880 national retail price indexes and convert them into dollar amounts based on the 1875 family expenditure values. I match this series to the dataset by the nearest year to each census year. The demographic and household background information includes birth year, foreign birth, illiterate parent, sex, race, Hispanic origin, disability, number of household members, number of children in the household, and census region[3]. The agricultural production input information are census year- and state-specific average numbers of livestock and acres per farm, made available by the IPUMS-NHGIS project. Table 2 shows the summary statistics of all variables in my sample, grouped by childhood farm status.

5 Results and Discussion

5.1 The model estimation

Before I present the main results, it is important to gain some preliminary insight into the empirical relationship between the key variables of interest. Figure 1 shows the semi-parametric estimation[4] of the probability of literacy as a function of real household wages in terms of food prices. For non-farm households, the estimated function is largely increasing, while for farm households, it is slightly decreasing. Analogous to my economic model prediction, how relative wages/prices correlate with literacy depends on the type of household a person lives in during childhood. In this sense, Figure 1 provides a suggestive perspective of the results that may follow.

[1] See the official IPUMS-USA documents for details about this variable.

[2] See https://www.minneapolisfed.org/community/teaching-aids/cpi-calculator-information for details.

[3] Base region: Northeast.

[4] A local linear regression is estimated using kernel-weighted local polynomial smoothing, and the confidence interval endpoints are approximated via a logit transformation. Nichols (2008) has provided technical details.

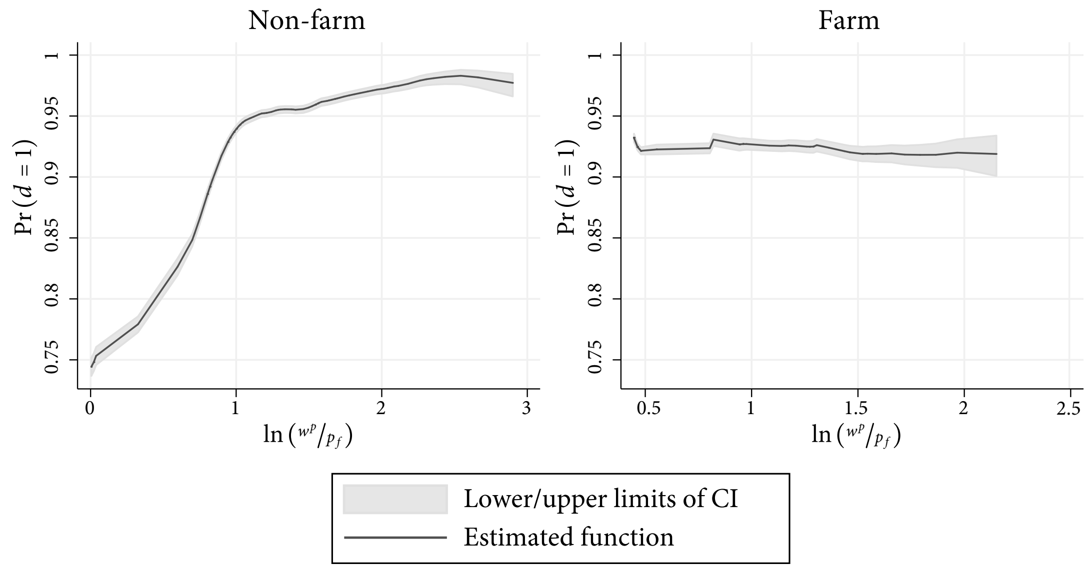

Figure 1: Semi-parametric estimation of $\Pr\left(d = 1\right)$ as a function of $\ln\left({}^{w^p}/_{p_f}\right)$

Table 3 reports the OLS estimates for three specifications of the linear probability model. Specification (1) is the crude regression of literacy on prices and wages; this specification accounts for the distinct food price effects between non-farm and farm households in relation to household wages by restricting $\beta_2 = -\beta_4 - \beta_6$, $\beta_3 = -\beta_5 - \beta_7$, and $\beta_7 = 0$. Specification (2) is closest in spirit to the structure of my economic model, where demographic characteristics, household environments, and agricultural inputs are included. Specification (3) further takes into account the differential food price effects with respect to both household wages and nonfood prices by restricting β_2 and β_3 only. Specification (4) allows for more flexibility by introducing heterogeneity in demographic characteristics and household environments between the two types of households.

As expected, all specifications show the correct sign for $\hat{\beta}_2$; all are negative and statistically significant at conventional levels. These results support my first hypothesis that $\beta_2 < 0$. The positive coefficients of w^p and p_{nf}—hence the negative coefficient of p_f—for non-farm households indicate that ceteris paribus, a decrease in food prices relative to household wages and nonfood prices will raise the probability of literacy, since non-farm households will (1) substitute food for leisure; (2) substitute food for nonfood; and (3) have a higher real income in terms of food. Regarding $\hat{\beta}_3$, I find it to be positive and statistically significant at conventional levels in the first and second specifications, while it shows an unexpected sign in the last two specifications. These results provide some support of my second hypothesis that $\beta_3 > 0$, yet the results from the last two specifications indicate that the linear probability model may not be the best choice for estimating the non-linear conditional expectation.

Therefore, I re-estimate the coefficients for the four specifications of the logit model, and the results are in Table 4. As is the case with the linear probability model, the logit estimation confirms that $\hat{\beta}_2$ is highly significant in every specification, which strongly supports my first hypothesis that $\beta_2 < 0$. Furthermore, all four specifications yield positive estimates for β_3, and except for the third specification, these estimates are also statistically significant, providing a strong support for my second hypothesis. The results indicate that the positive farm profit effect cancels out, to some degree, the negative income and substitution effects associated with ${}^{w^p}/_{p_f}$ in farm households.

To examine the magnitudes of the effects and their differences, I calculate the average partial effects based on the logit estimates. The results are shown in Table 5. For a one-unit increase in $\ln p_f$ (i.e. a 171.8% increase in any food price level), the probability of literacy will change, on average, by: -83.5% (non-farm) and -75.0% (farm) in Specification (1); -70.2% (non-farm) and -68.1% (farm) in Specification (2); -70.4% (non-farm) and -67.9% (farm) in Specification (3); and -76.0% (non-farm) and -63.5% (farm) in Specification (4). As can be seen from these calculations, there are differences in the effect magnitudes depending on the household types.

Looking at other effects, I find that for later cohorts literacy has significantly improved, reflecting the broader economic and institutional development of the American society over time. Disadvantaged groups, including those who are nonwhite, Hispanic, and disabled, as well as those who live outside of the Northeast region, suffer more heavily from illiteracy, which is consistent with their socioeconomic status.

In the most comprehensive specification, i.e. Specification (4), on average, a 1% increase in food price level reduces children's probability of literacy by 0.44% for non-farm households and 0.37% for farm households; the average food price effect for farm households is 5/6 of that for non-farm households, after controlling for nonfood prices, household wages, demographic characteristics, household environments, and agricultural production inputs. These findings not only resonate well with my preceding theoretical predictions, but also uncover an additional source of heterogeneity of the food price effects, namely the food-nonfood substitution patterns across the two types of households.

5.2 Limitations

The empirical part of this paper has presented evidence that supports my economic model. Nevertheless, due to data limitations, several caveats are worth mentioning. First, while there was substantial convergence in wages and prices across states in the mid to late 19th century and early 20th century (Barro and Sala-i Martin, 1992), my use of the national price series, as opposed to regional ones in Baten, Crayen, and Voth (2014), introduces measurement errors that may cause small sample bias. The second limitation is that I do not take into account each farm household's status of being a net buyer or a net seller of food, which may have concealed heterogeneous impacts. For example, if the household is autarkic (though this is less likely in the mid to late 19th century and early 20th century U.S.), then p_f has no effect on anything. Another limitation is that the identification of the partial effects comes from the economic model, whose assumptions may be too restrictive. The fourth limitation is my dependent variable, literacy, which is not a continuous measure of cognitive skills. Admittedly, if additional data becomes available in the future, I will employ some more robust estimation and identification strategies. It is possible that the results and the interpretations may be reviewed and revised.

6 Conclusion

By exploiting historical price and census data in the mid to late 19th century and early 20th century United States, I investigate the impact of food prices on children's cognitive ability. Through household production, my economic model explicitly describes the relationships among food prices, nutrition, and cognitive development, and I motivate my empirical strategy based on these relationships.

My empirical results confirm that there exist significant differences between farm and non-farm households in terms of the partial effects of food prices on children's cognitive development. Using the preferred specification of this paper, I find that on average, a 1% increase in food price level reduces children's probability of literacy by 0.44% for non-farm households and 0.37% for farm households; the average food price effect for farm households is 5/6 of that for non-farm households, after controlling for nonfood prices, household wages, demographic characteristics, household environments, and agricultural production inputs.

These results may provide useful information to policymakers who want to address childhood nutrition and cognitive skill issues in developing countries. In particular, such policy prescriptions need to take the population composition into consideration. Going back to the policy debate about price stabilization, my empirical results suggest that it is less desirable than what appears at first sight. Indeed, in a related paper by Bellemare, Fajardo-González, and Gitter (2016), the authors found that at the height of the quinoa price boom, the well-being of quinoa producers in Peru actually increased faster than that of the rest of the population. Given the nonlinear nature of the relationships among literacy and the right-hand-side variables, it is possible that some farm households may actually benefit from higher food prices as far as consumption and children's cognitive development are concerned.

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Table 2: Summary statistics (non-farm N = 40318; farm N = 41151)

Variables	Non-farm Mean	(Std. Dev.)	Farm Mean	(Std. Dev.)	Difference Mean	(Std. Err.)
Cognitive development						
Literacy (all cohorts)	0.932	(0.251)	0.925	(0.264)	0.008	(0.002)
Literacy (1841–1850 cohort)	0.968	(0.176)	0.938	(0.241)	0.030	(0.008)
Literacy (1851–1860 cohort)	0.955	(0.208)	0.943	(0.233)	0.012	(0.005)
Literacy (1861–1870 cohort)	0.864	(0.343)	0.865	(0.341)	-0.001	(0.004)
Literacy (1871–1880 cohort)	0.977	(0.150)	0.965	(0.184)	0.012	(0.002)
Prices						
Food price (log)	5.959	(0.146)	5.952	(0.152)	0.007	(0.001)
Nonfood price (log)	5.741	(0.126)	5.737	(0.127)	0.004	(0.001)
Household wage (log)	7.236	(0.649)	6.749	(0.483)	0.488	(0.004)
Demographics						
Birth year (log)	7.533	(0.004)	7.533	(0.005)	0.000	(0.000)
Foreign born	0.015	(0.120)	0.005	(0.072)	0.009	(0.001)
Parent illiterate	0.109	(0.311)	0.104	(0.305)	0.005	(0.002)
Female	0.367	(0.482)	0.321	(0.467)	0.046	(0.003)
Nonwhite	0.087	(0.283)	0.044	(0.205)	0.044	(0.002)
Hispanic	0.006	(0.079)	0.003	(0.056)	0.003	(0.000)
Disabled	0.001	(0.025)	0.001	(0.028)	-0.000	(0.000)
Household members (log)	1.820	(0.372)	1.900	(0.348)	-0.080	(0.003)
Household children (log)	0.911	(0.511)	0.993	(0.503)	-0.082	(0.004)
Midwest	0.308	(0.462)	0.465	(0.499)	-0.157	(0.003)
South	0.253	(0.435)	0.342	(0.474)	-0.089	(0.003)
West	0.037	(0.188)	0.026	(0.159)	0.011	(0.001)
Agricultural inputs						
Acres of land (log)	0.000	(0.000)	4.950	(0.368)	-4.950	(0.002)
Number of livestock (log)	0.000	(0.000)	3.458	(0.452)	-3.458	(0.002)

Table 3: Estimated coefficients of the linear probability model

Independent variables	(1)		(2)		(3)		(4)	
Constant	0.927***	(0.006)	-45.883***	(1.621)	-45.869***	(1.621)	-42.767***	(2.277)
Childhood farm status	0.088***	(0.004)	0.205***	(0.018)	0.218***	(0.021)	-4.838	(3.291)
Food price	-0.477***	(0.025)	-0.677***	(0.028)	-0.647***	(0.039)	-0.618***	(0.042)
Food price × childhood farm status	0.078***	(0.003)	0.017***	(0.003)	-0.035	(0.046)	-0.101*	(0.056)
Household wage	0.073***	(0.002)	0.032***	(0.002)	0.032***	(0.002)	0.034***	(0.002)
Household wage × childhood farm status	-0.078***	(0.003)	-0.017***	(0.003)	-0.017***	(0.003)	-0.023***	(0.004)
Nonfood price	0.403***	(0.025)	0.645***	(0.028)	0.615***	(0.039)	0.584***	(0.042)
Nonfood price × childhood farm status					0.052	(0.046)	0.124***	(0.056)
Birth year			6.238***	(0.215)	6.236***	(0.216)	5.824***	(0.303)
Birth year × childhood farm status							0.673	(0.437)
Foreign born			0.009	(0.008)	0.009	(0.008)	0.010	(0.009)
Foreign born × childhood farm status							-0.008	(0.018)
Parent illiterate			-0.142***	(0.003)	-0.142***	(0.003)	-0.140***	(0.004)
Parent illiterate × childhood farm status							-0.005	(0.006)
Female			-0.002	(0.002)	-0.002	(0.002)	0.004	(0.002)
Female × childhood farm status							-0.012***	(0.003)
Nonwhite			-0.259***	(0.004)	-0.260***	(0.004)	-0.266***	(0.005)
Nonwhite × childhood farm status							0.017**	(0.008)
Hispanic			-0.109***	(0.012)	-0.109***	(0.012)	-0.095***	(0.015)
Hispanic × childhood farm status							-0.035	(0.025)
Disabled			-0.181***	(0.030)	-0.181***	(0.030)	-0.144***	(0.045)
Disabled × childhood farm status							-0.063	(0.060)
Household members			-0.010***	(0.003)	-0.010***	(0.003)	-0.018***	(0.005)
Household members × childhood farm status							0.019***	(0.007)
Household children			0.001	(0.002)	0.001	(0.002)	0.003	(0.003)
Household children × childhood farm status							-0.004	(0.004)
Midwest			-0.003	(0.002)	-0.003	(0.002)	-0.005*	(0.003)
Midwest × childhood farm status							0.007	(0.004)
South			-0.088***	(0.002)	-0.088***	(0.002)	-0.087***	(0.003)
South × childhood farm status							0.003	(0.005)
West			-0.004	(0.005)	-0.004	(0.005)	-0.020***	(0.006)
West × childhood farm status							0.052***	(0.011)
Land			-0.036***	(0.004)	-0.036***	(0.004)	-0.037***	(0.005)
Livestock			-0.002	(0.003)	-0.002	(0.003)	-0.008**	(0.004)
Number of observations	81469		81469		81469		81469	
Adjusted R-squared	0.021		0.233		0.233		0.233	

Standard errors in parentheses; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 4: Estimated coefficients of the logit model

Independent variables	(1)		(2)		(3)		(4)	
Constant	3.888***	(0.179)	-1044.960***	(36.561)	-1044.978***	(36.564)	-1172.290***	(55.264)
Childhood farm status	1.244***	(0.052)	1.240***	(0.339)	1.222**	(0.476)	224.689***	(75.309)
Food price	-12.939***	(0.770)	-14.518***	(0.671)	-14.567***	(1.148)	-15.737***	(1.215)
Food price × childhood farm status	1.320***	(0.053)	0.438***	(0.060)	0.508	(1.310)	2.593*	(1.463)
Household wage	1.258***	(0.034)	0.674***	(0.040)	0.674***	(0.040)	0.685***	(0.044)
Household wage × childhood farm status	-1.320***	(0.053)	-0.438***	(0.060)	-0.438***	(0.060)	-0.491***	(0.071)
Nonfood price	11.680***	(0.771)	13.843***	(0.672)	13.893***	(1.151)	15.052***	(1.218)
Nonfood price × childhood farm status					-0.070	(1.311)	-2.102	(1.466)
Birth year			139.651***	(4.861)	139.654***	(4.862)	156.597***	(7.349)
Birth year × childhood farm status							-29.712***	(9.996)
Foreign born			-0.076	(0.200)	-0.075	(0.200)	-0.037	(0.242)
Foreign born × childhood farm status							-0.107	(0.431)
Parent illiterate			-1.219***	(0.039)	-1.219***	(0.039)	-1.161***	(0.059)
Parent illiterate × childhood farm status							-0.100	(0.078)
Female			0.006	(0.034)	0.006	(0.034)	0.164***	(0.052)
Female × childhood farm status							-0.275***	(0.068)
Nonwhite			-1.358***	(0.045)	-1.357***	(0.045)	-1.508***	(0.063)
Nonwhite × childhood farm status							0.302***	(0.091)
Hispanic			-1.477***	(0.155)	-1.477***	(0.155)	-1.419***	(0.195)
Hispanic × childhood farm status							-0.213	(0.322)
Disabled			-1.917***	(0.378)	-1.917***	(0.378)	-1.970***	(0.651)
Disabled × childhood farm status							0.094	(0.797)
Household members			-0.027	(0.071)	-0.027	(0.071)	-0.107	(0.108)
Household members × childhood farm status							0.158	(0.144)
Household children			-0.132***	(0.047)	-0.132***	(0.047)	-0.165**	(0.072)
Household children × childhood farm status							0.053	(0.095)
Midwest			-0.411***	(0.070)	-0.411***	(0.070)	-0.305***	(0.094)
Midwest × childhood farm status							-0.282*	(0.152)
South			-2.033***	(0.065)	-2.032***	(0.065)	-1.895***	(0.078)
South × childhood farm status							-0.328**	(0.148)
West			-0.639***	(0.142)	-0.639***	(0.142)	-0.775***	(0.177)
West × childhood farm status							0.249	(0.300)
Land			-0.175**	(0.074)	-0.175**	(0.074)	-0.180***	(0.090)
Livestock			-0.020	(0.057)	-0.020	(0.057)	-0.041	(0.063)
Number of observations	81469		81469		81469		81469	
Pseudo R-squared	0.047		0.313		0.313		0.314	

Standard errors in parentheses; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 5: Average partial effects based on the logit estimates

Independent variables	(1)		(2)		(3)		(4)	
Childhood farm status	0.080***	(0.003)	0.060***	(0.016)	0.059**	(0.023)	10.854***	(3.638)
Food price	-0.835***	(0.050)	-0.702***	(0.032)	-0.704***	(0.055)	-0.760***	(0.059)
Food price × childhood farm status	0.085***	(0.003)	0.021***	(0.003)	0.025	(0.063)	0.125*	(0.071)
Household wage	0.081***	(0.002)	0.033***	(0.002)	0.033***	(0.002)	0.033***	(0.002)
Household wage × childhood farm status	-0.085***	(0.003)	-0.021***	(0.003)	-0.021***	(0.003)	-0.024***	(0.003)
Nonfood price	0.754***	(0.050)	0.669***	(0.032)	0.672***	(0.056)	0.727***	(0.059)
Nonfood price × childhood farm status					-0.003	(0.063)	-0.102	(0.071)
Birth year			6.751***	(0.236)	6.751***	(0.236)	7.565***	(0.355)
Birth year × childhood farm status							-1.435***	(0.483)
Foreign born			-0.004	(0.010)	-0.004	(0.010)	-0.002	(0.012)
Foreign born × childhood farm status							-0.005	(0.021)
Parent illiterate			-0.059***	(0.002)	-0.059***	(0.002)	-0.056***	(0.003)
Parent illiterate × childhood farm status							-0.005	(0.004)
Female			0.000	(0.002)	0.000	(0.002)	0.008***	(0.003)
Female × childhood farm status							-0.013***	(0.003)
Nonwhite			-0.066***	(0.002)	-0.066***	(0.002)	-0.073***	(0.003)
Nonwhite × childhood farm status							0.015***	(0.004)
Hispanic			-0.071***	(0.007)	-0.071***	(0.007)	-0.069***	(0.009)
Hispanic × childhood farm status							-0.010	(0.016)
Disabled			-0.093***	(0.018)	-0.093***	(0.018)	-0.095***	(0.031)
Disabled × childhood farm status							0.005	(0.039)
Household members			-0.001	(0.003)	-0.001	(0.003)	-0.005	(0.005)
Household members × childhood farm status							0.008	(0.007)
Household children			-0.006***	(0.002)	-0.006***	(0.002)	-0.008**	(0.003)
Household children × childhood farm status							0.003	(0.005)
Midwest			-0.020***	(0.003)	-0.020***	(0.003)	-0.015***	(0.005)
Midwest × childhood farm status							-0.014*	(0.007)
South			-0.098***	(0.003)	-0.098***	(0.003)	-0.092***	(0.004)
South × childhood farm status							-0.016**	(0.007)
West			-0.031***	(0.007)	-0.031***	(0.007)	-0.037***	(0.009)
West × childhood farm status							0.012	(0.014)
Land			-0.008***	(0.004)	-0.008**	(0.004)	-0.009**	(0.004)
Livestock			-0.001	(0.003)	-0.001	(0.003)	-0.002	(0.003)

Delta-method standard errors in parentheses; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$