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Home production, market substitutes, and the labor supply of mothers☆

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ABSTRACT

We study the interaction among the home production of food, the market for industrialized food, and the labor supply of mothers. For this, we introduce a model of child nutrition based on two substitutes. Industrialized food is produced in an imperfectly competitive market where its price, quality, and quantity are endogenously determined. Home-produced food is superior in quality but is time-consuming to make and, thus, entails opportunity costs for mothers. We derive the equilibrium and the socially optimal quality of industrialized food. Finally, we suggest government policies to boost the labor supply of mothers and social welfare, including setting regulatory quality standards and supporting technological changes in the production of industrialized and homemade food.

1. Introduction

One of the most documented changes in the 20th century is the increased participation of mothers with young children in the labor force. This notable change has been accompanied by the diffusion of industrialized substitutes for home-produced goods and labor-saving household technologies that facilitate child-rearing and afford women the unprecedented freedom to convert home production of goods into labor time.[1] For example, Eckstein and Lifshitz (2011), estimating a female dynamic labor supply model for cohorts born after 1935, find that 40% of female employment can be attributed to the reduction in the costs of child-rearing and home production.[2]

To the best of our knowledge, our model is the first to combine family economics—modeling parental time allocation and home production—with industrial organization—modeling the market for industrialized food. By doing so, we introduce

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[1] On the labor supply of women and home-production see for example Becker, 1965; Gronau, 1977, 1997; Etilé & Plessz, 2018; Ramey & Francis, 2009; Bailey, 2006; Goldin & Katz, 2002; Greenwood, Seshadri, & Yorukoglu, 2005; Aguiar & Hurst, 2007; González & Chapela, 2011.

[2] Attanasio, Low, & Sánchez-Marcos (2008) suggest that a decrease of more than 15% in childcare costs play an essential role in explaining the dynamics of participation rates observed for the 1950s cohort of American women.

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a framework for understanding and integrating the various empirical findings and analyzing the impact of government policy on household choices, most notably, the labor supply of mothers.[3] Our model focuses on child nutrition, although our results apply to other home-produced goods as well.

In the past, the home production of food was the traditional task of mothers. Babies depended on their mother's milk for nourishment, at least in their first year of life, and the family consumed homemade food. During the 20th century, however, there has been a worldwide shift to infant milk substitutes, and homemade food has been gradually replaced by industrialized food, significantly reducing the cost of children and boosting the labor supply of mothers. Marketization has also occurred in other parental time costs-intensive activities linked to having children. Crossley et al. (2018), Bar et al. (2018), Hazan and Zoabi (2015), and Siegel (2017) find that the price of market substitutes or services (ready-to-eat food, childcare, housekeeping, or other home production) has actually declined relative to home production, when accounting for the market value of time. Albanesi and Olivetti (2016) attribute a similar pattern in infant feeding to technological improvements in the production of infant formula. Commercially produced substitutes are now numerous and readily available.[4]

While these products have improved over the years, there is, however, an ongoing debate surrounding the issue of not only their nutritional value but also the quality of the commercially produced substitutions. Industrialized food occasionally fails to meet the World Health Organization's (WHO) dietary recommendations, and its quality is considered inferior to home-produced food (Anderson et al., 2008; Remnant and Adams, 2015). For example, using propensity score matching, Borra et al. (2012) suggest that four weeks of breastfeeding has substantial positive implications on the health of children and their cognitive (SATs) and non-cognitive outcomes (American Academy of Pediatrics, 2005; Barber-Madden et al., 1987; Oddy et al., 2010; Ruhm, 2000; WHO, 2003). Hall et al. (2019) finds in a randomized controlled trial that ultra-processed diets cause excess calorie intake (of 500 kcal/day) and weight gain, despite being matched to unprocessed diets daily for presented calories, sugar, fat, sodium, fiber, and macronutrients. They suggest limiting consumption of ultra-processed food as an effective strategy for obesity prevention and treatment. According to Neri et al. (2019), there is cumulative recognition that increases in the dietary share of ultra-processed foods result in deterioration of the nutritional quality of the overall diet and adverse health outcomes. Their results suggest that ultra-processed foods contributed 65% of total energy intake and 92% of energy from added sugars in the diet of US children aged 2 to 19 years. They conclude that public health efforts to reduce added sugars in the diet of US children must put greater emphasis on decreasing the consumption of ultra-processed foods.[5]

The primary purpose of our article is to introduce a comprehensive analytical framework that combines essential elements in mothers' labor supply–time allocation and firms' decisions on the quantity and quality of market substitutes. The model provides a theoretical basis for the empirical evidence mentioned above on the evolution of mothers' labor supply in the 20th century. Our results reveal the general-equilibrium effects of technological changes in both home production and the industrialized production of food. Moreover, the model also encompasses the heterogeneous effects on mothers in part-time jobs and full-time jobs and suggests policies to advance social welfare and alleviate the concerns for product quality.

We present an economy with heterogeneous altruistic mothers who derive utility from their child's nutrition, which is based on either home-produced food or industrialized food. Mothers allocate their time between work and home production of food and their income between consumption and purchase of industrialized food. Following the literature, we assume that home production of food, like other home production tasks, comes at the expense of labor time (as reflected, for example, in extended maternity leaves, part-time jobs, and reduced working hours).[6] We first characterize the equilibrium in the short and long run. As mothers differ in their wages, some mothers choose full-time jobs and use industrialized food while others want part-time jobs and prepare homemade food. Second, we endogenize the quality of industrialized food. In line with the literature, consumers have limited ability to observe the quality of products, which reduces the incentives of firms to invest

[3] The effect of product market regulation on the labor supply is empirically addressed in Bertrand and Kramarz (2002), Boeri et al. (2000), and Cacciatore and Fiori (2016), and theoretically in Benhabib et al. (1991), Blanchard and Giavazzi (2003), Ebell and Haefke (2009), Fang and Rogerson, (2011), and Koliousi et al. (2017).

[4] At the beginning of the 20th century, typical mothers between ages 23–33 were nursing their children for approximately a third of the time accounting for 35%–43% of their potential labor time. According to the CDC (Center of Disease Control and Prevention, 2016) in 2016, 44.5% of the mothers exclusively breastfed their infant three months after birth and 22.3% of the mothers breastfed their infant six months after birth.

[5] See dietary recommendations of the WHO at https://www.who.int/news-room/fact-sheets/detail/healthy-diet. Around the world, recalls in major food companies occur daily (see, e.g., the FDA website, https://www.fda.gov/Safety/Recalls/default.htm), and there have been instances where safety controls of these products have failed resulting in death and injury (see, e.g., the cases of impaired infant formula distributed in China in 2008 (Gossner et al. 2009; Sharma and Paradakar, 2010) and in Israel in 2003 (Hatsor and Shurtz, 2019)). Dranove and Jin (2010) review the literature on the market response to certification and quality disclosure programs. "Time with mom" also seems to contribute to the child's long-term health, cognitive and non-cognitive development (Berger et al. (2005), Ruhm (2004), Neidell (2000), Baum (2003), Belfield and Kelly (2012), Bernal (2008), Cunha et al. (2010), Gregg et al. (2005), and Rothstein (2013).

[6] For example, Ruhm (1998) examines the economic consequences of lengthy periods of maternity leave on women's careers in nine European countries over the period of 1969–1993. Chatterji and Frick (2005), using the NLSY, indicate that returning to work within three months is associated with a 16%–18% reduction in the probability to initiate breastfeeding and a reduction of 4–5 weeks in the length of breastfeeding. Based on a survey 40,015 U.S. mothers, Ryan, Zhou, and Arensberg (2006) conclude that by six months after delivery, mothers working part-time or not working are more likely to breastfeed (36.6% and 35%, respectively) compared with mothers employed full-time (26.1%). Fein and Roe (1998) find similar results using data on women's expectations to work full-time or part-time.

in quality (Akerlof, 1970; Bordalo et al., 2016; Chioveanu and Zhou, 2013; Tirole, 1996). In this framework, we study the interactions among home production, the quality, and quantity of the industrialized food, and the labor supply of mothers.

Our model suggests three main channels to augment social welfare and the aggregate labor supply of mothers. First, a decline in the production costs of firms (e.g., through technological improvements) leads to a reduction in the price of industrialized food. As a result, the utility of high-income mothers who work full-time and purchase industrialized food increases.

The second channel to increase social welfare is the diffusion of labor-saving technologies in the home production of food. An increase in productivity at home improves not only the utility of low-income mothers who prepare homemade food but also that of high-income mothers who purchase industrialized food. Low-income mothers who prepare (or switch to) homemade food have more spare time, augmenting their labor supply and consumption. Moreover, the reduction in the demand for industrialized food leads to a reduction in its price, which benefits high-income mothers who purchase industrialized food. Therefore, in the equilibrium, all mothers benefit from household labor-saving technologies, including the ones that never use them, because of the reduction in the price of market substitutes.

The effect of household labor-saving technologies on the aggregate labor supply is driven by two competing forces. Greater productivity at home alleviates the difficulties in reconciling work and motherhood. Consequently, instead of choosing full-time jobs, some high-income mothers switch to part-time jobs combined with home production of food, while low-income mothers already in part-time jobs can work longer hours. In our framework, in the short run, the latter effect prevails, but in the long run, as firms leave the market of industrialized food, the two effects cancel out.

The third potential channel to increase social welfare relates to the mean quality of industrialized food. In the long-run equilibrium, when each firm endogenously chooses the quality of its products, two forces determine the mean quality in the market. On the one hand, an increase in the mean quality augments the profits of firms, thereby attracting more firms into the market (because of the augmented demand for industrialized food). On the other hand, as more firms enter the market, each firm is less inclined to invest in quality (and more inclined to free-ride on other firms). Overall, the mean quality may be lower than the socially optimal one. In this case, the market is trapped in a "prisoners' dilemma." Coordinating product quality would increase social welfare as well as firms' profits and the labor supply of mothers. This equilibrium calls for government intervention to set a regulatory quality standard in the market.

The rest of the paper is organized as follows. In Section 2, we present the model. In Section 3, we derive the short and long-run equilibriums under exogenously given quality. In Section 4, we discuss social welfare. In Section 5, we endogenize the quality of industrialized food. Finally, in Section 6, we discuss the results.

2. The model

We study the tradeoffs among the home production of goods, their industrialized substitutes, and the labor supply of mothers by introducing a model of child nutrition. Consider a continuum of households consisting of a mother and her child, where each household is characterized by a family name $\omega \in [0, 1]$. We assume that each household ω provides the child with k calories of either home-produced food, $b(\omega)$, *or* industrialized food, $f(\omega)$. That is, either $b(\omega) = k$ or $f(\omega) = k$, respectively. The quality (per calorie) of home-produced food and industrialized food is denoted by q_b and q_f, respectively. Following the broad worldwide consensus that home production of food is healthier and safer than its industrialized substitutes, we assume that $0 < q_f^L \leq q_f \leq q_f^H < q_b < 1$. That is, the quality of industrialized food is lower than the quality of homemade food, where q_f^L and q_f^H are exogenous parameters given by the available technology of industrialized food.

While each child ω receives k calories of food, the quality of child nutrition, $t(\omega)$, is $q_b k$ if the food is homemade or $q_f k$ if industrialized food is purchased in the market,

$$t(\omega) = \begin{cases} q_b k & if \quad b = k \ (f = 0) \\ q_f k & if \quad b = 0 \ (f = k) \end{cases} \tag{1}$$

A mother ω derives utility from her consumption, $c(\omega)$, and from the quality of her child's nutrition, $t(\omega)$. To keep the model tractable, we use a linear specification:

$$u(\omega) = \alpha t(\omega) + \beta c(\omega), \tag{2}$$

where the parameters α and β (α, $\beta > 0$) denote the importance of child nutrition and consumption in the utility function, respectively.

Our model accounts for the fact that home production of food is time consuming and, thereby, interrupts mothers' labor time.[7] Each mother ω is endowed with one unit of time to be divided between work, $l(\omega) \geq 0$, and home production of food, $1 - l(\omega)$. She chooses between two alternatives: if she works full time, $l(\omega) = 1$, there is no time left for home production of food and, therefore, she purchases the k calories of industrialized food in the market at a price of p_f per calorie ($f(\omega) = k$).

[7] For example, breastfeeding is associated with lower mothers' employment, reflected in delaying the return to work after childbirth or working part time. For simplicity, we assume that consumption of industrialized food is not time consuming for mothers. The more realistic assumption that industrialized food is less time consuming than home cooking would not change our qualitative results. Similarly, the assumption that home-produced food is less expensive rather than free would not change our qualitative results.

Alternatively, she may work part-time and produce the food at home ($b(\omega) = k$) according to the following production function of homemade food (Delpierre and Verheyden, 2019; Glomm and Meier, 2016 use a similar specification for the home production of childcare):

$$b(\omega) = (1 - l(\omega))z. \tag{3}$$

where the parameter z, the productivity of time in the production of homemade food (in short, the productivity of home production or the productivity at home), translates the time dedicated to home production, $1 - l(\omega)$, into calories of homemade food. Productivity at home increases along with the diffusion of labor-saving household technologies. In the context of food, appliances like food processors, microwaves, and dishwashers shorten the time needed for the preparation of homemade food. When mothers decide to work part-time and produce food at home, their labor supply can be calculated from the production function of homemade food [Eq. (3)], given that they provide the child with k calories of food, $b(\omega) = k$. Therefore, the labor supply of a mother ω is given by

$$l(\omega) = \begin{cases} 1 - \frac{k}{z} & if \quad b = k \ (f = 0) \\ 1 & if \quad b = 0 \ (f = k) \end{cases}. \tag{4}$$

We assume that the productivity of the mothers at home is sufficiently high, or $z \geq k$, allowing them to combine home production with a part-time job ($0 \leq l(\omega) \leq 1$).

Mothers are heterogeneously endowed in human capital, captured by a wage rate, $w(\omega)$ (Delpierre and Verheyden, 2019). The labor income of mother ω equals her labor supply multiplied by her wage rate, and her non-labor income is given by $y(\omega) \geq 0$. Then, mothers consume their labor and non-labor income, net of their purchase of industrialized food. Formally, the consumption of household ω is

$$c(\omega) = \begin{cases} w(\omega)\left(1 - \frac{k}{z}\right) + y(\omega) & if \quad b = k \ (f = 0) \\ w(\omega) + y(\omega) - p_f k & if \quad b = 0 \ (f = k) \end{cases}. \tag{5}$$

2.1. The demand for industrialized food

Inserting Eqs. (1) and (5) into Eq. (2) yields the mother's utility if the food is homemade or purchased in the market, where each mother chooses the alternative that maximizes her utility.

$$u(\omega) = \begin{cases} \alpha k q_b + \beta\left(w(\omega)\left(1 - \frac{k}{z}\right) + y(\omega)\right) & if \quad b = k \ (f = 0) \\ \alpha k q_f + \beta\left(w(\omega) + y(\omega) - p_f k\right) & if \quad b = 0 \ (f = k) \end{cases} \tag{6}$$

Comparing the two alternatives, we derive a cut-off level of the wage rate, w_c, that defines the demand of mother ω for industrialized food,

$$f^D(\omega) = \begin{cases} 0 & if \quad w(\omega) < w_c \\ k & if \quad w(\omega) \geq w_c \end{cases}, \tag{7}$$

and her labor supply:

$$l^S(\omega) = \begin{cases} \left(1 - \frac{k}{z}\right) & if \quad w(\omega) < w_c \\ 1 & if \quad w(\omega) \geq w_c \end{cases} \tag{8}$$

where $w_c \equiv z(p_f + \frac{\alpha}{\beta}(q_b - q_f))$.[8]

Wage rates higher than the cut-off level, w_c, induce mothers to work full time and purchase industrialized food ($f = k$). These "career" mothers are also referred to as "high-income mothers." Accordingly, "low-income mothers" earn lower wage rates, work part-time (or do not participate in the labor market), and prepare food at home ($b = k$).[9]

For simplicity, we assume that $w(\omega)$ is uniformly distributed over the interval [0, 1], and accordingly (to avoid a trivial solution), the cut-off level lies in this range, $w_c \in [0, 1]$. Using this assumption, we calculate the aggregate demand for industrialized food,

$$F^D = k\left(1 - z\left(\frac{\alpha}{\beta}\left(q_b - q_f\right) + p_f\right)\right), \tag{9}$$

8 In our model, it is easy to verify that mothers who choose to work full time can always afford industrialized food, since $w_c \geq kp_f$ (unless $y(\omega) < 0$) and, thus, mothers do not face credit constraints.

9 We assume that fathers' labor supply (and thereby their income) does not change when mothers make decisions on their labor supply and on child nutrition. Accordingly, in our framework the non-labor income, $y(\omega)$, is a fixed component that cancels out and does not affect mothers' decisions.

and the aggregate labor supply of mothers

$$L^S = 1 - \left(\frac{\alpha}{\beta}\left(q_b - q_f\right) + p_f\right)k \tag{10}$$

Eqs. (9) and (10) suggest that the demand for industrialized food and correspondingly the aggregate labor supply of mothers increase (at the expense of time at home) in the following cases:

1. A reduction in the price of industrialized food, p_f.
2. An increase in the quality of industrialized food, q_f.
3. An increase in the importance of consumption relative to child nutrition ($\frac{\alpha}{\beta}$ declines) (as consumption is more important to mothers, they are more willing to compromise on the quality of child nutrition and, in turn, substitute industrialized food for homemade food).

The effect of the productivity at home, z, on the aggregate labor supply of mothers is less intuitive and driven by two competing forces that cancel out (see Eq. (10)). On the one hand, when the productivity at home increases, some high-income mothers shift from full-time jobs and the use of industrialized food to part-time jobs and the home production of food. On the other hand, augmented productivity at home alleviates the difficulty of reconciling work and motherhood. Specifically, each low-income mother that prepares homemade food has more available time for work. Therefore, while fewer mothers work full-time, mothers in part-time jobs work longer hours. Next, we describe the firms' decisions in the market of industrialized food.

2.2. The firms

Industrialized food is produced in an imperfectly competitive market consisting of n identical firms, where firm $i \quad (i = 1, \ldots, n)$ produces f_i calories of industrialized food. The quality (per calorie) of industrialized food, q_f, is exogenously given for now. The cost function of firm i is given by a quasi-fixed cost function:

$$TC_i\left(f_i, q_f\right) = \begin{cases} 0 & if \quad f_i = 0 \\ \lambda q_f f_i + A & if \quad f_i > 0, \end{cases} \tag{11}$$

where $A > 0$ denotes the quasi-fixed cost of production and λq_f denotes the marginal cost of production. $\lambda > 0$ is an exogenous parameter that measures the marginal cost of production per unit of quality. This form takes into account the fact that producing higher quality is costly to the firms (e.g., expensive inputs, self-monitoring, and investment in research and development). To avoid trivial solutions where there is no demand for industrialized food (recall that wages are distributed over the interval [0, 1]), we assume that the marginal cost cannot exceed the highest possible wage, 1.

Assumption 1. $\lambda q_f < 1$**.**

Given the cost of production [Eq. (11)] and the inverse demand function for industrialized food,

$$p_f = \frac{1}{z}\left(1 - \frac{F}{k}\right) - \frac{\alpha}{\beta}\left(q_b - q_f\right), \tag{12}$$

we obtain the profit function of firm i,

$$\pi_i\left(f_i, q_f\right) = p_f(F) f_i - TC_i\left(f_i, q_f\right). \tag{13}$$

In the next section, we derive the Cournot–Nash equilibrium in the short and long run.

3. The equilibrium under exogenous quality

We first derive the short-run Cournot–Nash equilibrium where the number of firms in the industry, n, is exogenously given.

3.1. The short-run equilibrium

Each firm i maximizes its profit [Eq. (13)] by choosing its production level, f_i, given the production of all the firms excluding firm i, F_{-i}, where $F = f_i + F_{-i}$. By differentiating the profit function of firm i [Eq. (13)] with respect to its production f_i we obtain the first-order conditions:

$$\frac{\partial \pi_i}{\partial f_i} = \frac{1}{z}\left(1 - \frac{2f_i + F_{-i}}{k}\right) - \delta = 0, \tag{14}$$

where $\delta \equiv \lambda q_f + \frac{\alpha}{\beta}(q_b - q_f)$ is exogenously given.

The firms are identical; in the equilibrium, therefore, firm i and firm j, $i, j \in [1, n]$, produce the same quantity of industrialized food, $f_i = f_j$, which implies that $F = n f_i$. Inserting $F_{-i} = (n-1) f_i$ into the first-order condition of each firm [Eq. (14)] yields its production at "the short run exogenous quality" (*sreq*) equilibrium

$$f_i^{sreq} = \frac{k}{1+n}(1 - z\delta). \tag{15}$$

To avoid a trivial solution with no market for industrialized food, we make the following assumption that guarantees that each firm produces a positive quantity.

Assumption 2. $z\delta < 1$.

According to Eq. 15 the market for industrialized food exits provided that its quality relative to the quality of homemade food, $q_f - q_b$, and the value mothers attribute to consumption relative to child nutrition, β/α, are sufficiently high; and mothers' productivity at home, z, and the marginal cost of production, λ, are sufficiently low.

We obtain the equilibrium price by inserting the aggregate production of industrialized food, $F^{sreq} = n f_i^{sreq}$, into the inverse demand function [Eq. (12)],

$$p_f^{sreq} = \frac{1}{1+n}\left(\lambda q_f(1+n) + \frac{1-z\delta}{z}\right) \tag{16}$$

where $p_f^{sreq} > 0$ due to Assumption 2.

Then, it is easy to obtain the aggregate labor supply and the cut-off level of the demand for industrialized food at equilibrium (inserting the price into Eq. (10)):

$$L^{sreq} = 1 - \frac{k}{1+n}\left(n\delta + \frac{1}{z}\right), \tag{17}$$

$$w_c^{sreq} = z\left(\frac{n\delta z + 1}{1+n}\right). \tag{18}$$

Before describing the effect of the model's parameters on the production of industrialized food and the labor supply of mothers, we assume the following.

Assumption 3. $\frac{\alpha}{\beta} > \lambda$.

According to Assumption 3, the relative importance of child nutrition is larger than the marginal cost of the firms. In this case, $\frac{\partial\delta}{\partial q_f} = \lambda - \frac{\alpha}{\beta} < 0$. Proposition 1 summarizes the comparative static:

Proposition 1.

$$\frac{\partial f_i^{sreq}}{\partial\lambda} < 0 \quad \frac{\partial p_f^{sreq}}{\partial\lambda} > 0 \quad \frac{\partial L^{sreq}}{\partial\lambda} < 0$$
$$\frac{\partial f_i^{sreq}}{\partial q_f} > 0 \quad \frac{\partial p_f^{sreq}}{\partial q_f} > 0 \quad \frac{\partial L^{sreq}}{\partial q_f} > 0$$
$$\frac{\partial f_i^{sreq}}{\partial z} < 0 \quad \frac{\partial p_f^{sreq}}{\partial z} < 0 \quad \frac{\partial L^{sreq}}{\partial z} > 0$$
$$\frac{\partial f_i^{sreq}}{\partial\left(\frac{\alpha}{\beta}\right)} < 0 \quad \frac{\partial p_f^{sreq}}{\partial\left(\frac{\alpha}{\beta}\right)} < 0 \quad \frac{\partial L^{sreq}}{\partial\left(\frac{\alpha}{\beta}\right)} < 0$$
$$\frac{\partial f_i^{sreq}}{\partial n} < 0 \quad \frac{\partial p_f^{sreq}}{\partial n} < 0 \quad \frac{\partial L^{sreq}}{\partial n} > 0 \quad \frac{\partial F^{sreq}}{\partial n} > 0$$

Proof. See appendix.

According to Proposition 1, the aggregate labor supply of mothers expands along with their use of industrialized food as a result of:

1. A reduction in the marginal cost of production (per unit of quality), λ, induces the firms to increase the production of industrialized food. The larger production pushes the equilibrium price downwards and, as a result, some low-income mothers shift to full-time jobs and industrialized food (the cut-off wage, w_c, declines). An increase in the number of producers, n, results in the same effect, except that each firm produces a smaller quantity.
2. An increase in the quality of industrialized food augments both the demand for industrialized food and the firms' production cost. Under Assumption 3, the demand effect prevails since the relative importance of child nutrition is larger than the marginal cost of the firms. Consequently, the price of industrialized food and the aggregate labor supply increase (the cut-off wage, w_c, declines).
3. A reduction in the importance of child nutrition relative to consumption, α/β, induces some low-income mothers to switch to full-time jobs (the cut-off wage w_c decreases) and increase their purchase of industrialized food.

We discuss the effect of the productivity at home, z, in the following section. The profit of firm i at equilibrium is obtained by inserting Eqs. (11), (15), and (16) into Eq. (13):

$$\pi_i^{sreq} = \frac{k(1-\delta z)^2}{z(1+n)^2} - A. \tag{19}$$

We limit the discussion to the case where the profits of the firms are non-negative and, thus, there is a market for industrialized food. Proposition 2 summarizes the effect of different parameters on the profits of firms.

Proposition 2.

$$\frac{\partial \pi_i}{\partial q_f} > 0, \quad \frac{\partial \pi_i}{\partial n}, \quad \frac{\partial \pi_i}{\partial \lambda}, \quad \frac{\partial \pi_i}{\partial z}, \quad \frac{\partial \pi_i}{\partial A}, \quad \frac{\partial \pi_i}{\partial \left({}^{\alpha}/_{\beta} \right)} < 0$$

Proof. See appendix.

Intuitively, the profit of each firm decreases in the cost of production (the marginal cost, λ, or the quasi-fixed cost, A) and the number of firms, n. Moreover, when mothers' productivity at home, z, or the relative importance of child nutrition, $\frac{\alpha}{\beta}$, increases, some high-income mothers switch from industrialized food to home production and, in turn, the profits of firms decline. However, an increase in the quality of industrialized food triggers an increase in its demand (which, under Assumption 3, compensates for the increase in the marginal cost of production $\lambda\, q_f$), and thus, firms' profits rise.

3.2. The long-run equilibrium

At the long-run equilibrium under exogenously given quality ($lreq$), firms join the industry until their profits are reduced to zero. Equating Eq. (19) to zero yields the number of firms at equilibrium:

$$n^{lreq} = \frac{(1-z\delta)\sqrt{k}}{\sqrt{Az}} - 1 \tag{20}$$

To guarantee a non-trivial solution where the market for industrialized food exists, the number of firms must be at least 1, or formally:

Assumption 4. $\frac{(1-z\delta)\sqrt{k}}{\sqrt{Az}} \geq 2$

It is easy to verify that this assumption also guarantees that production is positive in the equilibrium.

Proposition 3. *The number of firms in the long-run equilibrium increases when:*

1. The quality of industrialized food, q_f, increases.
2. The productivity of home production, z, declines.
3. The relative importance of the child's nutrition, $\frac{\alpha}{\beta}$, declines
4. The marginal cost of production, λ, or the quasi-fixed cost, A, declines.

Proof. See appendix.

In the long run, an increase in the profits of firms induces more firms to enter the market. According to Proposition 2, a reduction in the productivity at home, z, or in the relative importance of the child's nutrition, $\frac{\alpha}{\beta}$, and an increase in the quality of industrialized food, $q_{f,}$ boost the profits of firms (because the demand for industrialized food rises), which induces more firms to enter the market. Similarly, a reduction in the cost of production prompts the entrance of the firms into the market.

By inserting the number of firms [Eq. (20)] into Eqs. (15)–(18) we derive the production of industrialized food, the price of industrialized food, the labor supply of mothers, and the cut-off wage at the long-run equilibrium:

$$F^{lreq} = -\sqrt{Azk} + k(1-z\delta), \tag{21}$$

$$p_f^{lreq} = \lambda q_f + \sqrt{\frac{A}{zk}}, \tag{22}$$

$$L^{lreq} = 1 - k\left(\delta + \sqrt{\frac{A}{k}}\right), \tag{23}$$

$$w_c^{lreq} = z\left(\delta + \sqrt{\frac{A}{k}}\right). \tag{24}$$

It is easy to verify that the results in Proposition 1 hold and are further intensified at the long-run equilibrium, as the number of firms is endogenously determined, except for the following result: an increase in the productivity at home, z, has two offsetting effects on the labor supply of mothers. On the one hand, because of the augmented productivity at home, low-income mothers who prepare homemade food have more spare time and, thereby, increase their labor supply. On the other hand, some high-income mothers shift from full-time jobs to part-time jobs and home production of food (the cut-off wage rises). Consequently, as Proposition 1 suggests, mothers reduce their purchase of industrialized food and the price declines. Therefore, while fewer mothers work in full-time jobs, mothers in part-time jobs increase their working hours, augmenting the aggregate labor supply in the short run.

In the long run, however, the reduced demand for industrialized food induces firms to exit the market and reduce the production of industrialized food. As a result, the two effects cancel out, and the aggregate labor supply does not rise (see Eq. (23)). Thus, in our framework, the increase in productivity at home cannot explain the rising labor supply of mothers in the long run. This result is in line with new evidence arguing that the driving force is the reduction in the price of market substitutes relative to home production (Albanesi and Olivetti 2016; Bar et al., 2018; Crossley et al., 2018). In the next section, we define the social welfare function.

4. Social welfare

The social welfare function, W, aggregates the utilities of mothers in the long-run equilibrium,

$$W = \int u(\omega)\, d\omega = \int_{w=0}^{w_c} \left(\alpha k q_b + \beta\left(1 - \frac{k}{z}\right) w\right) dw + \int_{w=w_c}^{1} \left(\alpha k q_f + \beta\left(w - p_f k\right)\right) dw \tag{25}$$

where p_f and w_c are given by Eqs. (22) and (24).

The first factor of social welfare aggregates the utility of mothers who choose part-time jobs and home production of food, whereas the second factor aggregates the utility of mothers who choose full-time jobs and purchase industrialized food. In Proposition 4 we analyze the effects of the production cost, the productivity at home and the quality of industrialized food on welfare, taking into account the shift between the two groups of mothers in the equilibrium.

Proposition 4.

(i) *Social welfare increases when:*
  1) The production costs of the firms (A *or* λ) decline.
  2) The productivity at home (z) increases.
  3) The quality of industrialized food (q_f) increases.

(ii) The socially optimal quality is given by q_f^H.

Proposition 4 is derived directly from the social welfare function [Eq. (25)].

First, an increase in productivity at home, z, improves not only the utility of low-income mothers who prepare homemade food but (surprisingly) also that of high-income mothers who purchase industrialized food. Increased productivity at home reduces the required time for the production of homemade food, enabling mothers to increase their labor supply. The larger productivity at home also attracts mothers from full-time jobs and use of industrialized food to part-time jobs and home production of food (the cut-off wage w_c^{lreq} increases). The reduction in the demand for industrialized food leads to a reduction in its price, which benefits mothers who purchase industrialized food. Therefore, in the equilibrium, all mothers benefit from household labor-saving technologies, including high-income ones that never use them, because of the reduction in the price of market substitutes.

Second, a decline in the production costs of the firms (A *or* λ) leads to a reduction in the price of industrialized food. As a result, the utility of high-income mothers who purchase industrialized food increases. The utility of low-income mothers who prepare homemade food is unchanged, but because industrialized food becomes less expensive, some benefit from switching to purchasing industrialized food and full-time jobs (the cut-off wage w_c^{lreq} declines), and social welfare improves.

Third, an increase in the quality of industrialized food (q_f) has a similar qualitative effect on social welfare. High-income mothers who use industrialized food benefit from the improvement in child nutrition (note that this effect is partially offset by the price increase due to the increase in the cost of firms, recall Assumption 3). Although low-income mothers who maintain their home production of food are not affected, the improved quality of industrialized food may induce some of them to shift to industrialized food and full-time jobs to improve their utility (the cut-off wage w_c^{lreq} declines). Therefore, social welfare improves when the quality of industrialized food rises.

As we restrict the quality of industrialized food to $q_f \in [q_f^L, q_f^H]$; its positive effect on social welfare implies that the socially optimal quality of industrialized food is given by q_f^H. In reality, though, the socially optimal quality may be lower because of the cost of enforcement. We elaborate on that in Section 5.2.1 hereinafter.

Another potential policy goal may be to increase the labor supply of mothers in the long run [Eq. (23)]. The two latter channels mentioned above—a decline in the production costs of the firms or an increase in the quality of industrialized food—increase not only social welfare but also the labor supply of mothers.

4.1. Government policy

The results in Proposition 4 suggest that a government that seeks to increase social welfare and the labor supply of mothers may pursue policies that advance technological improvements in the production of industrialized food (an increase in its quality, q_f, or a reduction in the production costs, A *or* λ, see Proposition 4 and Eq. (23)). Such policies may include financial support in the form of subsidies or a reduction in taxes or fees for firms that promote new technologies in the food industry. The government may also reduce the bureaucracy and the regulatory burden on the firms (e.g., automation of certification processes like fee payment and submission of documents).

Another means of increasing social welfare is to increase the productivity at home z by promoting labor-saving technologies in the home production of food (see Proposition 4).

Additionally, the government may set a regulatory quality standard in case the quality of industrialized food is unsatisfactory (lower than q_f^H). An attendant question is whether a quality standard is needed when the quality of industrialized food is endogenously determined by firms. We answer this question in the next section.

5. The equilibrium under endogenous quality

Thus far, we assumed that the quality of industrialized food is exogenously given. In this section, we derive the equilibrium where each firm simultaneously chooses the quantity and the quality of its products.

Many products of the food industry have characteristics of credence goods; that is, their quality may be discovered only after many years or not at all.[10] Consumers may find it challenging to rank the products and precisely determine the differences among them (e.g., Bordalo et al., 2016; Chioveanu and Zhou, 2013; Piccione and Spiegler, 2012). As a result, the food industry is typically characterized by a “collective reputation” of the firms in the market (Evans and Guinnane, 2007; Huck and Lünser, 2010; Neeman et al., 2019; Tirole, 1996). According to Fishman et al. (2018), collective reputation “may motivate free riding on the group’s reputation, reducing investment in quality”.

In line with the literature on credence goods and collective reputation, we assume that mothers have limited knowledge of the quality of industrialized food. Specifically, when mothers form their demand for industrialized food [Eq. (12)], they observe the mean quality of the products in the market but not the exact quality of the product they purchase.

The mean quality in the market of industrialized food, q_f, is a weighted average of the product quality of all firms, $\sum_{i=1}^{n} \frac{f_i}{f_i+F_{-i}} q_{f,i}$, or

$$q_f = \frac{f_i}{f_i + F_{-i}} q_{f,i} + \frac{F_{-i}}{f_i + F_{-i}} Q_{f,-i}, \tag{26}$$

where $q_{f,i} \in [q_f^L, q_f^H]$ denotes the quality level of firm i and F_{-i} and $Q_{f,-i}$ denote the aggregate production of the other firms and the mean quality of their products, respectively.[11]

Given the inverse demand function for industrialized food [Eq. (12)], the production of other firms, F_{-i}, the mean quality in the market [Eq. (26)], and its cost function [Eq. (11)], the profit function of firm i [Eq. (13)] becomes:

$$\pi_i\left(f_i, q_{f,i}\right) = \left(\frac{1}{z}\left(1 - \frac{f_i + F_{-i}}{k}\right) - \frac{\alpha}{\beta}\left(q_b - q_f\right)\right) f_i - TC_i\left(f_i, q_{f,i}\right) \tag{27}$$

where $TC_i(f_i, q_{f,i}) = \lambda q_{f,i} f_i + A$ denotes its production cost.

5.1. The short-run equilibrium

In the short run, firm i maximizes its profit [Eq. (27)] by simultaneously choosing its production level, f_i, and the mean quality of its products, $q_{f,\,i}$. Differentiating Eq. (27) with respect to $q_{f,\,i}$ yields $\frac{\partial \pi_i}{\partial q_{f,i}} = (\frac{\alpha}{\beta}(\frac{f_i}{f_i+F_{-i}}) - \lambda) f_i$. Taking into account the fact that the firms are identical, or $f_i + F_{-i} = n f_i$, we obtain that, at the equilibrium,

$$\frac{\partial \pi_i}{\partial q_{f,i}} = \left(\frac{\alpha}{n\beta} - \lambda\right) f_i. \tag{28}$$

Therefore, the quality level chosen by firm i at the short-run endogenous quality equilibrium (*sren*), $q_{f,i}^{sren}$, is given by

$$q_{f,i}^{sren} = \begin{cases} q_f^H & if \quad n \le \dfrac{\alpha}{\beta\lambda} \\ q_f^L & if \quad n \ge \dfrac{\alpha}{\beta\lambda} \end{cases} \tag{29}$$

[10] See the vast literature on “credence goods” dating back at least to Nelson (1970), Darby and Karni (1973), and Emons (1997); and the literature on “experience goods,” including Dulleck and Kerschbamer (2006), Hörner, (2002), and Shapiro (1983). Around the world, undesirable qualities of industrialized food have been discovered and recalls in major food companies occur daily.

[11] The results are robust to the following modification: The product quality of each firm $q_{f,\,i}$ is the mean of the quality of its products, all drawn from a distribution with a mean $\bar{q}_{f,i}$ and a variance $\sigma^2_{q_{f,i}}$.

As the firms are identical, they all choose the same quality in the equilibrium. Thus, $q_{f,i}^{sren}$ is also the mean quality (in short, the quality) in the market, $q_f^{sren} = q_{f,i}^{sren}$, and the production of each firm, the price, the aggregate labor supply of mothers, and the cut-off wage —f_i^{sren}, p_f^{sren}, L^{sren}, and w_c^{sren}, respectively—are obtained by inserting q_f^{sren} into Eqs. (15)–(18).

Recall that when the quality in the market is exogenously given, it has a positive effect on the profits of firms (Proposition 2). Nevertheless, when firms can choose the quality of their products, they may choose the lowest possible quality level, q_f^L. The reason is that each firm does not internalize its effect on the mean quality in the market. If there is one firm ($n = 1$) there is no externality and consequently, the monopoly always chooses the highest possible quality level, q_f^H. This result holds as long as the number of firms in the market is sufficiently small ($n < \frac{\alpha}{\beta\lambda}$) and, in turn, the externality is small.

However, if the number of firms is sufficiently large ($n > \frac{\alpha}{\beta\lambda}$), each firm chooses the lowest possible quality level, q_f^L. Given that its market share is small, the effect of each firm on the mean quality is small, reducing its incentive to invest in quality (or, equivalently, increasing its incentive to free ride on other firms). Consequently, the profits of firms are not maximized (recall Propositions 2 and 4), and the market is trapped in a “prisoners’ dilemma” type equilibrium. That is, firms could have increased their profits if they had coordinated the high quality, q_f^H.

To summarize, our results suggest that in the short run, when the number of firms is exogenously given, a sufficiently low number of firms may yield the highest quality level of industrialized food, q_f^H. In the long run, however, more firms may enter the market, potentially reducing the mean quality of industrialized food. We discuss the long-run equilibrium next.

5.2. The long-run equilibrium

In the long-run equilibrium under endogenous quality (*lren*), firms join the industry until their profits are zero, that is, Eq. (20) holds. Additionally, in an interior solution, the profit maximization condition [Eq. (28)] equals zero:

$$\frac{\partial \pi_i}{\partial q_{f,i}} = \left(\frac{\alpha}{n\beta} - \lambda\right) f_i = 0 \tag{30}$$

which yields $n = \frac{\alpha}{\beta\lambda}$.

Inserting $n = \frac{\alpha}{\beta\lambda}$ into Eq. (20), we obtain the mean quality of industrialized food in an interior solution,

$$\hat{q}_f = \left(\frac{1}{\lambda(\alpha - \beta\lambda)}\right)\left(\alpha\lambda q_b + (\alpha + \beta\lambda)\sqrt{\frac{A}{kz}} - \frac{\beta\lambda}{z}\right). \tag{31}$$

By imposing the assumption that $q_f \in [q_f^L, q_f^H]$ we derive Proposition 5.

Proposition 5. *In the long-run equilibrium under endogenous quality, the quality of industrialized food is*

$$q_f^{lren} = \left\{\begin{matrix} q_f^H & if & \hat{q}_f \geq q_f^H \\ \hat{q}_f & if & \hat{q}_f \in \left(q_f^L, q_f^H\right) \\ q_f^L & if & \hat{q}_f \leq q_f^L \end{matrix}\right\}$$

Two forces determine the long-run quality in the market:

1) The zero-profits condition [Eq. (20)]: An increase in the mean quality of industrialized food increases the profits of firms (Proposition 2), thereby attracting more firms into the market in the long run (because of the augmented demand for industrialized food, see Propositions 2 and 3).
2) Profit maximization [Eq. (28)]: As more firms enter the market, each firm is less inclined to invest in the quality of its products (and more inclined to free-ride on the other firms).

Proposition 5 suggests that given the parameters of the model, the profit maximization and the zero-profit condition may, although not necessarily, lead to the socially optimal quality of industrialized food, q_f^H. However, when the quality of industrialized food is lower than q_f^H, there is room for government intervention to achieve the socially optimal quality.

5.2.1. Government policy

Proposition 5 shows that in the long-run equilibrium, when each firm endogenously chooses the quality of its products, the market may be trapped in a “prisoners’ dilemma.” In case the mean quality is lower than the socially optimal one, $\hat{q}_f < q_f^H$, coordinating product quality would increase firms’ profits, social welfare, and the labor supply of mothers. Therefore, this equilibrium calls for government intervention to set a regulatory quality standard of q_f^H in the market.

However, since a quality of q_f^H is not an equilibrium strategy for the firms, each firm has an incentive to reduce the quality of its products below the standard to increase its profits. To enforce the quality standard, the government can levy a fine on firms that deviate from the quality standard, $\phi(q_{f,i})$, that exhibits

$$\phi\left(q_{f,i}\right) > \pi_i\left(q_{f,i}\right) - \pi_i\left(q_f^H\right). \tag{32}$$

That is, to prevent deviation from the quality standard, the fine must be larger than the firms' gain from deviation. Note that in reality, the probability of discovering deviations from the quality standard is lower than 100%. This depends on the efficiency and quality of enforcement, the probability that the government inspects the firms, and other considerations beyond the scope of this study. These may be endogenously determined in a game between the government and firms (all of these variables are also a function of the cost of enforcement).[12]

6. Discussion

We develop a theoretical model to address the interactions between the industrialized food market, home production of food, and the labor supply of mothers. The model, to our knowledge, is the first to combine family economics and industrial economics, modeling the home production of food and the labor supply of mothers, along with the market for industrialized food. The model provides a rich framework to study the effects of government policy and technological improvements on social welfare and the labor supply of mothers.

Our results stress the importance of including both the product market and the labor market in the model when the effects of new policies are examined. We show that technological changes in the production of industrialized food may increase the utility of high-income mothers who use (or switch to) industrialized food as well as their labor supply (because a decline in production cost leads to price reduction). Improvements in home production technologies, however, increase the utility of all mothers, including high-income mothers who never use them because at the equilibrium, the price of the market substitutes declines. The overall effect of productivity at home on the aggregate labor supply of mothers is driven by two forces. Augmented productivity at home attracts high-income mothers to home production and part-time jobs on the one hand, and further allows low-income mothers who prepare homemade food to increase their labor time on the other hand.

When each firm endogenously chooses the quality of its products, two forces determine the mean quality in the market in the long run. On the one hand, an increase in the mean quality augments the profits of firms, thereby attracting more firms into the market (because of the augmented demand for industrialized food). On the other hand, as more firms enter the market, each firm is less inclined to invest in quality (and more inclined to free ride on other firms). Therefore, the mean quality may be lower than the socially optimal one. In this case, it is socially desirable to set a regulatory quality standard in the market. The improved quality would not only benefit high-income mothers who use (or switch to) industrialized food and increase their labor supply but would also increase the profits of firms.

Future study may explore the effect of each policy on income inequality, as well as additional policies that impact child-care at work, flexibility of working hours, work from home, or breastfeeding-friendly workplaces.[13] These policies could reduce friction and allow some integration between home production and work. Formally, instead of one unit of time for each mother to divide between work and home production of food, an extended model may allow some fraction of the time to be used for both activities.

To keep our full-blown model tractable, we use several standard simplifying assumptions. First, we assume a linear utility function, abstracting from potential credit constraints and effects of non-labor income on the labor supply of mothers and on the purchase of market substitutes (e.g., Bar et al., 2018; Siegel, 2017).

Second, the use of a linear utility function and a linear marginal cost function, disregarding the cost of the government enforcement of a quality standard, yields a corner solution for the socially optimal quality of industrialized food. Neverthelss, this solution captures the main forces that need to be balanced by the social planner, the relative importance of child nutrition, and the production cost of firms.

Third, we assume that each household has only one child. If a household has more children, its calorie requirement would be larger, which makes child nutrition more expensive in terms of both the expenditure on industrialized food (for high-income mothers) and the cost of time dedicated for home production of food (for low-income mothers). In our framework, these two considerations cancel out and the mothers' choice of career (full-time with industrialized food and part-time with home production of food) would not change. However, an extended model may potentially consider a return to scale in home cooking, which may shift mothers with more children to home cooking and reduce the labor supply (or purchase of home-cooking services, if affordable). Ceteris paribus, the increased home cooking provides a somewhat ignored "food advantage" for children raised in big families. These advantages offset, to some extent, the well-known quality–quantity tradeoff in households' fertility choices. Thus, policies aimed at increasing the labor supply of mothers should also consider their effects on children and provide further services to substitute for mothers' home production.

[12] According to the literature, to impose a quality standard, the government may need a fine significantly higher than the gain from deviation (e.g., Allingham & Sandmo, 1972 and Yitzhaki, 1974, in the context of tax evasion). Hatsor and Jelnov (2019) suggest that government inspection does not necessarily benefit consumers since it may crowd-out consumer malpractice lawsuits against the firms. Their results depend crucially on government efficiency and on its transparency in reporting its findings to the public. Dranove and Jin (2010) review the literature on the market response to certification and quality disclosure programs. These programs provide systematic information about the quality and safety in specific markets, including, for example, restaurant hygiene grade cards (Jin & Leslie, 2003) and nutritional labeling requirements (Mathios, 2000).

[13] It is often argued that work environment in terms of both policy and structure, is not supportive of women who wish to breastfeed. Barriers to breastfeeding at the workplace include lack of nearby childcare, rigid time schedules that do not allow for nursing breaks, lack of a location providing privacy for breast-pumping, and no facilities for refrigeration of pumped breast milk (Johnston & Esposito, 2007 and American Academy of Pediatrics, 1982).

Appendix

In this section, we present the proofs for Propositions 1, and –3.

Proposition 1. *Using Assumptions 2 and 3, we obtain the following:*

$$\frac{\partial f_i^{sreq}}{\partial \lambda} = -\frac{kq_f z}{1+n} < 0 \qquad \frac{\partial p_f^{sreq}}{\partial \lambda} = \frac{nq_f}{(1+n)} > 0 \qquad \frac{\partial L^{sreq}}{\partial \lambda} = -\frac{nq_f k}{(1+n)} < 0$$

$$\frac{\partial f_i^{sreq}}{\partial q_f} = \frac{kz(\alpha-\beta\lambda)}{\beta(1+n)} > 0 \qquad \frac{\partial p_f^{sreq}}{\partial q_f} = \frac{\beta\lambda n+\alpha}{\beta(1+n)} > 0 \qquad \frac{\partial L^{sreq}}{\partial q_f} = \frac{nk(\alpha-\beta\lambda)}{\beta(1+n)} > 0$$

$$\frac{\partial f_i^{sreq}}{\partial n} = -\frac{k(1-\delta z)}{(1+n)^2} < 0 \qquad \frac{\partial p_f^{sreq}}{\partial n} = -\frac{1-\delta z}{z(1+n)^2} < 0 \qquad \frac{\partial L^{sreq}}{\partial n} = \frac{k(1-\delta z)}{z(1+n)^2} > 0$$

$$\frac{\partial f_i^{sreq}}{\partial z} = -\frac{\delta k}{1+n} < 0 \qquad \frac{\partial p_f^{sreq}}{\partial z} = -\frac{1}{z^2(1+n)} < 0 \qquad \frac{\partial L^{sreq}}{\partial z} = \frac{k}{(1+n)z^2} > 0$$

$$\frac{\partial f_i^{sreq}}{\partial\left(\frac{\alpha}{\beta}\right)} = -\frac{kz\left(q_b-q_f\right)}{1+n} < 0 \qquad \frac{\partial p_f^{sreq}}{\partial\left(\frac{\alpha}{\beta}\right)} = -\frac{\left(q_b-q_f\right)}{1+n} < 0 \qquad \frac{\partial L^{sreq}}{\partial\left(\frac{\alpha}{\beta}\right)} = -\frac{kn\left(q_b-q_f\right)}{(1+n)} < 0$$

$$\frac{\partial F^{sreq}}{\partial n} = \frac{k(1-\delta z)}{(1+n)^2} > 0$$

Proposition 2. *Using Assumptions 2 and 3, we obtain the following:*

$$\frac{\partial \pi_i}{\partial q_f} = \frac{2k\alpha(1-\delta z)}{\beta(1+n)^2} > 0.$$

$$\frac{\partial \pi_i}{\partial \lambda} = -\frac{2k(1-\delta z)q_f}{(1+n)^2} < 0, \quad \frac{\partial \pi_i}{\partial n} = -\frac{2k(1-\delta z)^2}{z(1+n)^3} < 0,$$

$$\frac{\partial \pi_i}{\partial z} = -k\left(\frac{1-\delta z}{z(1+n)}\right)^2 < 0, \quad \frac{\partial \pi_i}{\partial\left(\frac{\alpha}{\beta}\right)} = -\frac{2k(1-\delta z)\left(q_b-q_f\right)}{(1+n)^2} < 0$$

Proposition 3.

$$\frac{\partial n^{lreq}}{\partial z} = -\frac{(z\delta+1)\sqrt{k}}{2z^{\frac{2}{3}}\sqrt{A}} < 0.$$

The rest of the derivatives are easily obtained.

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