Ferretti and Malorgio
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Food policies: balancing health and market in the era of ubiquitous ultra-processed foods

Fabrizio Ferretti[1*] and Giulio Malorgio[2]

*Correspondence:
fabrizio.ferretti@unimore.it

[1] Department of Communication and Economics, University of Modena and Reggio Emilia, Viale Allegri 9, 42121 Reggio Emilia, Italy
[2] Department of Agricultural and Food Sciences, Alma Mater Studiorum - University of Bologna, Viale Fanin 50, 40127 Bologna, Italy

Abstract

As the development of modern food systems continues to reshape dietary habits, the need for effective food policies to counter the rise of ultra-processed foods (UPFs) becomes increasingly urgent. UPFs are industrial formulations of several highly refined ingredients and additives with little or no nutritional value but potentially harmful health effects. In this paper, we develop a simple model of duopolistic competition in which food manufacturers compete by choosing the degree of food sophistication of their products (i.e., the degree of food formulation and processing). We show that when firms compete for market shares, an unhealthy degree of food sophistication is a strategically stable Nash–Bertrand equilibrium outcome. Furthermore, we compare the effectiveness of alternative health-related food policies. Our model highlights the shortcomings of nutrient-to-limit regulations and suggests that policy interventions should prioritize whole-food reformulation-based approaches within an 'ecological' regulatory framework.

Keywords: Nash–Bertrand equilibrium, Oligopolistic competition, Nutrient-to-limit regulation, Ultra-processed foods, Whole-food reformulation strategies

Introduction

The development of modern food systems has changed the eating habits of millions of people worldwide (Popkin 2017). One major change in both advanced and emerging economies is the gradual replacement of freshly unprocessed or minimally processed foods with convenient, long shelf-life and ready-to-consume ultra-processed foods (UPFs) (Vandevijvere et al. 2019). UPFs are industrial formulations of refined ingredients, often with little or no nutritional value, whose regular consumption may have harmful health effects. They typically contain high amounts of refined carbohydrates and added sugars, unhealthy fats (such as trans and saturated fats), sodium, and multiple additives. UPFs also come with captivating packaging designs, aggressive marketing strategies, and affordable prices (Monteiro et al. 2019).

The practical and appealing characteristics of UPFs allow them to replace traditional healthy foods and food practices in everyday eating habits. In Western economies, such as the USA, Canada, and the UK, UPFs currently account for more than 50% of the total daily energy intake (Poti et al. 2015; Moubarac et al. 2012; Rauber et al. 2019). The increased real incomes in developing economies have also led to a rise in the availability

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and consumption of UPFs in Africa and Latin America, as well as in many other middle- and low-income countries (PAHO 2015; Reardon et al. 2021; Gangopadhyay 2023).

These complex structural changes in dietary patterns have significant implications for public health. According to a recent comprehensive umbrella review, a large number of studies recognize the adverse health effects of the increasing prevalence of UPFs in modern food systems (Lane et al. 2023). A higher proportion of UPFs in the everyday diet is considered a major behavioral risk factor for several reasons. UPFs are often high-energy-dense products that lack essential micro- and macronutrients. Due to their high content of unhealthy added sugars and fats, UPFs provide a significant source of empty calories. Consuming excessive sugar and fat can lead to overweight and obesity, prolonged episodes of insulin resistance (a precursor to type 2 diabetes), and increased levels of LDL cholesterol. Similarly, excessive added salt in several UPFs (such as salty snacks and ready-to-eat meals) can lead to high sodium intake, resulting in hypertension. Furthermore, UPFs are often designed to be hyper-palatable, stimulating habit-forming behaviors that significantly increase the risk of overconsumption.

This is why the regular consumption of UPFs has been associated with an increased incidence of metabolic syndrome, a cluster of three or more unhealthy physiological conditions. These conditions include high blood pressure, high blood sugar, increased waist circumference, high triglycerides, and low HDL cholesterol. When these conditions occur together, they promote systemic inflammation (Shu et al. 2023) and significantly increase the risk of developing one or more non-communicable diseases (NCDs), primarily cardiovascular diseases (such as heart attacks and stroke), type 2 diabetes, chronic kidney and liver diseases, certain types of cancers, and even common mental health disorders (Srour et al. 2020; Cordova et al. 2023).

Whereas the health impacts of UPF consumption are extensively studied, less attention has been paid to the market mechanisms through which competition in the food industry promotes the global spread of UPFs and the development of unhealthy food environments. In this line of research, Moodie et al. (2021) and Wood et al. (2021) conducted in-depth systematic reviews to examine the political and market practices undertaken by the leading multinational food corporations. They gathered evidence on how the major global food manufacturers influence people's eating patterns and tend to undermine the development of effective policies for preventing NCDs. This influence is achieved through various strategies, such as intensive lobbying activities, aggressive marketing tactics (especially toward vulnerable consumers), dissemination of misleading health claims, and exploitation of regulatory gaps.

However, research has only recently begun to investigate the mechanisms through which the competitive pressure in different market structures can affect the healthiness of food composition. In this area of research, for instance, Van Dam et al. (2022) have analyzed the relationship between market concentration and food healthiness across European countries. Their findings revealed that higher market concentration in the domestic food industry was significantly associated with increased sales of unhealthy UPFs. Hamilton and Réquillart (2016) focused instead on the incentives for UPF producers to choose cost-reducing inputs. Abstracting from product differentiation, they showed that price competition among food processors leads firms to opt for unhealthy ingredients, leading to a decrease in the overall healthiness of their products, even when consumers are fully aware of the harmful content of the foods available on the market.

This article aims to contribute to this scant literature on the supply-side determinants of food healthiness. Specifically, we address the following research question: How does non-price competition among interdependent food manufacturers affect the health composition of processed foods? To this end, the paper proceeds as follows. First, we develop a simple model of duopolistic competition in which food manufacturers compete with each other by endogenously choosing the degree of food sophistication of their products. The model is based on an adapted Bertrand framework of oligopolistic competition with horizontally differentiated products. Second, we analyze the effectiveness of alternative health-related food policies, namely the nutrients-to-limit and whole-food reformulation strategies, to curb UPF consumption, improve eating habits, and promote people's health outcomes.

Conceptual framework

According to the World Health Organization (WHO), most European countries face a growing challenge from nutrition-related chronic diseases, which seriously threaten public health (WHO 2021). The increasing availability of UPFs has raised concerns about the health and economic sustainability of modern food systems (Fardet and Rock 2020). From this perspective, Campbell et al. (2023) suggest framing the widespread phenomenon of UPFs as a 'tragedy of the biological commons.' This approach allows us to better understand the dynamics and implications of the UPF transition process.

In his seminal article, Hardin (1968) shows how problems of overuse and depletion arise when scarce resources are treated as common property, and anyone can use them without regulations. According to Campbell et al. (2023), in modern food systems, people's health can be viewed as a shared and limited resource that tends to mirror the tragedy of the commons due to the over-exploitation from UPF manufacturers. As in Hardin's metaphor of a common pasture that herders use for grazing their cattle—where each herder has the incentive to add additional animals to the common pasture to maximize its profits—in today's global food market, large for-profit manufacturing corporations have the incentive to develop and aggressively launch ever-new unhealthy UPFs to increase their business profitability.

In this context, if we continue with the analogy, UPF manufacturers are like herders who seek to maximize their profits by exploiting the population's needs and wants for food. The various UPFs available on the market are comparable to a herd of animals competing for space on a common but limited pasture, represented here by the economic and physiological limits of the demand for food and the resulting impact on people's health. On the one hand, UPFs are private goods characterized by both excludability and rivalry. On the other hand, the population's eating-related health conditions are rivalrous but non-excludable (and thus exploitable) goods. From a public health perspective, people's health acts as a sort of 'open but limited' common pasture; it is open (non-excludable) to competition among firms that attempt to consolidate and increase their market shares, but it is also limited (rivalrous) by the biological laws that govern human nutrition and health.

As a result, competition in UPF markets remains sustainable as long as UPFs make up a small fraction of people's diets (i.e., when consumed only occasionally). Conversely, when UPFs become a structural and significant part of everyday eating habits, competition among food manufacturers in pursuit of profit-making opportunities can have harmful effects on people's health and well-being.

However, the detrimental effects of competition within the global UPF manufacturers extend beyond public health issues. Wood et al. (2023*a*), using an adapted structure-conduct-performance analysis, demonstrate how the strategies adopted by the world's leading food corporations lead to cycles of 'creative destruction' of traditional human diets and food cultures. This process has far-reaching negative implications for the economy, society, and the environment, underscoring the urgency of addressing the increasing role of UPFs in modern diets. In fact, the sustainability of modern food systems involves a complex set of interrelated natural, cultural, and economic (tangible and intangible) factors (FAO 2018). The traditional Mediterranean diet, for instance, based on unprocessed or minimally processed products, provides an excellent illustration of the multidimensional relationships that link food production, the natural, cultural, and economic environment, and human health (Dernini et al. 2013; Capone et al. 2021).

The market and non-market strategies pursued by UPF corporations—to expand demand, leverage innovative processing technologies, control the whole supply chains, drive down labor and intermediate inputs (i.e., agricultural) costs, and weaken (or delay) government regulations—tend to deconstruct the articulate set of formal and informal connections that hold together the various dimension of the sustainability of food system and human diets (Moodie et al. 2021; Wood et al. 2021). These disruptive effects are even exacerbated by the increasing process of financialization of the largest UPF corporations that tend to force firms to maximize short-run shareholder returns at the expense of the interests of the various actors and stakeholders involved in modern food systems (Wood et al. 2023b). In the following pages, we build on this literature to examine the competitive market mechanisms that drive the ongoing transition to UPF-based diets.

Methods

In modern food systems, virtually all foods consumed are processed to some extent. However, UPFs have some unique features. They are specific formulations of five or more highly purified ingredients, mainly exclusive to industrial use. These selected ingredients—including modified starches and sugars, hydrolyzed proteins, hydrogenated oils, stabilizers, flavors, flavor enhancers, colors, antifoaming, bulking, and gelling agents, for example—undergo several advanced processing techniques during the food production stages (Moubarac et al. 2014; Gibney 2019).

Competition among food manufacturers forces producers to regularly implement their formulating and processing procedures in order to develop increasingly tempting and hyper-palatable (i.e., highly appetizing and pleasing) foods. More appealing and tasty products allow firms to increase profits by expanding their market shares. We thus introduce a catch-all variable, denoted μ, to capture the degrees of food formulation and processing (Levine and Ubbink 2023). By summarizing these two dimensions, μ serves here as a measure of the degree of food sophistication. An increase in μ indicates a greater level of sophistication—i.e., a more appealing and palatable food—but also an increased adverse impact on people's health outcomes.

The degree of formulation refers to the selection of the number, type, and proportion of food and non-food ingredients used in making UPFs. In contrast, the degree of processing refers to the number, extent, and type of technological transformation that ingredients and their combinations undergo before becoming a final product. This is why UPFs should be more accurately referred to as 'ultra-formulated and ultra-processed foods.' Both formulation and processing contribute to the degree of food sophistication, which, in turn, has an impact upon the food matrix (i.e., the combination of the nutrient and non-nutrient components of foods and their molecular relationships). By damaging the natural food structures, food sophistication impairs the food matrix, with several adverse effects, ranging from diminished nutrient availability, alterations in the status of human gut microbiota, and the disruption of physiological processes, such as digestion kinetics and glycemic and satiety control mechanisms. As a result, highly sophisticated (formulated and processed) foods alter the functioning of the immune regulation system and thus contribute to promoting systemic inflammation (Henney et al. 2024).

A model of oligopolistic competition in the degree of food sophistication

According to Bertrand's model of oligopolistic competition, firms simultaneously set prices, and consumers set market quantities by deciding how much to buy. In a duopoly framework with horizontally differentiated products, consumers perceive goods offered by firms 1 and 2 as imperfect substitutes. Each firm's demand function depends not only on its own price but also on the price charged by the other firm (Perloff 2020). For our purposes, we modify Bertrand's original hypotheses slightly by introducing two new assumptions. First, to capture consumers' heterogeneous preferences over the products' characteristics, we include in the demand functions our measure of the degree of food sophistication (μ). Second, we continue to assume a price-setting environment. However, we postulate that duopolists engage in tacit collusion over prices to avoid the potentially disruptive effects of a price war. In other words, firms do have the ability to set prices, but they opt for non-price competition. By committing themselves to a tacit price-fixing arrangement, firms set the same price and compete with each other by designing increasingly palatable and pleasing products.

Under these assumptions, in the case of linear relationships, the demand functions for firms 1 and 2 can be described by the following equations:

$$q_1 = a_1 - b_1 p + d_1 \mu_1 - h_1 \mu_2 \tag{1}$$

$$q_2 = a_2 - b_2 p + d_2 \mu_2 - h_2 \mu_1 \tag{2}$$

where q_1 and q_2 are the quantities demanded, μ_1 and μ_2 are the degrees of food sophistication of each product, and p is the normal or full-cost price. According to post-Keynesian price theory, based on oligopolistic competition, fix-price markets, and the full-cost pricing rule (Eichner 1976; Rassuli and Rassuli 1988), we assume that firms set prices by adding to unit costs—calculated at the normal rate of capacity utilization—a net margin to cover profits and obtain a given target rate of return (Lavoie 2006). Under normal-cost pricing, if firms have similar cost structures, p can be interpreted as the tacit coordinated pricing outcome (Farm 2020).

In Eqs. (1) and (2), each firm faces a downward-sloping demand curve. The quantity demanded falls with an increase in p, whereas a change in the degree of food sophistication causes the demand curves to shift. For firm 1, for instance, an increase in μ_1 would cause its demand curve to shift rightward, whereas an increase in μ_2 would shift it leftward and vice versa. For simplicity, assume zero fixed costs and constant unit direct costs up to each firm's normal (standard) capacity utilization rate. Thanks to standardized production processes and technological advancements in automation, logistics, and supply chain management—which aim to improve efficiencies and reduce variability in production—average and marginal costs can remain relatively stable for highly processed and packaged foods (Fernández-Salvador and Moreno 2016).

Let the unit direct costs be denoted by c. The profit functions for firms 1 and 2 can be written as:

$$\pi_1 = (p - c)q(p, \mu_1, \mu_2) = (p - c)(a_1 - b_1 p + d_1\mu_1 - h_1\mu_2) \quad (3)$$

$$\pi_2 = (p - c)q(p, \mu_2, \mu_1) = (p - c)(a_2 - b_2 p + d_2\mu_2 - h_2\mu_1) \quad (4)$$

where π_1 and π_2 and (p—c) measure total and per unit profits, respectively. As in Bertrand's model, we proceed by differentiating Eqs. (3) and (4) with respect to p. However, given that firms set prices but compete for market share through product differentiation, we solve each first-order condition for μ_1 and μ_2, respectively. For firm 1, this gives:

$$\mu_1 = \frac{[b_1(2p - c) - a_1]}{d_1} + \frac{h_1}{d_1}\mu_2 = A_1 + B_1\mu_2 \quad (5)$$

with $A_1 \equiv [b_1(2p - c) - a_1]/d_1$ and $B_1 \equiv h_1/d_1$. Equation 5) describes the reaction function for firm 1, hereafter denoted by $R_1(\mu_2)$, when μ rather than p is taken as the competitive variable.

It is worth noting that this expression differs from the usual best price (i.e., profit-maximizing) response function. In this model, firms set prices according to the normal-cost method, in which normal unit direct costs are independent of the production level (at least, as long as it is below full capacity). In setting prices, firms consider both cost and demand conditions. Then, given p, each firm adjusts the quantity produced—by changing the degree of capacity utilization—in response to changes in demand. Other things equal, the demand for firm 1 changes as the degree of food sophistication of firm 2 changes, and vice versa. Variations in μ affect the quantities sold at price p; thus, given c, they affect each firm's total profits.

As a result, given the demand and cost conditions, $R_1(\mu_2)$ indicates how 1 reacts to the decision firm 1 expects its rival will make about u_2. Specifically, for any level of food sophistication that firm 2 might set, firm 1's reaction curve gives the level of u_1 that 1 should set to preserve and compete for its market shares. Similarly, firm 2 reacts to actual or expected changes in the firm's 1 degree of food sophistication according to its reaction function: $R_2(\mu_1) = A_2 + B_2\mu_1$, where $A_2 \equiv [b_2(2p - c) - a_2]/d_2$ and $B_2 \equiv h_2/d_2$. The slope of each firm reaction curve is given by the ratio of the impacts of a one-unit increase in μ on the corresponding quantity demanded, and it will typically be upward.

For instance, if firm 2 increases its degree of food sophistication, firm 1 will find it profitable to increase μ_1 to offset the decrease in demand caused by a higher μ_2. Thus, for firm 1, the greater the value of h_1 (i.e., the one-unit impact of μ_2 on q_1), the higher the increase in μ_1 required to respond to a given increase in μ_2 by firm 2 (and vice versa).

Results

Each firm must choose its food sophistication strategy, relying on reasonable assumptions concerning the expected (or accounting for the actual) behavior of its rival. The market for ultra-processed foods is depicted in Fig. 1, where μ_1 and μ_2 are measured on the y- and x-axes, respectively. The market equilibrium—i.e., the degree of sophistication of foods 1 and 2 that will prevail in the market—is found by simultaneously solving $R_1(\mu_2)$ and $R_2(\mu_1)$, which describe how each duopolist adjusts its strategy in response to the other firm's choice. As shown in Fig. 1, the reaction curves intersect at point E, where

$$\mu_1^* = \frac{A_1 + A_2B_1}{1 - B_1B_2},\ \mu_2^* = \frac{A_2 + A_1B_2}{1 - B_1B_2} \tag{6}$$

In E, both firms are on their reaction functions, and neither firm has the incentive to change its strategy by unilaterally choosing a degree of food sophistication different from μ^*_1 and μ^*_2.

Let us consider a disequilibrium condition in which firm 2 chooses a degree of μ well below μ^*_2, such as μ'_2. Given its reaction function $R_1(\mu_2)$, firm 1 reacts to the strategy of firm 2 by opting for μ'_1. However, if firm 1 selects μ'_1, firm 2's reaction curve indicates that 2 should respond by increasing the degree of sophistication of its product. In other

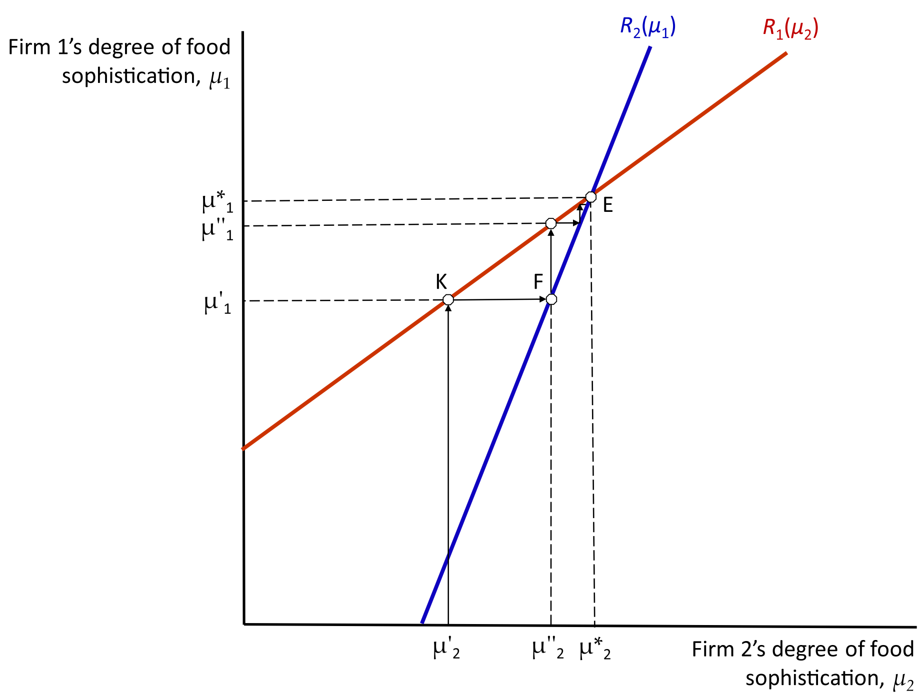

Fig. 1 A Nash-Bertrand equilibrium in the degree of food sophistication

words, firm 2 has the incentive to redesign its food by offering, for instance, a more tasty (i.e., sweet, crunchy, and fragrant) product. Therefore, given $R_2(\mu_1)$, firm 2 reacts to μ'_1 by choosing μ''_2. Again, with μ_2 at a level equal to μ''_2, firm 1 would undergo a decrease in its residual market demand. This stimulates 1 to further enhance the appeal and palatability of its product by increasing the degree of sophistication up to μ''_1, and so forth.

This process tends to converge. If allowed to continue, it will lead both firms to design even more tempting foods until μ^*_1 and μ^*_2, which are the market equilibrium levels of food sophistication. Point E is thus strategically stable, and the pair of values (μ^*_1, μ^*_2) is a Nash-Bertrand equilibrium (Gravelle and Rees 2004). In short, when interdependent firms compete for market shares by designing more tempting products, an unhealthy degree of food sophistication is the 'natural' equilibrium outcome, as shown in Fig. 1. With a greater number of firms, the market equilibrium will lead to the pervasive availability of a wide range of unhealthy products able to replace freshly prepared dishes and meals based on unprocessed or minimally processed foods (such as whole grains, fresh fruit and vegetables, pulses, eggs, and traditional dairy products).

Discussion

Unhealthy diets are one of the main modifiable risk factors behind the increasing worldwide incidence of non-communicable diseases. UPFs are typical building blocks of unhealthy food environments. They are ubiquitous in modern food markets. It has been estimated that in large, populous countries such as Brazil, China, India, and the USA, only an average of US$1.10 is spent on healthy foods for every US$10 spent on the products of the top 20 global food and beverage companies (Bandy et al. 2023). UPFs are not merely natural foods that have undergone some form of processing but rather industrial formulations of several highly refined ingredients and additives with little or no nutritional value. Designed to be hyper-palatable and habit-forming, the daily consumption of UPFs provides empty calories and is also suspected of promoting low-grade inflammatory processes (Christ et al. 2019).

Faced with the growing health and economic burden of major diet-related diseases, several countries have implemented policies aimed at promoting healthier diets. Overall, such food and nutrition policies span from supporting better-informed dietary choices (e.g., nutrition education programs, labeling regulation, and public information campaigns) to changing the market environments (e.g., taxes, subsidies, marketing restrictions, and voluntary or mandatory different types of reformulation strategies) (Capacci et al. 2012). Although each of these measures is potentially useful and has been proven somewhat effective in slowing down the worsening of human diets (Mazzocchi 2017), we are still far from reversing the UPF transition process.

The multiple influences that shape the evolution of modern food systems (Traill et al. 2014) suggest that single policies, albeit helpful, cannot prevent the displacement of healthy dietary patterns with UPF-based diets composed of intrinsically unhealthy products. The evidence indicates the need for a unified framework based on an impactful mix of policies to overcome the limitations of single instruments (Popkin et al. 2021). Recognizing people's health as a 'biological common', an effective whole-food reformulation strategy should be implemented within an ecological regulatory context (Northcott et al.

2023) to encompass all dimensions of food system sustainability (Belik 2020; Malorgio and Marangon 2021).

As the FAO (2012) advocates, sustainable diets are affordable, nutritionally adequate, and protective of environmental and cultural biodiversity. This approach, together with a new narrative about the adoption of healthy eating habits (Borrello et al. 2023)—and supported by system-based evaluations of food-related policy design, implementation, and outcomes, such as those performed within the Pan-European Policy Evaluation Network (PEN) (Kamphuis et al. 2022)—can promote the set of necessary conditions needed to reverse the UPF transition process in a win–win scenario (Soler and Thomas 2020), where regulation forces market competitions to operate toward sustainable diets.

Implications for food policy

Our results have significant implications for health-related food policies. Besides the general labeling rules to provide consumers with comprehensive information about food content and composition, such as those adopted within the European Union (Himmelsbach et al. 2014), several countries have begun enacting fiscal and regulatory instruments to curb the consumption of UPFs and counter the associated adverse health effects. Taxes, nutritional warning labels, marketing restrictions, voluntary agreements, and alternative reformulation policies (such as nutrients-to-limit and whole-reformulation strategies) have been proposed and, in some cases, implemented to discourage UPF purchasing and promote healthier eating habits (GFRP 2021).

Specifically, nutrients-to-limit policies are frequently advocated to mitigate the harmfulness of UPFs by reducing the content of single 'negative' nutrients, such as added salt, sugars, and trans-fatty acids. Our model helps clarify why these policies may have a positive but limited impact on the harmful effects of UPF-based diets. As in the case of taxes, mandatory standards, and voluntary agreements that target single nutrients, they can encourage food manufacturers to further reformulate their products by using other unhealthy ingredients (for instance, by replacing refined sugar with highly processed non-caloric sweeteners) and merely adding negligible amounts of some specific 'positive' micronutrients, such as one or more vitamins and/or minerals (Scrinis and Monteiro 2017).

In terms of our model, this corresponds to movements along given reaction curves that trigger competition among firms in designing even more sophisticated products without significantly improving their nutritional quality. For instance, if firm 2 creates a newly reformulated product (using unhealthy non-caloric sweeteners) and advertises it as 'sugar-free,' firm 1 may respond with a slightly different, more sophisticated product, promising 'fewer calories with the same appealing taste.' As in the above-described example (Fig. 1), the market starts at point K. The nutrients-to-limit policy promotes a process that increases the degree of food sophistication from point K to F up until point E. The final result is again a set of hyper-palatable UPFs with, at least, uncertain health benefits. Furthermore, these reformulated products—that meet the required regulatory targets—allow marketers to aggressively promote them as 'beneficial' components of an everyday healthy diet. This results in fixing E as a persistent long-run equilibrium.

Conversely, our findings suggest that policy interventions should prioritize whole-food reformulation approaches rather than focusing solely on nutrient-specific changes.

Whole-food reformulation strategies aim to comprehensively improve foods' nutritional properties by replacing highly processed industrial ingredients with a few minimally processed and unprocessed ones (Scrinis and Monteiro 2017). Voluntary agreements about whole-food reformulations can be implemented along with mandatory front-of-package warning labels and severe marketing and sales restrictions for all products that do not comply with regulatory requirements.

Within the model depicted in Fig. 2, this approach can help prevent the vicious cycle of increasing food sophistication. For instance, if firm 2 chooses μ^{R}_{2} to adhere to a whole-food reformulation agreement, firm 1 has little incentive to keep its product unchanged. Restrictions on TV/online ads, sponsorships, and sales in schools (and other protected environments) would significantly reduce firm 1's residual demand. Therefore, a well-designed whole-food reformulation strategy forces firms to move downward along their reaction curves until they meet the regulatory health-related requirements (such as μ^{R}_{1} and μ^{R}_{2}, at point J). These degrees of food sophistication can be interpreted as a short-run disequilibrium outcome that will prevail in the market under the regulatory framework (i.e., when firms' behavior is constrained, given the demand and cost conditions, by the new regulatory context).

Furthermore, research has shown that UPFs are not only nutritionally unbalanced products.

Besides being formulated with unhealthy ingredients, UPFs can be habit-forming or even quasi-addictive products (Gearhardt and DiFeliceantonio 2022). This implies that their widespread availability promotes the adoption of unhealthy dietary patterns. In turn, the regular consumption of these habit-forming foods shapes consumers' tastes and purchasing behaviors, increasing the demand for unhealthy products. Thus, UPF

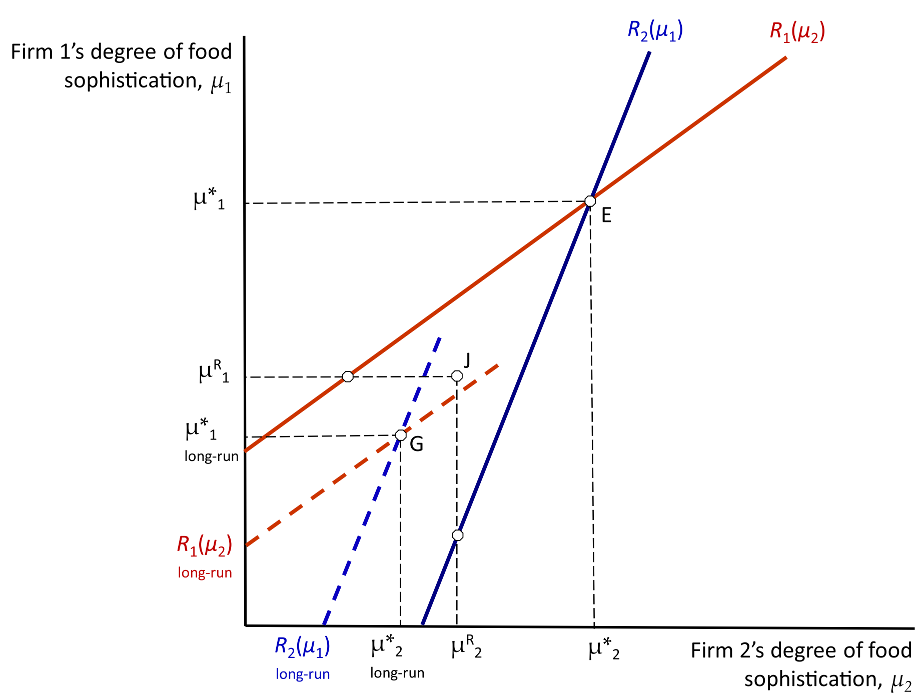

Fig. 2 Impact of whole-food reformulation policies

consumption tends to generate a self-reinforcing process that links unhealthy eating habits and negative health effects in a vicious circle that increases the incidence of nutrition-related diseases (Ferretti et al. 2021). Consequently, by combining voluntary agreements and mandatory restrictions, an effective whole-food reformulation strategy can promote positive structural changes in eating habits. In the long-run, better eating habits imply different demand conditions (i.e., an increased demand for healthier and minimally processed foods). In Fig. 2, this is captured by an inward shift of the reaction curves (from the solid to the dotted lines) that results in a long-run equilibrium characterized by a low degree of food sophistication. The long-run reaction curves that reflect the healthier dietary patterns intersect at point G, where the degree of food sophistication is lower than the initial recommended one (μ^{R}).

Conclusions

The objective of this study was to examine the determining market forces behind the global rise of UPFs in modern food markets. To this end, we took a supply-side perspective to build a modified Bertrand model of oligopolistic competition in which firms compete by choosing the degree of food sophistication (i.e., formulation and processing). The main theoretical implication of our model is that unregulated processed food markets tend to converge toward an equilibrium with an unhealthy product composition. Interdependent firms have an incentive to continuously implement foods' palatability and attractiveness in attempting to increase their market shares. This result may help in designing improved health-oriented food regulations. Specifically, the model highlights the market mechanism underlying the main shortcomings of nutrient-to-limit approaches and provides support for implementing whole-food reformulation-based policies. Further research is needed to overcome the many limitations of our basic model. Potential interesting extensions of our research should include in the analysis several other features of food markets, such as price competition, the role of food chain distribution, the leader–follower relationships among food manufacturers, and the impact of fiscal policies.

Abbreviations

FAO	Food and Agriculture Organization of the United Nations.
GFRP	Global Food Research Program.
PAHO	Pan American Health Organization.
PEN	Pan-European Policy Evaluation Network.
UPFs	Ultra-processed foods.
WHO	World Health Organization

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Author contributions

Fabrizio Ferretti conceived and designed the study, developed the theoretical model, analyzed and interpreted the results, and wrote the paper. Giulio Malorgio analyzed and interpreted the results and contributed to writing the paper. All authors read and approved the final manuscript.

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Declarations

Competing interests
The authors declare that they have no competing interests.

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