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Can foods produced with new plant engineering techniques succeed in the marketplace? A case study of apples

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Abstract

We present a model for research and development (R&D) investment in food innovations based on new plant engineering techniques (NPETs) and traditional hybridization methods. The framework combines uncertain and costly food innovation with consumers' willingness to pay (WTP) for the new food. The framework is applied with elicited WTP of French and US consumers for new improved apples. NPETs may be socially beneficial under full information and when the probability of success under NPETs is relatively high. Otherwise, the traditional hybridization is socially optimal. A probable collapse of conventional apples raises the social desirability of new apples generated by NPETs and traditional hybridization.

KEYWORDS

apple, consumer information, food innovation, gene editing, industrial organization, new plant engineering techniques, willingness to pay

JEL CLASSIFICATION

C91, D12, Q16

New plant engineering techniques (NPETs), such as gene editing (GE), are a group of recent biotechnologies allowing to accurately target deoxyribonucleic acid (DNA) manipulation of various organisms at a relatively low cost by silencing, suppressing, adding, or altering genetic material without introducing foreign genes.[1] Various applications of those techniques already exist and many others are actively explored for their promising potential in human and animal medicine, as well as in agriculture (Erpen-Dalla Corte et al., 2019; Herrero et al., 2020; NAS, 2016; Ormond et al., 2017; Qaim, 2020; Zhao et al., 2019). For example, in horticulture, GE and other NPETs could be path-breaking to alter fruits and vegetables by improving the strength of their production, by increasing their resistance to biotic stresses, and by favoring their appearance and/or their nutritional quality (e.g., improved starch content in potatoes or higher lycopene content in tomatoes, Erpen-Dalla Corte et al., 2019). For arable crops like cereals or legumes, NPETs are useful for strengthening plants' characteristics to endure prolonged droughts or bypassing pesticides resistance, and acute problems likely to cripple yields and ultimately supply security (Osakabe et al., 2016; Ricroch et al., 2017; Zafar et al., 2020). Animal applications are addressed in Zhao et al. (2019).

This potential revolution in agricultural and food production innovation may be facing a major headwind, especially in many European countries where a significant proportion of consumers are reluctant to purchase "anything produced with biotechnologies."[2] Under this considerable uncertainty in the marketplace, several questions are paramount and require answers. Will consumers and policymakers discount NPETs-based novel foods and compromise their market emergence, as it has happened for many GMOs? There is emerging evidence that consumers, especially in European countries (e.g., France), have concerns for and therefore discount NPETs-based foods, but to a lesser extent than for GMOs (Beghin & Gustafson, 2021). What are the consequences for research and development (R&D) investments relying on GE, or other NPETs, and producer strategies in terms of innovations' adoption, as well as the potential social benefits resulting from these innovations? Will such innovations be facilitated by increasing problems with many diseases and pests, such as the Fusarium fungus affecting Cavendish bananas (Crop Biotech Update, 2021), and the ringspot virus, which has whipped out traditional papayas in Hawaii (Gonsalves et al., 2007)? The papaya case represents a tangible case of the collapse of a conventional crop leading to greater consumer acceptance of GMO-based food innovation (the resistant papaya). Environmental issues such as climate change or water scarcity could also facilitate these innovations.

Our paper provides a framework to answer the above questions and contributes to the current debate on new biotechnologies by studying the link between consumers' preferences and firms' incentives for R&D of new foods through GE and other NPETs or through conventional hybridization methods and their emergence on markets. This is the conceptual contribution of the paper. We analyze the social value of food innovations utilizing a simple industrial organization (IO) model that combines the cost of food innovations (with different technologies, NPETs or traditional hybridization) with consumers' willingness to pay (WTP) for those innovations. Our analysis relies on three main components. First, the WTP is conditioned on the level of acceptance or rejection of the technology used to innovate. The framework highlights the role of consumer acceptance of technology and their information levels regarding the technology underlying the novel food. Consumer acceptance or reluctance implies a potential cost of ignorance and regret if consumers are not informed on the technology embodied in the new food before they buy it. Second, the model accounts for the uncertain and costly nature of R&D processes for traditional hybridization and NPETs. The model allows identifying each preferred technology (NPETs or traditional hybridization) that emerges under varying assumptions and their respective economic welfare outcomes. Third, the framework is also suitable for analyzing a collapse scenario in which the existing conventional food item (the default option for consumers) disappears and must be replaced by the new food. Consumers can no longer revert to conventional food, making the new food the unique choice available to consumers. The welfare implications of such a collapse scenario are evaluated.

We follow with an application of the model to a case study of a hypothetical development and introduction of new apple varieties into the market. The application builds upon the results of two experimental surveys of consumers' preferences in France and the United States for novel apples, relative to conventional apples (Marette et al., 2021).

Our paper provides several contributions to the literature evaluating WTP for novel foods based on NPETs techniques and their emergence. First, recent studies identify significant discounting of GE and other NPETs foods by consumers compared to conventional foods, which is reminiscent of past reluctance to GMO food (Bunge & Dockser, 2018; Caputo et al., 2020; De Marchi et al., 2019, 2020; Edenbrandt et al., 2018; Hudson et al., 2015; Lin et al., 2019; Marette et al., 2021; Muringai et al., 2020; Shew et al., 2018; and Yunes et al., 2019; Beghin & Gustafson, 2021 for a survey). See Bredahl, 1999; Lusk, 2011 for earlier studies on attitudes toward GMOs. We go one step further by providing a conceptual framework to analyze the social desirability, thus value, of NPETs-based food innovations and their potential emergence and success in the marketplace based on consumer valuation and cost of R&D.

Second, the application to apples leverages the recently elicited WTPs into the proposed framework. A welfare analysis uses the WTPs to calibrate the model of food innovations under competing technologies (traditional hybridization, GE as representative of NPETs). The approach accounts for the fixed cost of R&D and the probability of innovation success under both technologies. The proposed framework is applicable to other food novelties that could emerge with similar technologies or other disruptive technologies contributing to a sustainable food supply (see Herrero et al., 2020, for a list of these technologies).

Third, we analyze the situation of a potential agronomic collapse of conventional foods to evaluate whether the emergence of NPETs-based foods can be facilitated under this extreme case scenario. We draw some *ex ante* policy implications, thus before any actual realized outcomes. This inclusion of probabilities of innovation and a collapse case scenario is new and differs from previous contributions to the literature on experimental methods (Lusk et al., 2005; Lusk & Marette, 2010; Marette et al., 2008; Rousu et al., 2007, 2014). In the latter, the introduction of new goods is certain and the innovation is "predictable" and effectively existing, while our paper introduces R&D uncertainty and sunk costs into the analysis.

The remainder of the paper is organized as follows. Section 1 discusses new genetic technologies for food innovations in agriculture, as a potential solution for addressing risks related to complete collapses (or disappearance) of conventional food crops. Section 2 presents the analytical strategy based on a simple IO model of R&D investment combined with the consumer demand for the new food varieties and consumer surpluses leading to the welfare analysis. Section 3 presents the application of the model to apples and summarizes the hypothetical experiments' results used to derive the consumer demands and welfare valuations. The main results of the application follow and the extension to the collapse of conventional apples is also studied. In the conclusions, we discuss potential extensions of our research approach and some implications for regulatory policies.

1 | NPETS TECHNOLOGIES FOR FOOD

In this paper, we focus on the case of quality enhancement of food brought about by NPETs and rely on a hypothetical case of improved apples. The innovation relies on editing the genetic sequence of the apple to neutralize or delete the gene responsible for browning. More specifically, we refer to the CRISPR-Cas9 technique,[3] which has become an engineering tool that makes it easier and more precise to modify DNA sequences. This process clearly differs from traditional GMOs since no external gene is introduced in the new good.

Beyond the hypothetical cases, the actual commercialization of new fruits and vegetables based on GE or other NPETs is limited. Nonbrowning mushrooms obtained with GE and nonbrowning potatoes obtained with RNAis have been patented but not yet commercialized (Jalaluddin et al., 2019). Currently, only the Arctic© apple and the Simplot Innate® potatoes are sold in Canada and the United States on a limited basis and with caution.[4]

Innovations and varietal improvements in agriculture are slow and costly processes. For example, it takes around 20 years of R&D for getting a new apple variety. Besides, consumers may react negatively to innovations (Glenna & Jussaume, 2007). Consequently, producers and private innovators often prefer newly augmented traditional methods, such as the marker-assisted selection that combines genetic knowledge and classical hybridization into so-called selective breeding, even if such techniques remain quite expensive (Wannemuehler et al., 2019). GE and other NPETs innovations in food are mainly driven by public research institutes or by marketing orders with checkoff program funding agricultural research, or with public involvement like the one led by Washington State University for designing new apples. Those public organizations of R&D potentially mitigate the reluctance of innovators and producers by maintaining conditions under which new goods could emerge. This is important because of crops' agronomic fragility, pesticide resistance and outbreaks, and even collapse of the conventional variety of the good. Biotechnology appears as a potential solution for preventing these risks (Crop Biotech Update, 2021; Le Page, 2019; NAS, 2016). Examples of major outbreaks include cocoa with the swollen-shoot virus, tomatoes with the brown rugose virus, and bananas with the Fusarium fungal disease (Tropical Race 4). Regarding papayas, a GMO variety was introduced over 20 years ago and saved the entire Hawaiian industry from the ringspot virus (Gonsalves et al., 2007). Now the GMO papaya is ubiquitous and fully accepted by consumers in Hawaii. The papaya case motivates the analysis of a collapse scenario.

NPETs can appear as an important revolution in the field of fruit and vegetables for improving the strength of their production and/or the quality of goods including the context of possible collapse. However, public investment in R&D should also account for the potential reluctance of many consumers for new goods created with GE and other NPETs—as in the past for GMOs. Consumers' acceptance influencing private and social profits could be estimated ex ante via experiments, namely before the actual introduction of food on a market.

2 | METHOD

2.1 | ANALYTICAL STRATEGY

We develop a simplified model incorporating IO considerations and consumers' valuation of novel foods. Our model accounts for the probability of having new goods resulting from R&D investments. This is consistent with a benevolent regulator deciding how to invest in

R&D. The proposed model allows for a simplified estimation of potential market effects with one or two goods, which is a proxy for market adjustments with many imperfect substitutes. For simplicity, we consider decisions based on welfare measures focusing on surpluses of consumers and public investment decisions in R&D to maximize consumer welfare. Extensions to the basic model are proposed in the subsections 4.5 and 4.6 and in Appendix C in the Data S1.

Consumer valuation is based on two experimental surveys of consumers' preferences in France and the United States for novel apples. They used hypothetical and fictitious choices in a lab and different technology messages (on traditional hybridization and GE as a representative case of NPETs) to estimate the WTP[5] of 162 French and 166 U.S. consumers for new apples, which do not brown upon being sliced or cut.[6] Messages centered on the social and private benefits of having the new apples relative to conventional ones.

In those surveys, consumers in France and the United States exhibit similar preferences with respect to biotechnology. Many, but not all consumers, in both countries, discount the apple improvement obtained through GE techniques, relative to traditional hybridization-based innovation. However, there is a significant group of consumers knowingly accepting the new GE apple. This group of accepting consumers is relatively larger in the United States than in France, strongly suggesting that the acceptance of GE foods is possible in a significant segment of the population (at least in some countries).

Based on the consumers' WTP values in the two countries, we derive the demand for the new apples and associated consumer surplus. Then, we derive *ex ante* (i.e., before the actual introduction of the new variety of the good) estimates for the welfare impacts of GE apples onto the market, by taking into account both R&D cost of innovation and probability of innovation success. Our simulations suggest that GE may be socially beneficial if full information on the technology is provided to consumers and if the probability of success under GE is significantly higher than under the traditional hybridization. In the case of partial or no information, consumers discounting the GE apples would buy them unknowingly, experiencing regret losses relative to their true valuation of the GE apples. Thus, in this context, traditional hybridization remains the socially optimal innovation technique.

2.2 | An IO model integrating experimental results

2.2.1 | A three-stage game

The market equilibrium is determined as a three-stage game summarized in Figure 1. The equilibrium is solved by backward induction (i.e., subgame Nash equilibrium). Assumptions of the game are detailed in Figure 1.

In Stage 1, the benevolent regulator in charge of innovation decides whether to choose one type of innovation, namely hybrid or NPETs, denoted by $N = \{HY, NPETs\}$. If the innovation is selected, the economy incurs a sunk expenditure F_N, associated with the R&D investment, leading to a probability λ_N of getting the new good as revealed in Stage 2. The innovation does not emerge with a probability $(1-\lambda_N)$.

Traditional hybridization is characterized by F_{HY} and λ_{HY}, and NPETs is characterized by F_{NPETs} and λ_{NPETs}. It is assumed that $F_{NPETs} > F_{HY}$ and $\lambda_{NPETs} > \lambda_{HY}$, which means that sunk costs and probabilities of innovation are positively correlated.[7] Sunk costs are incurred when investments are made in the first stage and cannot be recovered (Sutton, 1991). To select the

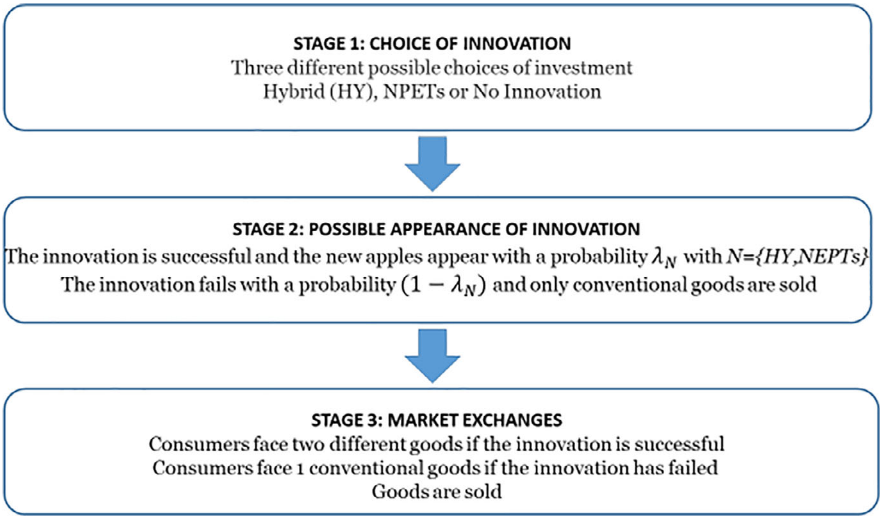

FIGURE 1 Stages of the IO model. IO, industrial organization [Color figure can be viewed at wileyonlinelibrary.com]

innovation, the regulator considers expected welfare defined simply by the sum of consumers' surpluses minus the sunk costs of R&D.[8]

In Stage 2, the outcome of the innovation investment previously decided in Stage 1 becomes known. If the innovation is successful, with a probability of success λ_N, new goods (hybrid or NPETS) are offered on the market. Conversely, if the innovation fails, with a probability $(1-\lambda_N)$, only the conventional goods are sold on the market.

In Stage 3, the exchanges occur. Consumers know the characteristics of the sold good(s), except for the information about the type of innovation. Two cases are considered. First, consumers are fully informed about the underlying technology. Second, they are not or only partially informed on the technology and face costs of ignorance and regret. Market prices of goods are exogenously given for simplicity.

We now turn to equilibria at different stages, by starting, according to the backward induction principle, with Stage 3 and the way consumers' demand is determined.

2.2.2 | Stage 3: Demands and surpluses under different configurations

Consumers' demands depend on the estimations of their surpluses that relate to their WTP. To convert consumers' WTP into demand curves, we assume that each consumer purchases one unit, providing the largest surplus approximated by the difference between WTP and the market price (Roosen & Marette, 2011; Rousu et al., 2014). Choices can be real or inferred, and hypothetical, depending on the type of survey and goods being considered.[9]

For the estimation of purchases in Stage 3, the available goods sold on the market are given depending on the innovation investment made in Stage 1 and its realization in Stage 2. Consumers individually choose either, to purchase or not to purchase one unit of the goods, without mixing the two types of goods if both conventional and new goods are offered. The unit of the conventional good is sold at a price P (observed or relevant at the time of the experiment/

survey) and the new good is assumed to be sold at the same price $P_N = P$, for simplicity. The WTP for the new good is denoted by $WTP^m_{N_k}$ and the WTP for the conventional good is denoted $WTP^m_{C_k}$ for an informational message m on the technology and a consumer k. Informational messages m cover the technologies {*HY, NPETs*} and the case of no information provided on the technology.

Without innovation investment in Stage 1, or if the innovation fails to provide the new goods in Stage 2, the consumer k (with $k = 1,\ldots,K$) can choose between two outcomes in Stage 3: conventional good and none, with a utility, normalized to zero. This case corresponds to the reference baseline of any experiment. Consumer k chooses a single unit of the conventional good, when this good brings a positive surplus, given by the difference between the WTP and the market price (and no good otherwise). Thus, the consumer surplus (*SC*) leading to the purchasing decision of good is given by

$$SC^0_{C_k} = Max\left\{WTP^0_{C_k} - P, 0\right\}. \tag{1}$$

There is no information to be revealed since no new technology appeared.

With innovation investment in Stage 1, and if this innovation is successful in Stage 2, the consumer can choose between three outcomes in Stage 3: new good, conventional good, and none. For a message m on the novelty component, consumer k chooses the purchasing alternative that generates the highest utility; her surplus becomes

$$Max\left\{WTP^m_{C_k} - P, WTP^m_{N_k} - P, 0\right\}. \tag{2}$$

The new good is selected if $WTP^m_{N_k} - P \geq Max\left\{WTP^m_{C_k} - P, 0\right\}$, and not selected otherwise, for turning to the other options depending on the comparison between 0 and $WTP^m_{C_k} - P$.

Two subcases can be considered here: i) with full information about the innovative technology and ii) without (or just partial) information about the technology. Under the first configuration, the consumer is fully informed on the innovation process and there is no ignorance cost or regret effect. Thus, the surplus for consumer k is described by Equation (2) with a valuation for each technology (*HY* and *NPETs*) and with their respective "full-information" messages. Directly from Equation (2), we derive the surplus for consumer k under the full information message (denoted by the superscript $m = fi$)

$$SC^{fi}_{HY_k} = Max\left\{WTP^{fi}_{C_k} - P, WTP^{fi}_{HY_k} - P, 0\right\}, \tag{3a}$$

and

$$SC^{fi}_{NPETs_k} = Max\left\{WTP^{fi}_{C_k} - P, WTP^{fi}_{NPETs_k} - P, 0\right\}. \tag{3b}$$

The second configuration with no (or only partial) information about the type of innovative technology (and denoted by the superscript $m = ni$) leads to a decision based on Equation (2) that subsequently the consumer could regret once that full information is revealed on the technology. Some consumers would make different decisions with the full information provided *ex* *ante*.[10] Therefore, the costly ignorance effect linked to the lack of full technology information needs to be accounted for by a benevolent regulator in the computation of the "complete" surplus. For a consumer purchasing a specific good, the effect of ignorance is given by the WTP for the good with full information minus the WTP related to the purchase. This allows us to measure the difference between the "ideal" choice under full information and the "actual" choice without (or partial) information.

If goods sold are generated by hybrid methods, the effect (or cost) of ignorance is defined by $J_{C_k}\left[WTP^{fi}_{C_k} - WTP^{ni}_{C_k}\right] + J_{HY_k}\left[WTP^{fi}_{HY_k} - WTP^{ni}_{HY_k}\right]$, where J_{C_k} (respectively, J_{HY_k}) is an indicator variable, taking the value of 1 if consumer k is predicted to have chosen the conventional (respectively new hybrid) good in the absence of information. It means that, if a product is predicted to be purchased without information, this effect of ignorance is measured by the difference between the WTP under full information and the WTP without (or partial) information. The effect of ignorance corrects the surplus (2) with $m = ni$, by integrating "a distance" to the full information context, meaning that the consumer *ex post* could regret the purchase done without information. In other words, if she had full information, she might have bought a different basket.[11] The complete surplus for consumer k, considered by the decision-maker, and integrating the effect of ignorance, is equal to

$$SC^{ni}_{HY_k} = Max\left\{WTP^{ni}_{C_k} - P, WTP^{ni}_{HY_k} - P, 0\right\} + J_{C_k}\left[WTP^{fi}_{C_k} - WTP^{ni}_{C_k}\right] + J_{HY_k}\left[WTP^{fi}_{HY_k} - WTP^{ni}_{HY_k}\right], \quad (4)$$

If goods sold are NPETs-generated goods, the effect (or cost) of ignorance is defined by $J_{C_k}\left[WTP^{fi}_{C_k} - WTP^{ni}_{C_k}\right] + J_{NPETs_k}\left[WTP^{fi}_{NPETs_k} - WTP^{ni}_{NPETs_k}\right]$, where J_{C_k} (respectively, J_{NPETs_k}) is an indicator variable taking the value of 1 if consumer k is predicted to have chosen the conventional (respectively, new NPET) good in the absence of information. Explanations about the effect of ignorance are similar to the ones in the previous paragraph, and the complete surplus for consumer k is equal to

$$\begin{aligned} SC^{ni}_{NPETs_k} = {} & Max\left\{WTP^{ni}_{C_k} - P, WTP^{ni}_{NPETs_k} - P, 0\right\} + J_{C_k}\left[WTP^{fi}_{C_k} - WTP^{ni}_{C_k}\right] \\ & + J_{NPETs_k}\left[WTP^{fi}_{NPETs_k} - WTP^{ni}_{NPETs_k}\right], \end{aligned} \quad (5)$$

Under the different configurations, the regulator will take into account the expected average surplus for one unit of the good over the K consumers in the economy (with *E[.]* the expectation operator), namely $E\left(SC^0_C\right)$ for the baseline without the new good, $E\left(SC^{fi}_{HY}\right)$ and $E\left(SC^{fi}_{NPETs}\right)$ for hybrid- and NPETs generated goods under full information about the technology, $E\left(SC^{ni}_{HY}\right)$ and $E\left(SC^{ni}_{NPETs}\right)$ for hybrid- and NPETs-generated goods under no (or partial) technology information.

2.2.3 | Stages 1 and 2: Choice of investment in R&D and expected welfare

The innovation investment in Stage 1 is decided based on expectations of events and market equilibria related to Stages 2 and 3. Stage 2 determines the realization of the investment resulting in a new good or not. For innovation investments $N = \{HY, NPETs\}$, the innovating agent has a probability λ_N to get the innovative good leading to welfare with new goods, and the innovation does not emerge with a probability $(1 - \lambda_N)$ leading to welfare without innovation.

Sunk expenditures F_N are associated with R&D investments and the authorization of new goods. They are incurred by the innovation agency and withdrawn from the welfare of consumers.

Under full information about technology and if the regulator chooses to invest with the technology $N = \{HY, NPETs\}$, the expected welfare takes into account the probabilities λ_N and $(1-\lambda_N)$. For the hybrid investment, the overall expected welfare (W) summed over all the consumers with their average consumption is given by

$$W^{fi}_{HY} = \left[\lambda_{HY} E\left(SC^{fi}_{HY}\right) + (1-\lambda_{HY}) \times E\left(SC^{0}_{C}\right)\right] \times EXT - F_{HY}, \tag{6}$$

with EXT being an extrapolation parameter equal to the number of consumers multiplied by expected average consumption over a year. For the NPETs investment, the overall expected welfare is

$$W^{fi}_{NPETs} = \left[\lambda_{NPETs} E\left(SC^{fi}_{NPETs}\right) + (1-\lambda_{NPETs}) \times E\left(SC^{0}_{C}\right)\right] \times EXT - F_{NPETs}. \tag{7}$$

In the absence of information about technology, the corresponding welfare measures are

$$W^{ni}_{HY} = \left[\lambda_{HY} E\left(SC^{ni}_{HY}\right) + (1-\lambda_{HY}) \times E\left(SC^{0}_{C}\right)\right] \times EXT - F_{HY}, \tag{8}$$

and

$$W^{ni}_{NPETs} = \left[\lambda_{NPETs} E\left(SC^{ni}_{NPETs}\right) + (1-\lambda_{NPETs}) \times E\left(SC^{0}_{C}\right)\right] \times EXT - F_{NPETs}. \tag{9}$$

Finally, without any innovative investment and any new good, the expected welfare with conventional goods only is $W^0_C = \left[E\left(SC^0_C\right)\right] \times EXT$.

For a given context of information (*fi, ni,0*), the comparison of *ex ante* welfares determines the regulator choice. For instance, for the case under full information, the regulator chooses the strategy resulting from $Max\left\{W^{fi}_{HY}, W^{fi}_{NPETs}, W^0_C\right\}$, which depends on surpluses and parameter values. Interestingly, the welfares comparison may lead to inequalities helping to define optimal strategies. The inequality $W^{fi}_{HY} > W^0_C$ is equivalent to $\varphi_{HY} < \lambda_{HY}\left[E\left(SC^{fi}_{HY}\right) - E\left(SC^0_C\right)\right]$, with $\varphi_{HY} = F_{HY}/EXT$, being the sunk cost per unit of sold good. In other words, this is a sunk cost by the sold unit without being passed onto consumers into the market price. The same parameter will be used for $\varphi_{NPETs} = F_{NPETs}/EXT$. The relevant inequalities will conduct to the determination of the optimal policy, now applied to the apple case.

2.3 | Application to apples

2.3.1 | Summary of the apple experiments

We now apply the framework to a case study of novel apples. We first summarize the results from two recent experiments on WTP for apples under different technology messages (Marette et al., 2021).[12] We then expand and build upon those results by deriving consumer demands and performing a welfare analysis of the potential emergence of the new apple innovation.

Those hypothetical experiments were undertaken in France (Dijon) in December 2019 and the U.S. Midwest (Ames, IA) in early March 2020. The number of surveyed consumers was equal to 162 in France and 166 in the United States. Successive rounds of WTP elicitation were conducted (see Figure A1 in Appendix A in Data S1). An initial round (the baseline) focused on the conventional apples without an informative message (message #0). Then, both conventional and new apples were presented in the following rounds, and consumers were asked to value conventional and new apples with improved attributes (nonbrowning and reduced bruising) under three different messages. These messages were as follows:

- The first message mentioned the innovation slowing the browning process without specifying the technology generating the innovation (corresponding to message *ni*).
- The second message delivered full information and specified traditional hybridization as the underlying technology (message *fi* for hybrid technology).
- The third message also provided full information and indicated GE as the source of the innovation (a specific case of NPETs; message *fi* for GE).[13]

Pictures of goods were presented, and no specific apple variety reference was indicated. A multiple-price list (payment card) was used for eliciting WTP of consumers for 1 kg of apples in France and 1 pound in the United States, for both conventional and new apples. During each round, consumers were asked to choose whether (or not) they will buy the good for prices varying from €1.60 to €3.30 for 1 kg of apples in France and from \$0.70 to \$2.40 for 1 pound in the United States (the quantity gap is justified by differences in consumption habits between these two countries). For each round and each good, the WTP was determined by taking the highest price consumers were willing to pay (the highest "Yes" checked off in the list). If a consumer never replied "yes" to each line of the multiple-price list, the selected WTP was supposed to equal 0.

Those rounds of information lead to WTPs for new apples denoted by $\mathrm{WTP}_{N_k}^m$ ($N =$ HY, GE), and for conventional apples denoted $\mathrm{WTP}_{C_k}^m$ for an informational message $m = \{0, ni, fi\ for$ HY, $fi\ for$ GE$\}$ and consumer k.

Experiment results show strong heterogeneity in consumers' WTP for both the conventional and new apples in both countries. To highlight this heterogeneity and compare the two countries, we normalize the WTP expressed by a consumer for the new good by the WTP she expressed for the conventional one, for a given message. For an informational message m and a consumer k, the ratio is thus $\left(\mathrm{WTP}_{N_k}^m / \mathrm{WTP}_{C_k}^m\right)$x100. Figure 2 presents the unitless ratios for informational message *ni* (only mentioning the benefits from the new good but not the underlying technology) and message *fi* for GE (detailing the GE innovation as a specific case of NPETs).

We abstract from the ratios for the traditional hybridization (with message *fi* for HY) because they were nearly similar to those under message *ni*. The graph on the left presents results for France, while the graph on the right reports results for the United States. In each graph, observations related to consumers are on the X-axis and ratios on the Y-axis. Ratios are sorted by increasing order.

For both countries and curves, three groups of consumers can be distinguished: those who do discount the innovation (left part of curves with ratios lower than 100), those who are indifferent between both goods (central part of curves with ratios equal to 100), and those who value

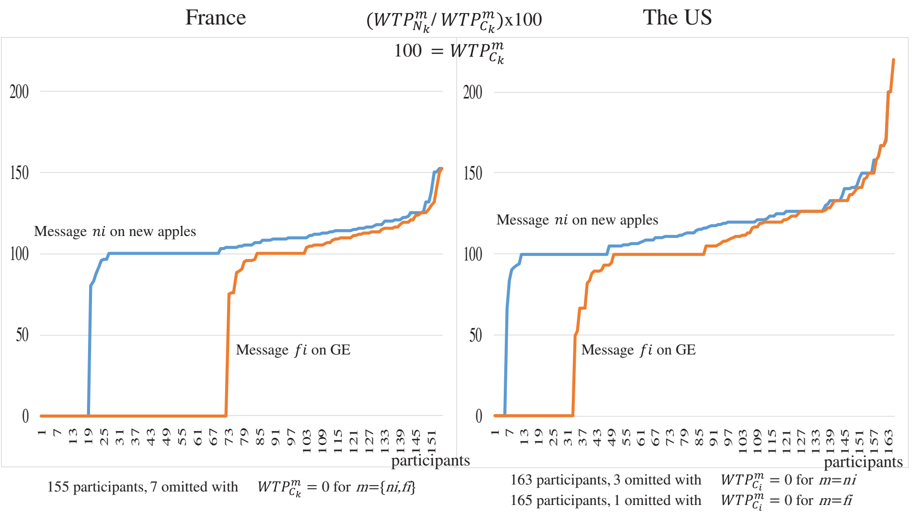

FIGURE 2 WTP expressed for the new GE apples relative to the WTP expressed for the conventional apples. WTP, willingness to pay [Color figure can be viewed at wileyonlinelibrary.com]

the new nonbrowning GE good with a positive premium (right part of curves with ratios higher than 100). The impact of full information on GE technology on consumer WTP can be seen by the comparison between the blue curve (after message *ni*) and the red curve (after message *fi* for GE). The provision of information on GE leads to a significant decrease in WTP expressed for the new good.

A larger number of surveyed consumers discount the innovation with a negative premium. The decrease in premia is noticeable in the United States and substantial in France. This result questions the acceptance of the GE innovation by some consumers, particularly in France.

However, in both countries, there is also a significant group of consumers with a positive premium (ratios higher than 100) when fully informed about the GE innovation process (the right part of the orange curves), and a priori accepting the new technology. This group of accepting consumers is relatively larger in the United States than in France. Around 34% of participants in France and 47% of participants in the United States value the new nonbrowning GE good with a positive premium. Moreover, in the United States, a few consumers give very high value to the GE innovation (extreme right of the orange curve), which could reflect social desirability bias. Given this caveat, the group of accepting consumers with a valuation above 100 contributes to the emergence of the market for GE-based apples and makes the adoption of GE possible and potentially socially desirable when full information about the GE technology is provided.

The values shown in Figure 2 become the basis for the surpluses computed in the next subsection. The heterogeneity in consumer preferences (with pro- and anti-GE) particularly matters for understanding market adjustments and consumers' surpluses.

2.3.2 | Simulations

Some additional assumptions are necessary before conducting simulations to select the socially optimal innovations. Consumers' surpluses derived from Equations (1) to (5) are obtained by comparing their WTP and market prices. To set prices, we rely on observed prices in supermarkets at the time of the experiments and use the average observed price P_C for the conventional apples equal to €2.10 per kg in France and $1.20 per pound in the United States.[14] For simplicity, we keep assuming $P_N = Pc = P$ for the new good.[15] For allowing comparisons between both countries, the average surpluses for 1 kg with the French experiment are converted in a value of 1 pound (kg 1 = LBs 2.2) in $, by multiplying the French average surplus by (1.10/2.20), with €1 equal to $1.10 on March 1, 2020, at the time of the second experiment. We now turn to simulations' results.

2.3.3 | Estimated surpluses

Table 1 presents the average surpluses estimated for each country and for the different configurations, as described in Stage 3 of Figure 1 and presented in Equations (1)–(5), with GE being the specific NPETs technology.

Table 1 shows that for each configuration, the average surpluses are higher in the United States than in France. For each country, surpluses with the new apples coming from the innovations are generally higher than the surpluses under the absence of new apples, except the case with GE under no technology information (message *ni* in the experiment, GE apple variety). Still, the situation without information about the process of innovation leads to a surplus lower than the surplus under full information for the equivalent good (messages *fi* for HY and *fi* for GE). This result comes from the cost of regret in the absence of information on technology, which is included in the total consumer surplus.

The surpluses with hybrid apples are higher than the respective surpluses with GE apples since consumers are more enthusiastic about the hybrid technology than its GE counterpart. The discounting of the GE technology implies significant regret costs under the *ni* message when consumers would only learn *ex post* about the technology. This explains why GE without technology information (message *ni*) leads to a much lower surplus ($ −0.11 for France and $0.34 for the United States) than the configuration where only the conventional good is available in the market ($0.11 for France and $0.53 for the United States). The negative surplus for France ($ −0.11) is explained by the very high effect of ignorance leading to costly regrets.

In both countries, the surpluses with GE and full technology information (message *fi*, GE variety) are higher than those without the new good (message 0, conventional variety), but lower than the surpluses with hybrid apples (message *fi*, HY variety). However, the innovation with GE under information provision can be favored because of the higher probability of innovation success for GE than for traditional hybridization. These probabilities are now considered in *ex ante* welfare analysis to understand the R&D investment decision.

2.3.4 | Socially optimal innovation investments

We now derive ex ante welfare values in Stage 1 of the game, based on the consumers' WTP and related surpluses reported in Table 1. The comparison of ex ante per-unit welfare measures permits the selection of the socially optimal innovation strategy. We look at the potential investment choices maximizing per-unit welfares and leading to the possible emergence of innovation with a probability λ_N for $N = \{\text{HY,GE}\}$, with $\lambda_{\text{GE}} > \lambda_{\text{HY}}$, meaning that GE accelerates the innovation and the likelihood of success.

TABLE 1 Average surplus for one pound of apples in US$ under the different configurations

France		
Configuration: only conventional apples		
	Conventional variety	
Baseline (message *0*)	$E(SC_c^0) = 0.11$	
Configuration: both conventional and new apples (after the innovation success)		
	Hybrid variety	GE variety
No information (message *ni*)	$E(SC_{HY}^{ni}) = 0.16$	$E(SC_{GE}^{ni}) = -0.11$
Full information (message *fi*)	$E\left(SC_{HY}^{fi}\right) = 0.18$	$E\left(SC_{GE}^{fi}\right) = 0.17$
United States		
Configuration: only conventional apples		
	Conventional variety	
Baseline (message *0*)	$E(SC^0) = 0.53$	
Configuration: both conventional and new apples (after the innovation success)		
	Hybrid variety	GE variety
No information (message *ni*)	$E(SC_{HY}^{ni}) = 0.70$	$E(SC_{GE}^{ni}) = 0.34$
Full information (message *fi*)	$E\left(SC_{HY}^{fi}\right) = 0.72$	$E\left(SC_{GE}^{fi}\right) = 0.65$

Abbreviation: GE, gene editing.

We start with the configuration under no technology information, in which the social objective is given by Max$\{W_{HY}^{ni}, W_{GE}^{ni}, W_C^0\}$. The comparison of per-unit welfares leads to simulations presented in Figure 3a, with the French configuration presented on the left chart and the US configuration presented on the right chart. On both charts, the probability λ_{GE} of getting the GE innovation is represented on the X-axis. The sunk cost per unit of sold good for the GE investment, $\varphi_{GE} = F_{GE}/EXT$, expressed in \$, is represented on the Y-axis. Specific parameter values ($\lambda_{HY} = 0.6\,\lambda_{GE}$, $\varphi_{HY} = 0.8\ \varphi_{GE}$) are used both for France and the United States. The parameters related to the hybrid technology are implicitly represented since in the simulations, $\varphi_{HY} = b\ \varphi_{GE}$ and $\lambda_{HY} = r\,\lambda_{GE}$, with $r < 1$ and $b < 1$.[16]

Figure 3a shows that the hybrid investment is socially optimal for relatively low levels of per-unit sunk cost. For relatively high values of per-unit of sunk cost, there is no innovation investment and no emergence of the new good. Interestingly, the optimal hybrid investment linked to one unit of apples leads to a larger area for the United States compared to France, because the per-unit surpluses in Table 1 are higher in the United States than in France.

This result suggests that return to innovations would be higher in the United States than in France, providing larger R&D incentives in the United States. This effect is amplified by the larger number of US consumers embodied in the US extrapolation parameter *EXT* appearing in welfare Equations (8) and (9). For both countries, the GE investment under no technology information does not emerge, because the cost of regret undermines the positive valuation of the novel apples. As shown in Table 1, the average per-unit surplus with GE under no technology information is lower than the one without new apples and with only conventional apples, eliminating any incentive to invest with GE.

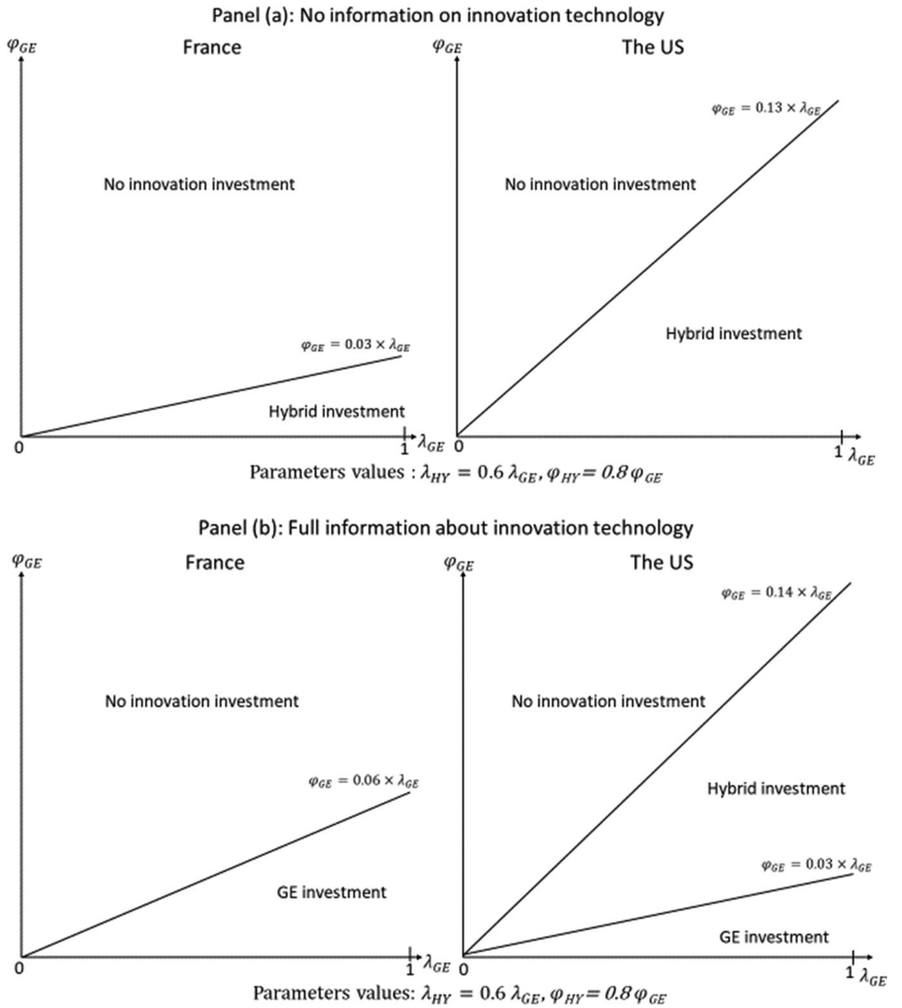

FIGURE 3 Social choices maximizing the per-unit welfare in France and the United States. (a) No information on innovation technology; (b) full information on innovation technology. *Note*: The sunk cost per unit of good $\varphi_{\text{GE}} = F_{\text{GE}}/\text{EXT}$ coming from the GE investment is represented on the Y-axis. On each chart, the constraints are derived from welfare comparisons for reaching max $\{W_{\text{HY}}^{ni}, W_{\text{GE}}^{ni}, W_C^0\}$. For France, the equation $\varphi_{\text{GE}} = 0.03\,\lambda_{\text{GE}}$ is given by the equality $W_{\text{HY}}^{ni} = W_C^0$. For $W_{\text{HY}}^{ni} > W_C^0$, the inequality $W_{\text{HY}}^{ni} > W_{\text{GE}}^{ni}$ is systematically verified, and for $W_{\text{HY}}^{ni} < W_C^0$, the inequality $W_C^0 > W_{\text{GE}}^{ni}$ is systematically verified, which leads to the choices of the chart on the left. For the United States, the same is observed with $\varphi_{\text{GE}} = 0.13\,\lambda_{\text{GE}}$. GE, gene editing

Figure 3b reports the simulations coming from a configuration under full information about the innovative technology with the regulator's maximization problem being $\text{Max}\left\{W_{\text{HY}}^{fi}, W_{\text{GE}}^{fi}, W_C^0\right\}$. The axes and the parameters values are similar to the ones in Figure 3a, except for the expected surpluses under different information contexts (see Table 1). Figure 3b shows that, under full information, the GE investment is socially optimal for relatively low level of per-unit sunk cost φ_{GE}. As the per-unit surplus with the GE under full information is relatively high and close to the hybrid one (Table 1), the GE is socially beneficial since the probability of success is higher than the one with the hybrid investment (with $\lambda_{\text{HY}} = 0.6\,\lambda_{\text{GE}}$). In France, the GE investment dominates the hybrid investment given these relative success probabilities.[17]

Moreover, because of consumers' preferences (Table 1), the traditional hybridization is preferred in the United States for medium values of the sunk cost f_{HY}, since this sunk cost is lower than the one for GE with $\varphi_{\mathrm{HY}} = 0.8\ \varphi_{\mathrm{GE}}$. When the sunk costs of investments rise high enough, no investment is selected.

Beyond these simulations, the comparison of Figure 3a,b shows that the emergence of GE is clearly linked to the context of information about the innovative technology. However, information about GE-based innovation might be difficult to grasp for consumers in actual situations, because of imperfect recall, labels/messages proliferations, and the complexity of the scientific knowledge leading to misunderstandings and confusions (Yokessa & Marette, 2019). This issue is larger than novel foods as most goods consumed (cars, phones, computers, online services, etc.) embody complex technologies and production processes beyond the grasp of many consumers.

2.3.5 | Extension with a collapse configuration

We now investigate the risk of a collapse resulting in the possible disappearance of the conventional product. Section 1 explored the acute issue of crop vulnerability. To account for his effect, we introduce ψ, the collapse probability of the conventional good following a disease, in Stage 2 of the game (see Section 2.1). The collapse does not happen with the probability $(1-\psi)$. The probability ψ is taken into account in Stage 1 by the benevolent regulator.[18] In such case, the conventional good disappears from Equations (1) to (5); while $(1-\psi)$ is the probability of having the conventional good on the market as in Equations (1) to (5) (see Appendix B in the Data S1 for the detailed equations and Table B1 for the per-unit surpluses under this collapse case scenario).

New *ex ante* welfare values in Stage 1, integrating the probability of a collapse, are computed based on the consumers' WTP and related per-unit surpluses (Table B1 in Appendix B in Data S1). The comparison of ex ante welfare measures (B3) to (B6) in Appendix B in Data S1 leads to the selection of the socially optimal strategy. The simulations are shown in Figure 4, for France and the United States (under full technology information only, for simplicity). A given level of per-unit sunk cost is assumed with $\varphi_{\mathrm{GE}} = \$0.03$. On each chart, the probability λ_{GE} of getting the GE innovation is represented on the X-axis and the probability ψ of collapse of conventional apples is represented on the Y-axis.

Figure 4 shows the respective influence of both probabilities λ_{GE} and ψ. When the probabilities of successful innovation λ_{GE} and $\lambda_{\mathrm{HY}} = 0.6\,\lambda_{\mathrm{GE}}$ are relatively low, the innovation investment is not selected (left side of each chart), because of low social benefits from new apples relative to the sunk cost $\varphi_{\mathrm{GE}} = \$0.03$. Conversely, a relatively high value for the probability of collapse ψ (even with a low value of probabilities of innovation λ_{GE}) leads to the selection of innovation investments.

The hybrid investment is socially optimum for medium values of λ_{GE} (middle of each chart). On the other hand, for a high value of λ_{GE} (right side of each chart and bounded by $\lambda_{\mathrm{GE}} = 1$), the GE investment clearly dominates because of the likely emergence of the innovation. Thus, the GE strategy is reinforced with the risk of a collapse. Note that this important significance of the GE investment also exists under no technology information for the United States with small areas, but not for France because of negative values of surplus from Tables 1 and B1 for GE under no technology information.

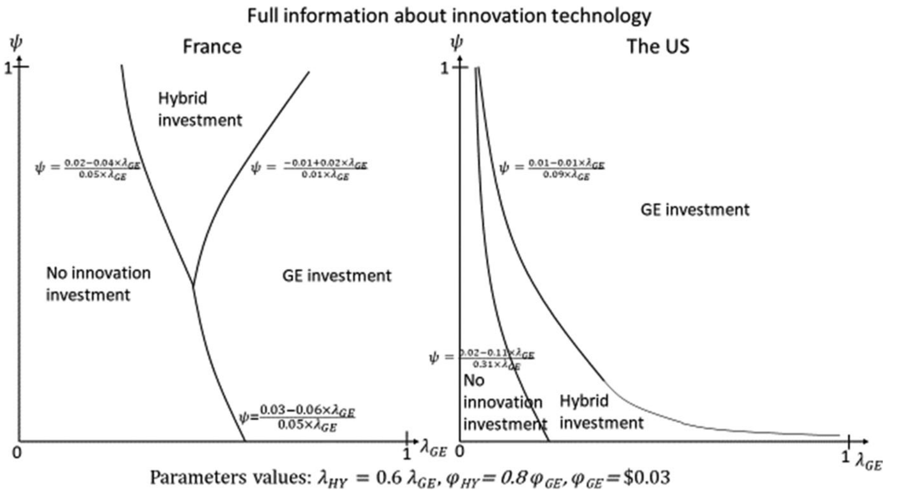

FIGURE 4 Risk of collapse and socially optimal choices in France and the United States. *Note*: The probability ψ of the collapse of conventional apples is represented on the *Y*-axis. On each chart, the constraints are derived from welfare comparisons for reaching max $\left\{\overline{W}_{\text{HY}}^{fi}, \overline{W}_{\text{GE}}^{fi}, \overline{W}_{C}^{0}\right\}$ with expressions given in Appendix B in Data S1

2.3.6 | Extension with costly regrets limited to a subgroup of consumers

We now explore the effect of ignorance under no technology information (see Equations (4) and (5)). In our analysis, the ignorance effect integrates differences in WTP under various contexts of information provision and concerns all consumers. In the real world (e.g., in stores outside the lab) however, regrets due to the ignorance effect are likely to only be costly for very concerned consumers.[19] To address this bias that may affect our analysis and identify consumers really concerned in reality by the innovation process (natural such as traditional hybridization vs. based on biotechnologies such as GE and other NPETs), we rely on the exit questionnaire answered by surveyed consumers during the experiment. This questionnaire provides clues regarding food habits and the level of concerns in real-world contexts. In particular, strong consumption of organic fruits and vegetables is likely to indicate a significant concern regarding information about NPETs such as GE, as many of these consumers try to shun GMOs via organic choices.

From the exit questionnaire, we isolate consumers with regular and exclusive consumption of organic fruits and vegetables and create a new dummy variable equal to 1 for those consumers (and 0 otherwise). This dummy variable is multiplied to J_{C_k} and J_{NPETs_k} in $\text{SC}_{\text{NPETs}_k}^{ni}$ given by Equation (5). In other words, the effect of ignorance really matters for those concerned consumers only, while others are indifferent to it outside the lab. Applying the new dummy variable to the US case only (and with GE as a specific case of NPETs) for simplicity, leads to an increase in the expected surplus for the GE innovation under no technology information from Table 1, with a shift from $E\left(\text{SC}_{\text{GE}}^{ni}\right) = 0.34$ to a new value $E\left(\text{SC}_{\text{GE}}^{ni}\right)' = 0.59$, reflecting the lower number of consumers really affected by regrets.[20] This new value integrated in Equation (5) leads to a higher acceptance of the GE technology under no technology information.

Figure 5 shows the social optimum R&D choice for the United States under this new configuration. Results reported in the left chart suggest that GE may be socially beneficial when consumers' losses from regrets are limited to a subgroup of very concerned consumers, and when

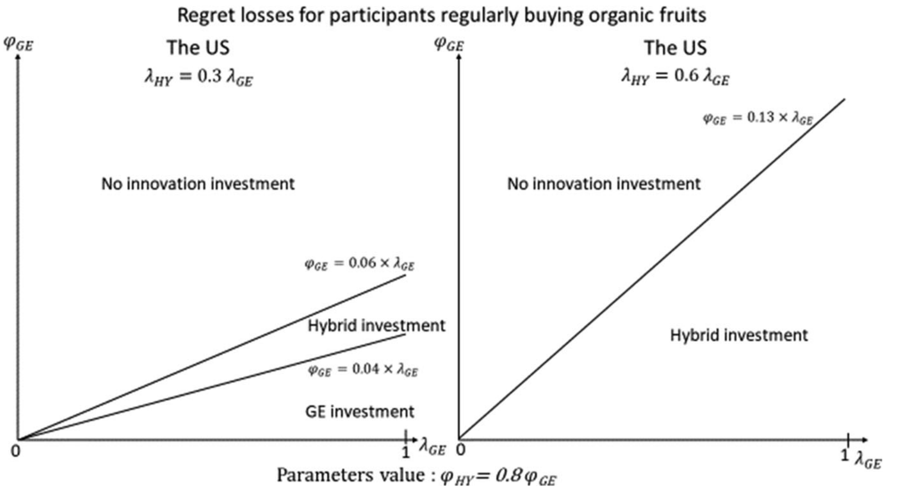

FIGURE 5 Social choices maximizing the per-unit welfare in the United States under no technology information

the probability of success with the GE is significantly higher than the one for traditional hybridization ($\lambda_{HY} = 0.3\ \lambda_{GE}$), and for low values of the sunk cost. However, when the probability of success of hybrids gets closer to that of GE (right chart, with $\lambda_{HY} = 0.6\ \lambda_{GE}$), GE does not emerge as socially optimal as it was already the case in Figure 3a.

We consider further extensions in Appendix C in Data S1, extrapolating our results to the whole country. We also discuss how to incorporate a supply chain with seedlings, apple producers, and retailers. In addition, prices for novel apples could be endogenized. Some dynamic elements could also be considered with multiple periods and consumers becoming more accepting of biotechnology as in the papaya case. The model could be extended to international trade with the associated regulatory issues for biotech goods to cross borders.

3 | CONCLUSIONS

We emphasized the important role of consumers' preferences, along with R&D spending, and uncertainty in the resulting success of innovative foods in the marketplace. We developed and utilized a simple IO model for R&D investment in food innovations based on NPETs and traditional hybridization methods, to identify which technology emerges under various parameter characterizations and associated economic welfare outcomes. Our simulations show that information delivered to consumers matters for determining social benefit outcomes resulting from innovations based on NPETs and hybridization. Performed simulations also suggest that NPETs, such as GE, may be socially beneficial when consumers are informed about the technology, or when they experience limited regret losses (thus, when not informed, before their purchases take place), and when the regulatory environment does not inflate the R&D cost. Otherwise, the innovation based on traditional hybridization is socially optimal, which is particularly true when the values of the probabilities of success under NPETs and hybridization are relatively similar. Finally, the reluctance for NPETs-based novel foods by some consumers makes the adoption of this technology uncertain, particularly in France.

We further explored a series of potential and easily implementable extensions, in Appendix C in Data S1, to flesh out the developed and utilized approach beyond the essence of consumers' WTP, sunk cost of R&D processes, technology information, and probabilities of success of those technologies. Noteworthy, we looked at a collapse scenario by altering the choice set for consumers in which conventional food was no longer available. This situation shows that the elimination of the conventional good option makes the NEPT-based innovation more palatable to consumers and more likely to succeed.

Despite limitations resulting from stylized WTP elicitations and IO approaches, our methodology can be replicated for R&D related to all sorts of food novelties and other potentially disruptive technologies as pointed out by Herrero et al. (2020). The case of apples demonstrates the feasibility of the approach and suggests it could be applied in varying configurations. The consumers' acceptance influencing private and social profits could be estimated *ex ante* via experiments before the effective introduction of a novel food on a market. Welfare estimates would help to guide public debates about the future of foods generated by new and sometimes controversial technologies.

An important configuration to consider in the future is what happens with international trade. Trade expands markets through exports but also increases competition through imports. Presumably, consumers benefit from more choices if new goods can emerge with domestic and foreign supplies. Effects on prices, the emergence of innovation, and welfare will have to be elucidated in several policy contexts depending on how countries regulate NPETs innovations and their exchange across borders.

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CONFLICT OF INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

DATA AVAILABILITY STATEMENT

The datasets used and/or analyzed during the current study are available from the corresponding author.

ENDNOTES

[1] NPETs also include other techniques such as RNA interference (RNAi) used to silence or suppress specific gene function in plants in a targeted way. These techniques do not rely on the traditional gene splicing of older genetically modified organisms (GMOs). The framework applies to most NPETs although we focus on GE in the application.

[2] Policymakers and regulatory delays could also be a major impediment in many countries, especially those in which GMOs faced very stringent and slow regulatory approvals and countries treating NPETs as traditional GMOs, such as in the European Union (Purnhagen & Wesseler, 2021).

[3] CRISPR stands for clustered regularly interspaced short palindromic repeats. The Nobel Prize in Chemistry 2020 was awarded jointly to E. Charpentier and J.A. Doudna for the development of this new and promising method for genome editing.

[4] In 2019, production of Arctic apples reached 4000 short tons for the US market (mostly for expanded sales in food-service). In 2020, production increased to 6500 tons. In retail, there were three sizes of bags with precut apples (10, 5, and 2 oz) available for sale and two varieties (Arctic Golden and Arctic Granny).

[5] Even if hypothetical WTP are likely to be upward biased, some contributions downplay risks of biases for marginal WTP related to a quality characteristic or the impact of additional information. By comparing hypothetical and nonhypothetical responses, Lusk and Schroeder (2004) showed that marginal WTP for a change in quality/characteristic is, in general, not statistically different across hypothetical and real (consequential) payment settings.

[6] The fictitious situation is inspired by the Artic© apple, which uses RNAi rather than GE to suppress the gene responsible for browning and bruising in apples. Arctic apples have been approved in the United States and Canada. They are sold through food service as well as very limited number of retail establishments in some U.S. states.

[7] Few empirical cases suggest an opposite relationship for the cost, with $F_{NPETs} < F_{HY}$ and $\lambda_{NPETs} > \lambda_{HY}$. This configuration is not studied in this paper, but it is likely to lead to the welfare dominance of the NPETs if consumers are not too averse to this new technology.

[8] Consumer surplus includes consumers' valuation of some environmental dimensions, like the issues related to food wasting or perennial crop diversity. This may not completely internalize externalities since other agents could still be harmed by external effects. These external effects could be addressed using a per-unit cost multiplied by the size of the externality per unit consumed. For example, food waste reduction could be accommodated by a reduction of a "rectangle" (food waste per unit × environmental cost per unit). The social planner regulator would internalize this additional element in its calculus. Profits in the supply chain are addressed in the extension section.

[9] The consumers' surplus with the integration of the possible cost of ignorance regarding the innovation process is fully compatible with the value of information defined under welfare theory (Foster & Just, 1989; Teisl et al., 2001).

[10] With the revelation of information about traditional hybridization or NPETs, consumers who were not initially purchasing a good could start buying it or start buying the alternative good or stop buying any good, and vice versa.

[11] Note that the new goods under NPETs could have additional sustainability attributes and be more valued than the hybrid one if known by consumers. This would achieve a more complete valuation of sustainability attributes, by revealing additional information about the sustainability or the environment impact related to NPETs to participants for eliciting new WTP after such an information. These WTPs could be taken into account in the cost of ignorance as defined by equations (4) and (5). This would enrich the content of the complete information crucial for defining the effect and cost of ignorance. The reader should keep in mind that the marginal effect of additional messages tends to be low after several messages.

[12] The experiments and the estimated WTPs are reported in detail in Marette et al. (2021).

[13] A fourth message noted GMO as the biotechnology used to generate the innovation. Given the overwhelming discounting of the new apple under that technology, it was clear that GMO apples would not emerge as an acceptable innovation. We, therefore, exclude this last round of WTP elicitation in the present paper.

[14] These average prices are not in the middle of the price interval of the multiple-price lists for allowing higher valuations related to the innovation process.

[15] Prices could be different and endogenously determined, by considering a retailer choosing a price for the new good (with the price of the conventional apple being given) based on the WTP and assuming some ability to mark prices up.

[16] Comparisons of welfares were performed using Mathematica software.

[17] For $\lambda_{\text{HY}} \geq 0.7\,\lambda_{\text{GE}}$, the hybrid investment replaces the GE investment in France.

[18] This is a simplifying assumption making the regulator able to predict the probability of accident. In many configurations, the collapse cannot be predicted in Stage 1 and cannot directly influence the R&D investment with the timing for the innovation to emerge, that is, very long (20–25 years). Despite the absence of a clear

probability, a R&D policy can be implemented for having an option value with new foods if a collapse happened.

[19] The lab creates a focalization bias toward specific questions related to food innovation which some consumers will forget outside the lab.

[20] Two caveats apply here. GMO is currently not widely available in France, and that it is mandated to be labeled as such. Hence, organic consumption is not a necessary strategy for consumers who want to avoid GMO. Moreover, the assumption that only consumers that purchase 100% organic fruits and vegetables are truly concerned about GMO is strict.

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SUPPORTING INFORMATION

Additional supporting information may be found in the online version of the article at the publisher's website.

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