Promoting Green Consumption in Retail Markets: Behavioural Interventions under Strategic Pricing

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Abstract

Behavioural interventions such are nudges or awareness campaigns are increasingly used to promote sustainable choices in retail contexts. They usually drive consumers' attention to environmental qualities in order to raise their willingness to pay. I show, using a structural model of supply and demand, that this approach might be ineffective in supporting sustainable consumption when firms set their prices strategically. Interventions making consumers more sensitive to prices perform better because they exert a downward pressure on prices. My empirical analysis relies on consumer panel data and focuses on organic egg purchases in French retailers. I also show theoretically that my findings generalize to a wide class of intervention design problems and derive some sufficient statistics for the price variation. Overall, this work shows that the design and evaluation of pro-environmental behavioural interventions should pay more attention to how they shape attitudes towards prices.

1 Introduction

Our day-to-day grocery shopping, however minor it may seem, has major environmental consequences. Food systems are known to be responsible for roughly 30% of greenhouse gas emissions globally [1]. They are also major drivers of water use and pollution, deforestation and biodiversity loss. The transition to more sustainable production modes cannot happen without dramatic changes in daily consumption choices. For instance, the EU Farm to Fork strategy [2] has set ambitious targets for the development of organic farming - an agricultural practice deemed beneficial for biodiversity - and calls for the reorientation of advertising towards more sustainable products, the implementation of front-of-pack labelling and the spread of digital-based environmental information tools to raise the demand for this industry.

Such behavioural interventions are increasingly used to promote sustainable consumption when typical price-based instruments such as taxes and subsidies are off the table. Yet, sales of organic food have stalled in France in 2021 after a decade of two-digit growth [3], in spite of rising advertising budgets [4] and easier access to simple and salient environmental information thanks to barcode scanner apps. Organic food, just as many green products, struggles to become more than a niche market. In such situations, the standard remedy consists in increasing the dose : provide more information on environmental qualities to further increase consumer willingness to pay. Is it really the change in purchasing behaviour that behavioural interventions should aim at in order to maximize green consumption ?

In this paper, I argue that pro-environmental behavioural interventions should rather make consumers more sensitive to prices than more willing to pay for green products. Being sensitive to prices means that one's consumption of a good varies sharply depending on whether its price is below or above a reference level. Examples of behavioural interventions making consumers more sensitive to prices are price advertising [5], making prices more visible at the point of sales, imposing the display of a reference price [6], providing price comparison tools or even launching a price-related boycott movement [7].

Two key observations that point towards this approach are that 1) retailers price green products based on consumer demand and 2) consumers reacting to pro-environmental behavioural interventions tend to be few, purchasing green more often [8, 9] and less sensitive to prices [10] than others. Under perfect competition, prices would be determined by costs and left unaffected by behavioural interventions. In practice, increasing consumer willingness to pay for environmental qualities is likely to result in higher retail prices. One usually thinks of pro-environmental interventions as triggering a uniform increase in willingness to pay in a relatively homogeneous population, which - in spite of the increase in price due to strategic pricing - would still lead to a rise in green consumption overall. However, since consumers are actually quite heterogeneous in their willingness to pay for the green good before and even more so after usual interventions, the direction of the change in demand is ambiguous. Conversely, making consumer more sensitive to prices might foster competition, push prices down and make them more affordable to consumers that are less willing to pay. I call "price effect" this indirect change in green consumption due to the price response of the retailer following an intervention.

This paper uses both a theoretical model and simulations based on a structural model calibrated on consumer panel data to validate the previous rationale. I consider changes in purchasing behaviour that could result from plausible behavioural interventions and I investigate which would be most beneficial to green consumption overall. I find that the price effect matters for the design and evaluation of pro-environmental behavioural interventions and that making consumers more sensitive to prices can reverse the opportunistic price response by the retailers, to the benefit of green consumption.

I first introduce a theoretical model of how behavioural interventions affect the price and demand for a green good under monopoly pricing. The behavioural intervention is introduced as a change in the demand function of a given fraction of the consumers, the policy choice being the purchasing behaviour adopted by these consumers. I define the price effect formally and I show that it must be non-negative for behavioural interventions that maximize green consumption. I derive an estimate of the magnitude of the price effect for interventions affecting only a small share of consumers, determine an upper bound on the price effect and show that it is the main driver of demand change in any optimal intervention. The results of the theoretical model are extended to the case of a multi-product monopolist and symmetrical Nash-Bertrand oligopolists.

The empirical analysis is performed by estimating a structural model of the demand and supply for eggs at major French retailers in 2012 - with organic eggs as the reference green product. The demand model is a multinomial logit model with random coefficients on price sensitivity and valuation of the organic attribute. It is estimated on home-scanned purchase data from a consumer panel representative of the French population. Even though organic eggs enjoy a large utility premium, their even larger prices limit their market share to 10%. Computing the Bayesian posterior means of the random coefficients, I obtain household-level estimates for price-sensitivity and willingness to pay for the organic attribute. I find that consumers willing to pay the most for organic attributes turn out to be also less price-sensitive than others. The supply model assumes Nash-Bertrand oligopolistic competition and constant marginal costs. The latter can be retrieved from the first-order condition at the initial equilibrium, knowing prices, demand and demand elasticities. I find that retailers indeed set higher margins on organic eggs than on unlabelled eggs.

Having calibrated my model, I can simulate behavioural interventions by changing the household-level willingness to pay and price sensitivity parameters for a small subset of the population in the demand model and computing the new market equilibrium. This allows me to compare interventions varying in their type (raising consumer willingness to pay or price sensitivity), targeting (which consumers change their purchasing behaviour) and scale (how many consumers change their behaviour). Raising willingness to pay for the organic label among low price-sensitivity consumers - an implicit objective and likely consequence of current interventions - has a limited effect on organic consumption overall, because of the price effect. Conversely, making these consumers more price-sensitive can significantly increase total organic consumption, even when the population affected by the intervention purchases mostly organic eggs at current prices.

Related literature

It is common in empirical IO studies of food markets to consider that retailers adapt their prices to policy interventions. This approach has not only been applied to price-based policies, but also to behavioural interventions such as mandatory front-of-pack nutritional labels [11] and a hypothetical ban of advertising for junk food [12]. The usual conclusion is that the price reaction of the firms strongly attenuates the intended effect of the policy.

The closest related work in this literature might be [13], which measures experimentally how several nutritional labels change the demand curve and use this to simulate the retailers' strategic price response if the intervention was implemented at scale. The conclusions of my paper are much more general: since I abstract from how interventions are implemented to focus on how they affect the demand curve, I can explore a much wider range of interventions, both theoretically and in simulations.

My theoretical model is in essence very similar to [14]. This other article asks how the incentives of a firm vary when the demand curve it faces is modified. Using its terminology, raising consumer willingness to pay means shifting the demand curve rightwards, whereas making consumers more sensitive to prices means rotating it anticlockwise. [14] finds that, in niche markets, firms prefer spreading consumer willingness to pay, while in mass market, they prefer to gather it around a specific value. The results of my theoretical model provide a reinterpretation of this insight: gathering consumer willingness to pay around a well-chosen price is an optimal way to transition from niche to mass market.

Finally, [7] provides a thorough empirical analysis of a large intervention having made consumers more sensitive to prices. This article studies a boycott on cottage cheese that took place in 2011 in Israel and documents the key role of the rise in price sensitivity in explaining the long-lasting price cuts that followed the boycott. The boycott rule implemented by the movement turns out to belong to a class of optimal behavioural interventions analyzed in my theoretical model. While [7] is an ex-post analysis, my article can be understood as providing theory- and simulation-based methods to predicting ex-ante the price effect of behavioural interventions.

Policy implications

The main message of the paper is that communicating about the merits of a product without mentioning its price or production cost is not the best way to support its consumption in retail markets. Organic consumption is only one setting out of many where this rationale applies: the same goes for fruits and vegetables under a "5-a-day"-like public health campaign, food items with a better Nutriscore or ranked high by barcode scanning apps.

More generally, the paper has implications for the design and evaluation of behavioural interventions affecting the consumption of a good priced by a strategic agent. The theoretical model stresses the importance of thinking beyond experimentally-measured average treatment effects in order to anticipate the firm price response to the intervention. In particular, one striking consequence of the theoretical model is that optimal interventions require that affected consumers stop purchasing at current prices, which means that the average treatment effect of the intervention on sustainable consumption at current prices is negative. Besides, the theoretical upper bound for the magnitude of the price effect derived from the model provides a practical rule of thumb to test the relevance of the price effect for a given market and intervention.

The model also has implications for environmental justice. The widespread use of consumption-based GHG emissions accounting - based on product-level life cycle assessment - to attribute environmental responsibility to consumers totally ignores the price effect. Therefore, this approach underestimates greatly the extent to which green price-insensitive consumers could further support green consumption, hence their potential for action. Being well-informed and careful regarding green product prices could contribute to environmental objectives more than accepting to pay a disproportionate price for these items. The distribution of sensitivity to prices in the population being quite different from that of income, this has also implications for the literature linking inequalities and demand-side mitigation policies.

The rest of the paper is structured as follows. Section 2 introduces a simple theoretical model that illustrates the mechanisms of the paper, provides some insights on the evaluation and design of behavioural intervention and yields some sufficient statistics for the magnitude of the price effect of small-scaled interventions. Section 3 describes the data and the methodology of the empirical analysis and simulations, while Section 4 presents and comments their results. Finally, Section 5 discusses qualitatively some policy-relevant aspects that are not accounted for in the previous sections.

2 Theory

This section provides a model of how pro-environmental behavioural interventions affect the price and demand for green goods. I first introduce the model notations and formalize the idea of a "price effect", the change in green consumption due to the firm price response to a behavioural intervention. I focus on the consumption of a green good sold by a monopolist firm and introduce the behavioural intervention as a change in the demand function of some consumers. In this setting, I then study what type of purchasing behavior should be induced by behavioural interventions in order to maximize green good consumption. I find that, in optimal interventions, affected consumers lower their demand at current price in order to obtain a price cut, which increases the consumption of the green good among non-affected consumers. Finally, I derive formulas for the magnitude of the price change following small-scaled interventions and conclude that the price effect plays a major role in all optimal behavioural interventions.

2.1 Notations and mechanisms

I analyze a setting where a monopolist sells at a price p an homogeneous green good, acquired at a constant marginal cost c. The firm generates a profit $\Pi(p) = D(p)(p - c)$ where $D(p)$ is the aggregate demand for the green good.

To keep the model simple, I do not include explicitly brown good consumption and consider that the policy objective is to maximize green good consumption. Brown good consumption can be safely ignored when modeling the behaviour of the firm if the price of the brown good is fixed - for instance, due to strong competitive pressure. It can also be ignored from an environmental policy perspective as long as consuming the brown good is as detrimental to the environment as other plausible outside options external to the market.

The consumer population is split ex ante between the consumers that are affected (A) by the intervention and those that are not (N) - neutral consumers. The aggregate demand for the green good can thus be decomposed as $D(p) = D^A(p) + D^N(p)$, with one aggregate demand function per consumer group.

There are two periods, (1) before and (2) after the intervention. In period $i \in \{1, 2\}$, the aggregate demand among affected consumers is $D_i^A(p)$ and the price p_i is set by the firm to maximize the profit function $\Pi_i(p) = D_i(p)(p-c) = (D_i^A(p) + D^N(p))(p-c)$. When several prices yield the same profit, I assume that the firm picks the lowest. I also assume that all the demand functions are asymptotically dominated by the inverse of the price, so that the corresponding profit functions tend to zero as the price goes to $+\infty$. Thus, equilibrium prices are always well-defined.

The purchasing behaviour of affected consumers after the intervention, D_2^A, is the main policy choice analyzed in the paper. In this theory section, I obtain some results that are valid for any intervention-induced purchasing behaviors D_2^A, not just for the two specific cases of interventions raising consumer willingness to pay and interventions raising consumer price sensitivity. The purchasing behaviour of affected consumers before the intervention, D_1^A, depends on the targeting of the intervention.

The policy objective is to maximize the final green good consumption $D_2(p_2)$ - or equivalently, the change in demand, denoted $\Delta D = D_2(p_2) - D_1(p_1)$. Another interesting outcome variable is the change in price, denoted $\Delta p = p_2 - p_1$.

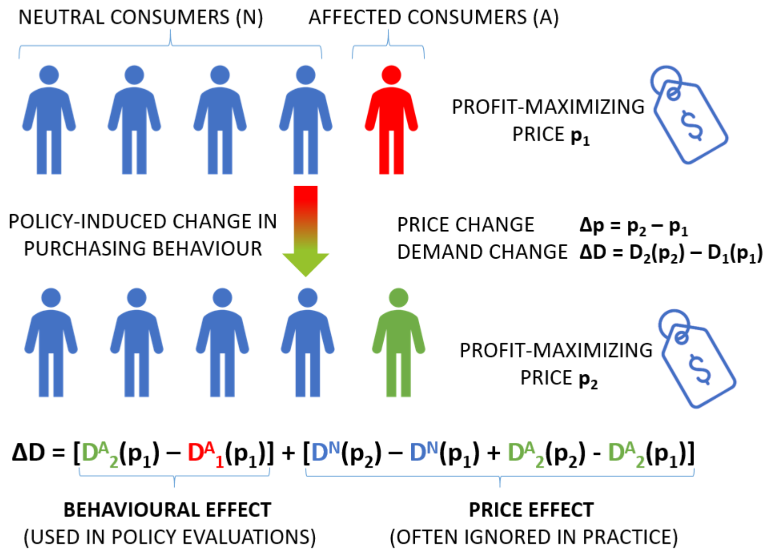


Figure 1: The effects of a non-price policy in the model

The main argument of the paper can be understood from the following accounting identity :

$$\Delta D = \underbrace{\left[D_2^A(p_1) - D_1^A(p_1)\right]}_{\text{behavioural effect}} + \underbrace{\left[D_2^N(p_2) - D_1^N(p_1) + D_2^A(p_2) - D_2^A(p_1)\right]}_{\text{price effect}} \tag{1}$$

The first term $\left[D_2^A(p_1) - D_1^A(p_1)\right]$ captures the demand change taking place in the affected population before the price response of the firm, which I call the behavioural effect. It is the typical outcome variable used in the experimental evaluation of behavioural interventions.

The second term captures the green consumption change due to the price response of the firm to the intervention, which I call the "price effect". The term $D_2^A(p_2) - D_2^A(p_1)$ is arguably of second order in many interventions because both the affected population size and the corresponding price change are small. However, there is no reason to think that the same goes for $D_2^N(p_2) - D_1^N(p_1)$. The main argument of the paper is that $D_2^N(p_2) - D_1^N(p_1)$ should not be ignored when designing and evaluating pro-environmental behavioural interventions.

2.2 Optimal induced purchasing behaviour

In this subsection, I ask what purchasing behaviour should be triggered by pro-environmental behavioural interventions to achieve the policy objective of raising green consumption. I call "optimal" any induced purchasing behaviour D_2^A such that the equilibrium demand $D_2(p_2)$ is maximized. Of course, this question only makes sense if there is somehow a limit to green consumption in the affected population.

To formalize this idea, let us impose the constraint that $0 \leq D_i^A(p) \leq \epsilon$ for $p \in \mathbb{R}$ and $i \in \{1,2\}$. One can interpret ϵ as the share of affected consumers, when each of them has a unit demand. This reflects both the fact that the behavioural effect is limited by the number of affected consumers and the extent to which their demand for the green good is already saturated.

Formally, the problem of finding an optimal intervention writes as follows:

$$\text{Maximize } D_2(p_2) = D_2^A(p_2) + D^N(p_2) \text{ over the choice of } D_2^A$$
$$\text{such that } 0 \leq D_2^A(p) \leq \epsilon \text{ for all } p > 0$$
$$\text{and } p_2 = \underset{p>0}{\arg\max} \left[D_2^A(p) + D^N(p)\right](p - c)$$

I will show that it is optimal that affected consumers stop purchasing the green good when its price is above a given threshold, and always purchase it otherwise. Let me call the corresponding demand function a cut-off purchasing behavior.

Definition 1. *A cut-off purchasing behavior with threshold price p^A refers to the function $D^A(p) = 1_{(0,p^A]} \times \epsilon$*

In practice, what sort of behavioural intervention could lead to such a cut-off purchasing behavior ? A consumer group or activists from an environmental NGO might decide to stop consuming a product when its price is deemed too high and they could set a clear threshold for that, as in the boycott movement analyzed in [7]. Other less radical initiatives could also generate a dramatic shift in demand around a limit price, such as a large price advertisement campaign or the display of a recommended retail price on the packaging of the product.

Theorem 1, the main theoretical result of this subsection, characterizes a threshold price p^{A^*} such that the corresponding cut-off purchasing behavior is optimal among all possible purchasing behaviors. In a nutshell, the proof goes as follows. First, Proposition 1 characterizes the optimal threshold price p^{A^*} that maximizes total consumption $D_2(p^2)$ among all cut-off purchasing behaviors. Then, Lemma 1 shows that this outcome is optimal among all possible demand function D_2^A. The formal proof of these results is available in the appendix, as well as that of Theorem 2, an extension of Theorem 1 to the case of n symmetrical oligopolists.

The determination of the optimal threshold price p^{A^*} is simple. Notice that when affected consumers adopt a cut-off purchasing behaviour with a threshold price p^A below the initial price p_1, the firm faces an alternative : either it sets its price p_2 at the threshold price p^A so that affected consumer purchase the green good, or it sets its price p_2 above this threshold and affected consumers will not consume the good. In the latter case, the firm will set the price p^N defined below.

Definition 2. *The neutral price p^N is the price that would be set by the firm if the affected consumers were absent from the market. Equivalently, it corresponds to the equilibrium price p_2 when $D_2^A = D^N$.*

We have shown that the firm must choose between the prices p^A and p^N. If the firm finds it strictly more profitable to set the price p^A than the price p^N, an intervention with a slightly lower p^A would have increased the consumption of neutral consumers without changing that of affected consumers. This shows that, at the optimal threshold price p^{A^*}, the firm is indifferent between setting either of these two prices. Thus, the the optimal threshold price p^{A^*} is characterized by

$$\Pi^N(p^N) = \Pi^N(p^{A^*}) + \epsilon(p^{A^*} - c) \ , \quad p^{A^*} \in [c, p^N]$$

Proposition 1 wraps up these ideas. I assume that Π^N is smooth, single-peaked in p^N and that D^N is decreasing on $[c, p^N]$.

Proposition 1. *There exists a unique price $p^{A^*} \in [c, p^N]$ such that the cut-off demand function with threshold price p^{A^*} makes the firm indifferent between (1) setting the price p^N to sell the product to some neutral consumers and (2) setting the price p^{A^*} to sell the products to more neutral consumers and all the affected consumers. It is characterized by*

$$\Pi^N(p^N) = \Pi^N(p^{A^*}) + \epsilon(p^{A^*} - c) \ , \quad p^{A^*} \in [c, p^N]$$

The equilibrium demand under a cutoff demand with threshold price p^{A^*} is

$$D_2(p_2) = D^N(p^{A^*}) + \epsilon$$

So far, we have only considered the case of cut-off demand functions. Lemma 1 shows that this class of demand functions is optimal among all possible demand function D_2^A (assumed to be asymptotically dominated by the inverse of the price so that the equilibrium price is well defined). Its proof is available in the appendices and relies mostly on the facts that D^N is decreasing and D_i^A is bounded by ϵ for $i \in \{1, 2\}$. This leads us to the main Theorem :

Theorem 1 (Optimal purchasing behaviour)**.** *The purchasing behaviour $D_2^A = 1_{(-\infty, p^{A^*}]}$ maximizes $D_2(p_2)$ over all possible choices of D_2^A. Conversely, every optimal purchasing behaviour D_2^A must be such that $p_2 = p^{A^*}$ and $D_2(p_2) = D^N(p^{A^*}) + \epsilon$*

Note that Theorem 1 does not state that the optimal purchasing behaviour is unique. Besides, one can easily construct an optimal purchasing behaviour different from a cut-off demand function, for instance by starting from a cut-off function with threshold ${p^A}^*$ and decreasing the demand in the $(0, {p^A}^*)$ price range. However, any optimal purchasing behaviour D_2^A must lead to the equilibrium price $p_2 = {p^A}^*$ and satisfy $D_A^2({p^A}^*) = \epsilon$.

Theorem 1 has a striking implication for behavioural intervention evaluation. Contrary to the common intuition, all optimal interventions are such that consumers stop right away to consume at the current price p_1 - since it is higher than ${p^A}^*$. A typical experimental evaluation measuring only the behavioural effect - the immediate consumption change before the price reaction of the firm - would thus dismiss any optimal intervention as strongly ineffective.

The theorem also provides a theoretical upper bound for the price and demand changes following a behavioural intervention. The next subsection will formalize this idea and derive tractable expressions related to the market conditions for the intervention effects .

2.3 Magnitude of the effects

In this subsection, I derive simple formulas for the magnitude of a price change following an intervention when the affected population is small. I focus on two important cases : optimal interventions - as defined in the previous subsection - and interventions that induce the same purchasing behaviour no matter the size of the affected population.

I focus on the case of a small share of affected consumers. Indeed, most of the non-price interventions that are actually implemented have a limited scale as compared to their relevant market. Marketing practices and nudges are usually decided and implemented by a single actor, be it a firm or some local public authority, hence cannot affect every consumer. Advertisements and environmental awareness campaigns on TV, radio or Internet target their audience to increase their cost effectiveness. If one of the most famous food barcode scanner app in France, Yuka, claims up to 16.5 millions users in France in 2021, this figure is likely to drop dramatically if we consider only active users and focus on searches regarding one specific product category. Even mandatory product labelling is unlikely to be noticed, understood and actually used by more than a small fraction of the consumers.

I will use the parameter ϵ introduced previously to account for the scale of the intervention. In the previous search for an optimal purchasing behaviour, ϵ was an upper bound on D^A that could be interpreted as the share of affected consumers. More generally, a purchasing behaviour D_i^A can be interpreted as the aggregate demand resulting from the purchasing behaviour $\underline{D}_i^A$ being adopted by each individual in the mass ϵ of affected consumers. This leads to the following formula :

$$D_i(p) = D^N(p) + D_i^A(p) = (1-\epsilon)\underline{D}^N(p) + \epsilon \times \underline{D}_i^A(p)$$

Here, ϵ is the share of affected consumers and $1-\epsilon$ that of neutral consumers. By extension, I introduce $\underline{\Pi}^N := \underline{D}^N(p)(p-c)$ and $\underline{\Pi}_i^A := \underline{D}_i^A(p)(p-c)$ the profit functions associated to one individual in each consumer group. Note that ϵ says nothing of how much the intervention alters the purchasing behaviour of the affected consumers, it only restricts their number. When ϵ is small, so is the affected population as compared to the neutral population. In the extreme case where $\epsilon = 0$, no consumer is affected by the intervention and the firm sets the price $p_1 = p_2 = p^N$ - which, by definition, is optimal for the neutral demand D^N.

Using a first-order approximation of the profit function of the profit function Π^N in the neighborhood of p^N and the previous characterization of the final equilibrium price $p_2 = p^{A^*}$ for optimal interventions, one can derive an equivalent of the price change when the population size is small.

Proposition 2. *[Optimal purchasing behaviour] Under an optimal intervention - for instance, when D_2^A is a cut-off demand function with threshold price $p^{A^*}(\epsilon)$ - we have*

$$\Delta p^* \underset{\epsilon \to 0}{\sim} \sqrt{\frac{2(p_1 - c)}{\frac{\partial^2 \Pi^N}{\partial p^2}(p_1)}} \times \sqrt{\epsilon}$$

Proposition 3 shows that the price change - hence the price effect - following an optimal intervention goes as the square root of ϵ, the share of consumers affected by the intervention. Since the behavioural effect $D_2^A(p_2) - D_2^A(p_1) \leq D_2^A(p_2) \leq \epsilon$ is at most linear in ϵ, this means that the price effect dominates. In other words, the most important driver of consumption change in small optimal interventions is the price effect, not the behavioural effect.

Moreover, the previous result provides a tractable asymptotic upper bound for the price and demand change following a small-scaled intervention, which can be used to perform back-of-the-envelope estimations. In particular, the second-order derivative of the profit of the firm at current prices and its absolute margin on the green good seem to be the key determinants of this upper bound.

Proposition 3 (Interventions that induce the same purchasing behaviour $\underline{D}_2^A$ no matter the size of the affected population)**.** *When $D_2^A = \underline{D}_2^A \times \epsilon$ and $\underline{D}_2^A$ is smooth, we have*

$$\Delta p \underset{\epsilon \to 0}{\sim} \frac{\frac{\partial \underline{\Pi}_1^A}{\partial p}(p_1) - \frac{\partial \underline{\Pi}_2^A}{\partial p}(p_1)}{\frac{\partial^2 \Pi^N}{\partial p^2}(p_1)} \times \epsilon$$

The case of interventions that induce the same purchasing behaviour $\underline{D}_2^A$ no matter the size of the affected population is also very relevant for applications. Many behavioural interventions are designed and evaluated without anticipating the scale at which they will be deployed or the share of consumers that they will actually be able to reach. Proposition 3 shows that the price change is linear in ϵ and in particular, asymptotically negligible as compared to the optimal case. This shows that interventions designed or evaluated independently of the scale of their deployment are inherently limited, as their price effect is bound to be at most linear.

The price change - hence the price effect - following such an intervention depends on the difference between the profit gradient of the affected demand before and after the intervention. This implies that the characteristics of the affected population - i.e. D_1^A - can affect significantly the magnitude of the price effect. In order to maximize it, the intervention should target consumers whose corresponding profit function is upward-sloping at current price. Assuming that Π_1^A is single-peaked, this means that the monopoly price for this consumer group is higher than the initial equilibrium price. In particular, this suggests that consumers with either a high willingness to pay for a green product or those with a low price sensitivity are suitable targets.

In conclusion of this theoretical section, the most effective behavioural interventions induce a positive price effect. To do so, it is profitable to target consumers for which the profit function is the least downward-sloping at current prices - for instance, those with a high willingness to pay for the green good. The induced purchasing behaviour should make their demand function steeper at the new equilibrium price. This corresponds to the informal definition of making consumers more sensitive to prices given in introduction. In the next sections, I will test these ideas using actual market data.

3 Data and methods

The empirical analysis of the paper is based on home-scanned data from a large consumer panel. It consists in estimating first a model for the demand of shell eggs in major French food retailers, then using it to calibrate a model for the supply and finally using both to perform some policy simulations.

3.1 Data and context

My empirical analysis is based on home-scanned egg purchase data for the year 2012 from a consumer panel (Kantar WorldPanel) representative of French households. The panelists have to scan the bar-code of the purchased products after each shopping trip, providing reliable information of the characteristics of their purchase. In particular, we know the brand, label, calibre and number of eggs in the box. We distinguish between three egg labels : battery hens, free-range hens and organic hens. Barn farming did not exist as a label at the time and the French "Label Rouge" label - slightly more demanding than free-range but much less than organic - cannot be distinguished from free-range in our data. We focus on eggs having medium (M) or large (L) calibre, sold under one of top three national brands or a retailer own brand.

I define a "simplified brand" variable by grouping together retailer own-brands with a similar range (top range, middle range and low range), and national brands in a forth group. At the time, the hard-discounters did not sell organic eggs under their own brands but offered some from a national brand.

The panelists must also report what store they went to. We limit the sample to non-specialized food stores, which accounted for 64% of organic eggs purchases in France in 2019 and more generally half of the sales of organic products in 2012 according to the French agency for organic food (l'Agence Bio) [15]. Since the central procurement service can be retrieved from the product barcode, I define a retailer as a pair formed by a central procurement service and a store format, so as to distinguish for instance convenience stores and hypermarkets from the same chain. There are four store formats : hypermarkets, supermarkets, junior department stores and convenience stores. I find 14 retailers in total, which is consistent with previous studies on the French retail industry. [11].

Non-purchasing is considered as a product of utility zero that is always available to the consumer. The shopping trips that led to no egg purchase are key in the identification of the utility derived from egg consumption. It is difficult in all generality to disentangle non-purchase due to some dissatisfaction with respect to the current offer from non-purchase due to an egg stock at home. Making use of the limited time eggs can be stored, the shopping trips included in the final sample are selected as follows. First, I draw randomly one shopping trip involving the purchase of eggs per four-week period and household, if any. Then, for periods during which no egg purchase was made, I draw at random one empty shopping trip during the period. Thus, I make sure that the observed decision not to purchase egg is never driven by an sufficient stock at home.

The identification of household-specific parameters requires a minimal number of observations. Therefore, I consider only households that have purchased eggs during at least 6 periods out of 13. Moreover, I use two available demographic variables : the quartile of the household in the distribution of income as well as its position over the life cycle - split in ten categories, depending on the composition and age of the members of the household .

Finally, estimating a multinomial logit model requires the definition of an appropriate choice set for each shopping trip. Starting from the set J_{rt} of products sold by retailer r during period t, I define the set J_{it} of products available to household i during period t as the union of the J_{rt} for several retailers r. The choice of this retailer list strongly determines the level of competition assumed in the model. The larger the number of retailers included in the list, the less captive consumers are, the higher the competitive pressure on retailers. On the one hand, if we use the union over all retailers, we consider that household i could have equally chosen to purchase eggs at any other retailer. This assumption ignores the constraints of limited retailer availability and transportation costs, as it is unlikely that the choice to visit a given retailer is entirely driven by the price and characteristics of their eggs only. On the other hand, if $J_{it} = J_{ir}$ where r is the retailer that was indeed visited at period t, then we are taking the choice of a visited retailer as entirely independent to the price and characteristics of their eggs. This may be a strong assumption. In order to build realistic choice sets, I take the union over all retailers that the household visited during the year 2012, so as to make sure that retailers in the list could indeed be considered by the household.

3.2 Demand model

This section introduces the structural model used to estimate consumer demand, providing details on how it deals with price endogeneity and household heterogeneity. The demand for eggs is modeled by a multinomial logit with random coefficients α_i for the price sensitivity and β_i for the valuation of the organic attribute. Appendix 6.0.1 gives the general expression of the likelihood function and the demand elasticities for this class of models. The structural equation estimated is the following :

$$U_{ijt} = -\alpha_i \times p_{jt} + \beta_i \times \text{IsOrganic}_j \times \text{BuysOrganic}_i + \gamma \cdot \mathbf{x}_j + \delta \times v_{jt} + u_{ijt} \tag{2}$$

The vector $\mathbf{x}_j$ stands for egg characteristics (other labels, calibre, simplified brand). BuyOrganic_i indicates whether household i has purchased organic eggs at least once in 2012, so that β can be interpreted as the valuation for organic eggs among those that sometimes purchase organic eggs. Noise terms u_{ijt} follow a standard Gumbel and are mutually independent. Note that the price is the only product characteristic that depends on the time period.

The term v_{jt} is a control function for the endogeneity of prices [16]. It corrects the bias induced by the correlation between price variations and unobserved determinants of purchase decision. For instance, special offers are often set in front display, increasing the probability of purchase. The control function is nonzero only for products that have been bought and is equal to the residual of the following regression

$$p_{jt} = \psi \cdot \mathbf{x}_j + \phi \cdot \mathbf{z}_j + v_{jt} \tag{3}$$

The purchase price is instrumented - as often in the literature [17, 18] - by the characteristics of the products and the average price of a similar product at competitors. Thus, in Equation 2, the price variable used is not directly the price p_{ijt} paid by the consumer - which is only available for the purchased product - but its average p_{jt} for the same product at this retailer during period t. This definition applies to all the products available in the choice set.

The random coefficients α_i and β_i are random variables with one realization per household. Because of the factor BuysOrganic_i in the structural equation, the distribution of β_i is identified only on households that have purchased organic eggs at least once in the year, and β_i is otherwise assumed to be zero. I made this unusual modelling choice for two reasons. Firstly, because it is difficult to identify the valuation of an attribute that is rarely included in consumer consideration set. Secondly, because the method to retrieve household-level valuation for the organic label presented in the next paragraphs makes little sense for households that never purchase organic eggs.

The model is estimated assuming a joint normal distribution of the coefficients α_i and β_i in the population. Their means $(\bar{\alpha}, \bar{\beta})$ are assumed to be income-group-specific whereas the variance covariance matrix Σ is shared across income groups. Hence the following equation, where w_i follows a two-dimensional standard normal distribution

$$(\alpha_i, \beta_i) = (\bar{\alpha}, \bar{\beta}) \cdot \mathbf{d}_i + \Sigma\ \mathbf{w}_i \tag{4}$$

Estimating the model tells us what the distribution of α and β is at the aggregate level, but says nothing of its value at the household-level. To do so, I determine α_i^{BAYES} (resp. β_i^{BAYES}), the expectation of the Bayesian posterior mean for α (resp. β) conditionally on household i's observed purchase decisions *achats*$_i$ and the parameters $\theta_{\text{LN}} = (\bar{\alpha}, \bar{\beta}, \Sigma)$ of the population distribution for (α, β). As mentioned previously, I assume $\beta_i = 0$ for households that have never purchased organic eggs in the year, consistently with the estimated demand model. The general analytical expression for the expectation of the Bayesian posterior mean is reminded in Appendix 6.0.1.

$$\begin{cases} \alpha_i^{\text{BAYES}} & = E(\ \alpha_i \mid d_i, \bar{\alpha}, \bar{\beta}, \Sigma, \text{purchase decisions for household } i\ ) \\ \beta_i^{\text{BAYES}} & = E(\ \beta_i \mid d_i, \bar{\alpha}, \bar{\beta}, \Sigma, \text{purchase decisions for household } i\ ) \end{cases} \tag{5}$$

The demand $D_{ij}(\mathbf{p})$ of household i for product j is assumed to be equal to the market share as predicted by Equation 2 when the constant α_i^{BAYES} has been substituted to the random variable α_i. Therefore, at the household-level, the demand model is assumed to be multinomial logit - without random coefficient. The aggregate demand $D_j(\mathbf{p})$ for product j is just the finite sum of all the household-level terms $D_{ij}(\mathbf{p})$.

3.3 Supply model

Each retailer r sells a set J_r of products, product j having a marginal cost c_j and being sold at a price p_j. Given the vector $\mathbf{p}$ of prices and the VAT tax rate $\tau = 5.5\%$, its profit writes

$$\Pi_r = \sum_{j \in J_r} D_j(\mathbf{p})([1-\tau]p_j - c_j)$$

Retailer r's program consists in setting its tax-inclusive prices $(p_j)_{j \in J_r}$ so as to maximize its profit Π_r. The first-order optimality condition with respect to the price of product $j \in J_r$, denoting $D_k(p)$ the aggregate demand for product k writes

$$D_j(\mathbf{p}^*) + \sum_{k \in J_r} \frac{\partial D_k}{\partial p_j}(\mathbf{p}^*) \; ([1-\tau]p_k^* - c_k) = 0 \tag{6}$$

Matricially, the first-order condition for each product can be grouped as

$$\mathbf{D}(\mathbf{p}^*) + \mathbf{\Omega}(\mathbf{p}^*)([1-\tau]\mathbf{p}^* - \mathbf{c}) = 0 \text{ avec } \mathbf{\Omega} = \left(1_{J_r}(k) \times \frac{\partial D_k}{\partial p_j}(\mathbf{p}^*)\right)_{(j,k) \in J^2} \tag{7}$$

In the previous equation, marginal costs can be identified from the price, demand and demand elasticities at equilibrium. Once the demand model has been estimated , it is possible to compute

$$\mathbf{c} = \mathbf{\Omega}(\mathbf{p}^*)^{-1}\mathbf{D}(\mathbf{p}^*) + [1-\tau]\mathbf{p}^*$$

Since price and demand fluctuate over the year, marginal costs are computed using data from an arbitrary period - period 11. The demand model is fundamentally a model of variety choice, but its predictive power regarding quantity is quite limited. In order to focus on the choice between egg variety, I remove the shopping trips that led to no purchases from the data and the possibility for households not to purchase during a shopping from the model. This means that the predicted market shares used here for retrieving marginal costs and later for simulating non-price interventions are conditional on the fact that the household purchases.

As explained earlier, the demand model $\mathbf{D}$ used here is a sum of household-specific multinomial logit predictions and not the direct predictions from the initial random coefficient multinomial logit model. In particular, price elasticities are just the sum of household-specific elasticities that have a very tractable expression since the model does not involve a random coefficient - see Appendix 6.0.1.

3.4 Intervention simulations

Using the previously described demand and supply model, one can perform some policy simulations. Let me clarify what interventions are considered and how they are simulated.

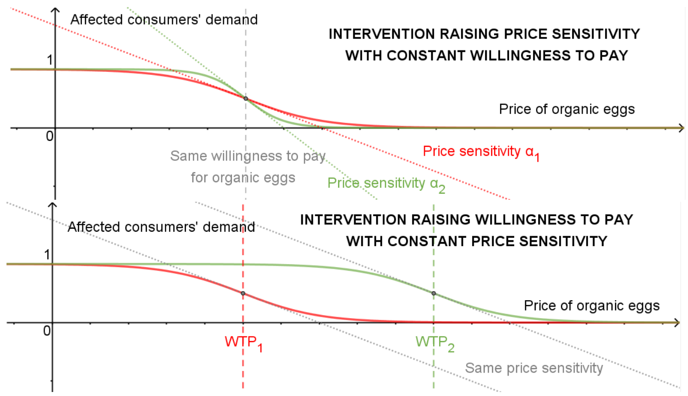
From the estimation of the demand model, I have retrieved some household-level determinants α_i and β_i of the purchasing behavior. In order to simulate non-price interventions, I change the value of these parameters in the affected population and compute the new market equilibrium. In this approach, an intervention can be specified as a set of affected consumers and the transformation that is applied to their parameters α_i and β_i.

The main claim of the paper is that, for interventions that affects mainly consumers that have either a high willingness to pay for green goods or a low price sensitivity, making them more price sensitive is more effective than making them more willing to pay. In order to test this statement, I need to define precisely what these interventions correspond to. I define WTP_i the willingness to pay for organic eggs of consumer i as the monetary value of an organic egg of medium calibre sold under a mid-range retail brand for this consumer. It is the ratio of the corresponding utility by the utility α_i of money and can be interpreted as the price that makes the consumer indifferent between purchasing a standard organic egg and not purchasing.

$$\text{WTP}_i = \frac{\gamma_{\text{Standard egg value}} + \beta_i}{\alpha_i}$$

From now on, I will always work on the (α_i, WTP_i) plane when I describe an intervention. What I refer to as a change in WTP means a change in β_i - holding α_i constant - such that the new WTP_i value is reached. In the (α_i, WTP_i) plane, testing my previous statement on intervention efficacy consists in comparing the effects of consumer movements to the right (pure increase in price sensitivity) to consumer movements to the top (pure increase in consumer WTP). I will also consider "mixed" interventions, that move consumers both to the top and to the right.

Once the demand from the affected population has been changed, a new equilibrium is computed. To do so, I use a classical iterative algorithm from the literature, detailed in the appendix. Note that this algorithms makes uses of a first -order condition that is necessary but not sufficient for optimality. Therefore, when the profit function of a firm has several local maxima, the iteration can get stuck in one of them and may not lead to a profit-maximizing price. As I consider only small changes in the demand function and do not explore the domain of very high value for the price sensitivity, it is unlikely that such



numerical issue arise.

4 Results

4.1 Estimated demand

Figure 2 shows the estimated parameter values for the demand model, as well as the predicted utility attributed by a reference household to each egg characteristic - normalized by the price sensitivity, so that each value can be interpreted as being expressed in euros. The sign of the estimated utilities are as expected for calibre, label and consumer own-brand range. More surprisingly, national brands are barely more valued than bottom-range own-brands. This could be due to the use by retailers of communication or shelf-filling practices that are more favorable to their own products. At the aggregate level, one can also notice that price sensitivity is logically higher for lower income groups.

Variable	Coefficient	Monetary value
Simplified brand		
Low-range own brand	-0.063	-0.003€
Medium-range own brand	0.620*	0.028€
Top-range own brand	1.420*	0.063€
National brand	0.251*	0.011€
Label		
No label	Reference	0.000€
Free-range label	1.325*	0.059€
Organic label	3.943*	0.176€
Calibre		
Medium	Reference	0.000€
Large	0.261*	0.012€
Price sensitivity		
Average (income Q1)²	-23.716*	
Average (income Q2)	-22.417*	
Average (income Q3)	-20.522*	
Average(income Q4)	-19.759*	
Variance and covariance		
Standard deviation (price sensitivity)	-6.633*	
Standard deviation (organic label)	-1.711*	
Correlation (price sensitivity and organic label)	1.133*	
Control variable		
Control variable	6.471*	

[1] The star * indicates that the hypothesis that the coefficient value is zero is rejected with probability at least 95%
[2] (income Q1) refers to the random coefficient average for the first quarter of the income distribution

Figure 2: Estimated coefficients for the demand model

4.2 Household-level heterogeneity

Figure 3 illustrates the joint distribution of the mean Bayesian posteriors in the $(\alpha_i, \mathrm{WTP}_i)$, highlighting several relevant consumer groups that will be later used as affected population in the intervention. Notice that the curve at the bottom correspond to households that never purchased organic eggs and have been attributed a value of zero for β. It is not a line but a curve because we are working with $(\alpha_i, \mathrm{WTP}_i)$ instead of the (α_i, β_i) plane.

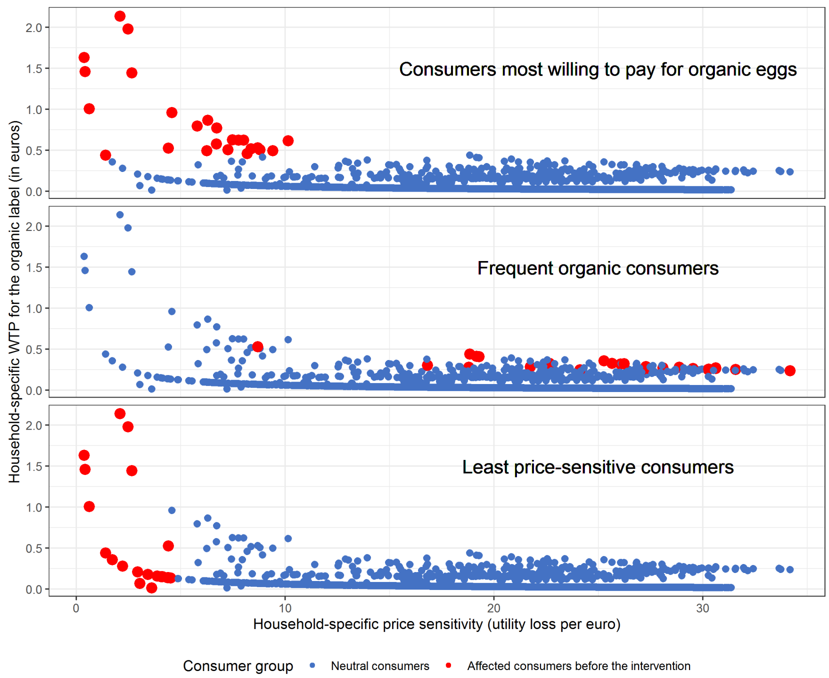


Figure 3: Affected consumer groups tested in the simulations

4.3 Retail marginal costs

Figure 4.3 illustrates variations in marginal cost and marginal benefit across labels, simplified brands and store format, under different competition assumptions. The marginal costs estimates vary as could be expected along these categories.

Category	Average price	Marginal cost	Marginal benefit
Cross-product average	0.272	0.197	0.076
Label			
No label	0.184	0.123	0.061
Free-range label	0.291	0.215	0.076
Organic label	0.417	0.311	0.106
Simplified brand			
Low-range own brand	0.148	0.090	0.058
Medium-range own brand	0.228	0.164	0.064
Top-range own brand	0.273	0.193	0.080
National brand	0.333	0.247	0.087
Format			
Hypermarkets	0.252	0.180	0.072
Supermarkets	0.278	0.200	0.077
Convenience stores	0.302	0.221	0.081
Junior department stores	0.332	0.249	0.083

Note: Prices, costs and benefits are given in euros

Figure 4: Calibration of the supply model

The model suggests that retailers enjoy a larger marginal benefit on organic eggs than for other labels, validating the niche pricing hypothesis. The difference in retrieved retail marginal costs between organic and free-range are not that far from those for their agricultural production as reported by the ITAVI [19] - the national technical agricultural institute that produces data on poultry production. However, the large difference in marginal costs between free-range and battery eggs is difficult to reconcile with this alternative data source.

4.4 Simulations

Using my calibrated model, I simulate behavioural interventions that make consumers more willing to pay for organic eggs, make them more sensitive to prices or do both. Then, I check the sensitivity of the results to the way the interventions are specified.

In order to specify a behavioural intervention, one must tell (1) which consumers are affected, (2) how many they are and (3) how their purchasing behaviour changes following the intervention.

I consider two consumer groups that could be affected by the intervention : those with a high WTP for organic eggs and those with a low price sensitivity. Figure 3 is an illustration of where these consumers are located in the $(\alpha_i, \mathrm{WTP}_i)$ plane for a population size of 1%.

Consumers that react to pro-environmental interventions are known to be of this type.

How should the affected population size be chosen ? The behavioural effect cannot increase the organic market share by more than the share ϵ of affected consumers - more precisely, ϵ times the average probability of non-organic egg purchase among them. Since consumers are polarized with respect to organic consumption, most consume organic less than 10% of the time, while some do so more than 90% of the time. Thus, the potential behavioural effect is roughly ϵ for general consumer groups and rather $\epsilon/10$ for frequent organic consumers.

I consider three types of interventions, which can be understood as transformations of the $(\alpha_i, \mathrm{WTP}_i)$ plane. I distinguish between interventions that (A) raise consumer WTP for organic eggs, those that (B) raise consumer price sensitivity and those that (AB) raise both. For each of these three categories, I focus on two possible implementations : either (Shift) the household-specific parameters are uniformly shifted - as in equation 8 - or (Target) they are increased until they reach a target level - as in equation 9. Figure 7 provides an illustration of what these transformations mean when the affected consumers are the 1% most frequent organic consumers.

$$\begin{cases} \mathrm{WTP}_{\mathrm{After}} & = \mathrm{WTP}_{\mathrm{Before}} + \Delta\mathrm{WTP} \\ \alpha_{\mathrm{After}} & = \alpha_{\mathrm{Before}} + \Delta\alpha \end{cases} \tag{8}$$

$$\begin{cases} \mathrm{WTP}_{\mathrm{After}} & = \max\left(\mathrm{WTP}_{\mathrm{Before}}, \mathrm{WTP}_{\mathrm{Target}}\right) \\ \alpha_{\mathrm{After}} & = \max\left(\alpha_{\mathrm{Before}}, \alpha_{\mathrm{Target}}\right) \end{cases} \tag{9}$$

Figure 5 gives some simulation results for the previously described affected consumer groups. I use a (Target) transformation. with parameter values $\alpha_{\mathrm{Target}} = 40$ and $\mathrm{WTP}_{\mathrm{Target}} = 0.6$. A price sensitivity of $\alpha = 40$ correspond to the top of the initial price sensitivity distribution, where the median price sensitivity in the population is $\alpha = 23$. To understand what a willingness to pay for organic eggs of 60 cents implies, consider the case of a consumer that has the choice between purchasing organic eggs at 41 cents and free-range eggs at 29 cents (the average market prices). Given my estimated demand model, with a WTP of 60 cents for organic eggs, this consumer would favour them more than 99% of the time. These parameter choices might seem extreme, but I will later perform similar simulations with any willingness to pay between 0 and 60 cents and any price sensitivity between 0 and 40.

For the simulated interventions, it is clear that what performs best is (AB) a raise in both price sensitivity and in willingness to pay for the organic label, followed by (B) a pure raise in price sensitivity. In order to analyze the results, notice that the price effect corresponds to the darker bars on the figure. When the simulated intervention is (A) a raise in WTP,

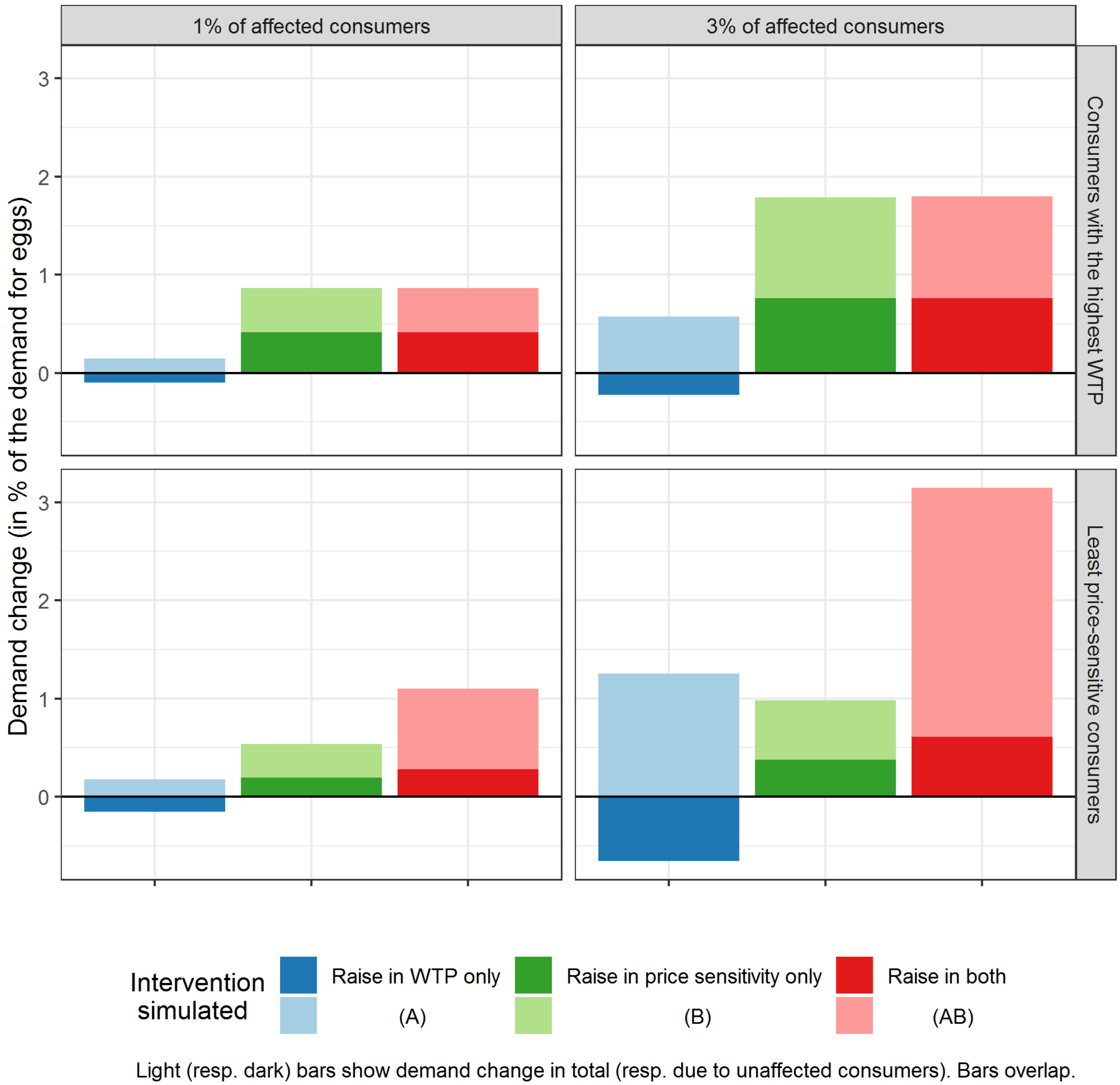


Figure 5: Simulations results : change in demand depending on intervention type

the price effect is negative. Even if the overall effect on green consumption is positive, it happens only through an increase in consumption among affected consumers and causes an almost comparable decrease among unaffected consumers. In contrast, the price effect is positive for the two other interventions types (B) and (AB).

The difference in results between the two consumer segments is also instructive. Increasing consumer WTP (A) seems to perform better when the intervention targets consumers with a low price sensitivity. Since those consumers rarely purchase organic eggs before the intervention, there is more room for improvement among affected consumers. However, due to their low price sensitivity, their increased WTP for organic eggs leads to higher organic prices that with the other consumer segment, which magnifies the negative price effect. Although (A) might be slightly more effective at increasing organic consumption than (B) in some settings, its distributional consequences are more controversial. It contributes to the polarization of organic consumption - higher for affected consumers, lower for others - by pushing prices up.

The magnitude of the price effect is half that of the intervention when it affects consumers with a high WTP for the green good, and a fourth of it when it affects consumers with a low price sensitivity. Therefore, it cannot be ignored when designing or evaluating interventions that are likely to affect mostly one of these two consumer segments.

The presence of a positive behavioural effect for (B) pure raises in price sensitivity might seem surprising. This is due to the way "holding willingness to pay" constant has been defined in section 3.4. When the price sensitivity is increased, I also increase the valuation of the organic attribute so that the willingness to pay for a medium organic egg remains constant. Since no such increase in valuation happens for non-organic eggs, the willingness to pay for them is reduced and this makes affected consumer more likely to choose organic eggs over other types of eggs. Still, this behavioural effect cannot be larger than size of the affected population times the market share of non-organic eggs among affected consumers before the intervention.

Therefore, the most important message from the figure is not that the total demand change is always higher when raising price sensitivity (since its behavioural part is debatable as it depends on technicalities on how the intervention is modeled) but rather that the price effect can be of comparable magnitude to the upper bound of the behavioural effect (which depends only upon the affected population, regardless of the simulated intervention). For the interventions considered in Figure 5, the ratio of the positive price effect to the upper bound for the behavioural effect in interventions (B) and (AB) varies between one to two and one to four.

Since Figure 5 contains the simulation results for only a few values of the intervention parameters, I could have missed an interesting parameter value. I will perform the same simulation with a wide range of parameter values. Before moving to the results in Figure 6, let me discuss how the range of tested parameters has been chosen.

First, notice that above a certain level, raising consumer WTP makes no difference in terms of affected demand and translate only into higher prices, hence a lower total demand. In particular, this is the case once the market share of organic products among consumers after the intervention is close from 100%. This criterion is met with the parameter value tested above. Therefore, there is no need to consider higher WTP parameter values.

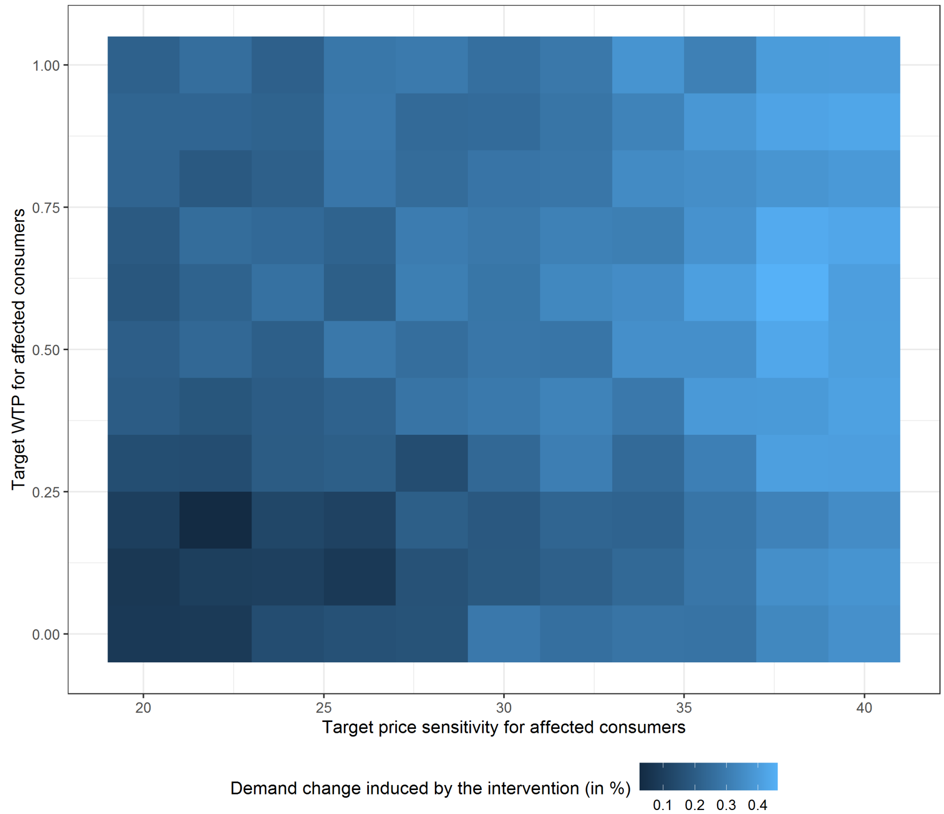
Second, it would be indeed highly interesting to test the case of extremely price-sensitive consumers. However, if the shape of the demand curve changes brutally, first-order condition in the algorithm that computed the price equilibrium may face some numerical issues. Using alternative algorithms could cope with this issue, but would be very computationally demanding. Therefore, I do not consider interventions that bring consumer price sensitivity higher than 40 (utility loss per euro). As mentioned above, a price sensitivity of 40 is already slightly above the highest price sensitivity observed in the data.

Third, it makes no sense to consider negative parameter values. In the "Shift" case, this amounts to reducing - as opposed to raising - consumer WTP and price sensitivity. In the "Target" case, this means that the transformation has no effect on affected consumers. Overall, we have restricted our analysis to a bounded set of intervention parameter values. Figure 6 displays the simulation results as heat maps in the space of parameter values in the "Target" case when the affected population is the 1% most frequent organic consumers.

On the heat maps, the lighter the tile, the more effective the intervention. It is clear than the best results in terms of total demand change are obtained with the highest price sensitivity targets. This is consistent with the theoretical model, as a higher price sensitivity means a steeper demand curve. In contrast, increasing further consumer WTP when it is already above the initial market price (roughly 0.4) does not seem to have any effect.

The heat map showing the change in passive demand illustrates a phenomenon that cannot be observed if we focus on the total price effect : the higher the WTP in the affected population, the smaller the change in consumption among non affected consumers. Our previous remark that total consumption stops raising with affected raising consumer WTP above a certain level can be explained by two compensating forces : while affected consumers get closer to consuming organic all the time, they also push prices up, which discourage organic consumption among passive consumers. Therefore, raising consumer WTP might just push some consumer groups to consume more often organic at the expense of other consumer groups.

In the appendices, I perform some robustness checks with the "Shift" specification of the



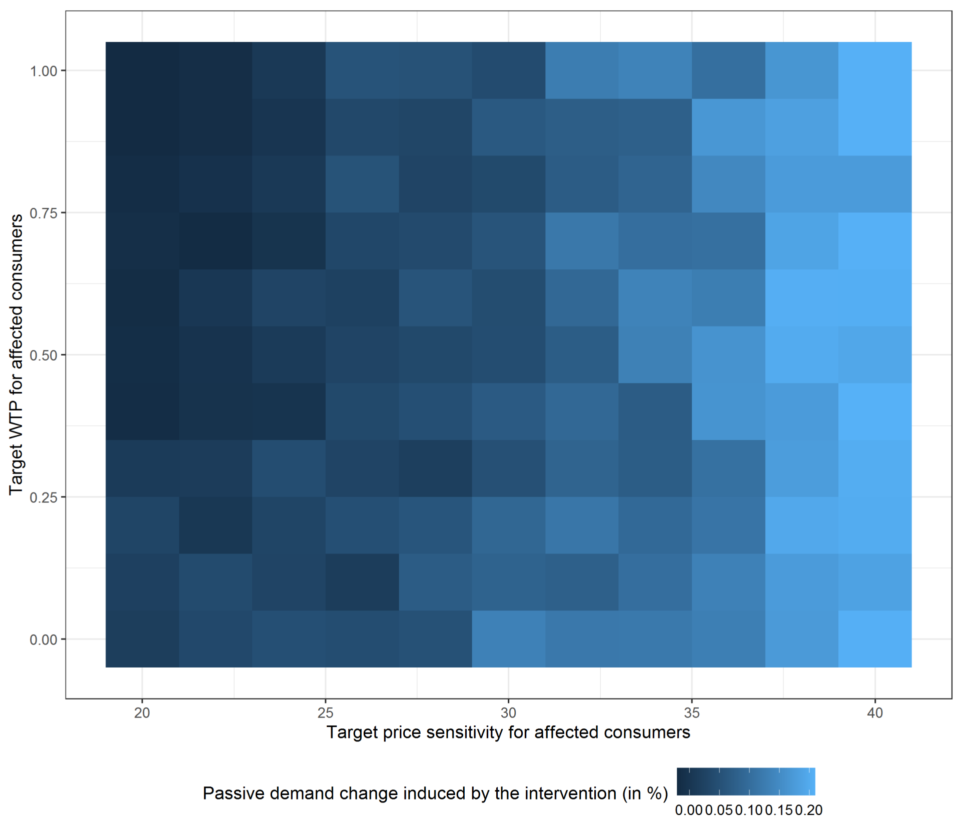


Figure 6: Sensitivity to intervention parameters α_{Target} and β_{Target}

change in demand due to the intervention. I replicate Figure 5 and 6 in this setting.

To summarize, I have performed simulations with various specifications of the behavioural interventions and considered plausible consumer segments that could be affected. I have found that making consumer willing to pay more induces a negative price effect and can be quite inefficient in increasing green consumption, in particular when affected consumers already have a high willingness to pay for the green good. In comparison, making consumers more sensitive to prices work much better. The effect is always at least as good when the two policies are combined, as the increased price sensitivity prevents any opportunistic price raise on the retailer side.

5 Discussion

This section analyzes qualitatively three important aspects of the policy that have not been explicitly modeled in this paper : possible upstream effects of raising consumer price sensitivity, the geographical scope of the model and finally the time dimension of the main mechanisms

5.1 Upstream effects

One of the assumption in our rationale is that only a limited share of the price premium on green products goes to their producers, to the benefit of retailers. If that higher margin was captured by the green product industry, it may help it expand or invest, inducing positive supply-side effects that might exceed the negative demand-side effects of a lower green consumption. In the case of organic eggs, as for most standardized food products involving few processing steps, there are reasons to believe that retailers, not producers, gain the upper hand. Major retailers group together to form even larger central procurement services that have a high market power and are able to purchase food products at a lower price [20]. Thus, in absence of strong brands - as for the soda industry - or a highly concentrated upstream industry - as for the French milk product industry [21], it can be expected that most of the margin will be captured by retailers. For instance, publicly available data on prices paid to producers for organic vegetables suggests that retail margins are higher than for non-organic vegetables [22].

Still, agricultural revenue is a burning political issue in France and the risk that raising consumer price sensitivity harms it cannot be ignored in the conception of the intervention. Two elements may limit this risk. First, the recent EGalim bills have imposed that upstream prices be set contractually between farmers and retailers on the basis of industry-specific cost indices. The objective is that the price of agricultural products "move forward", meaning that agricultural prices should follow the evolution of agricultural costs more than that of the demand. If this policy succeeds, then we should not expect a less price-elastic consumers demand to translate into lower agricultural prices. Second, the intervention could suggest different purchasing behaviour depending on the available information on upstream prices. The second EGalim bill has authorized five years of experimentation with the display of prices paid to farmers. Besides, a mandatory display had been implemented in France in 1999 for a few months by the Ministry for Agriculture, although the policy was limited to a few fruit categories [23]. It should be noted that some brands available in French supermarket already provide such information for their food products [24].

5.2 The risks of a local price response

In intervention simulations, the consumer sample and average prices per product and retailer were representative of the national level. Of course, there can be significant variations at a more local level : for instance, city boroughs inhabited mostly by high-income price-insensitive consumers, or some stores having higher retail prices because of higher commercial lease prices in the area. Should we worry that this may impede our argument ? If retailers were to set prices based on local demand and affected consumers were concentrated in specific geographical areas, then the price drop following the intervention might be stronger but local. According to Proposition 2, the magnitude of the maximal price effect goes as the square root of the share of affected consumers. Therefore, by concavity of the square root function, it is preferable that affected consumers are geographically evenly distributed. Besides, there is no environmental gain from obtaining a price decrease in areas were there is already a vast majority of green consumers. Therefore, the actual effect of the intervention might be weaker if prices were set based on local demand conditions.

However, most available evidence goes in the opposite direction. Some hard-discounters are known to set a unique price at the national level and use it as a promotional argument in their commercials. More generally, a recent literature has noted that retail prices are mostly uniform and react little to local demand shocks - see Section 2 in [25] for an overview. For instance, [26] notice that most US retail food chains set nearly uniform price, although there are huge discrepancies in price sensitivity across markets. Moreover, if the intervention is publicly announced and has a national scale, we might expect retailer head offices to take on the issue and design a coordinated price reaction because of reputational concerns. Overall, it seems more likely that the intervention produces nation-wide level, which confirms the methodology followed in our simulations.

5.3 Temporal dimension of the mechanisms

Our model considers an intervention that affects the purchasing behaviour of some consumers, which entails a price response from the retailers, and finally leads to a change in consumption in a wider population. These phenomena have various characteristic times, a dimension that is not accounted for in the model.

Let me start by describing an illustrative empirical case analyzed [7] whose nature is very similar to the type of intervention studied in this paper. The article discusses a boycott movement related to the price of cottage cheese that took place in 2011 in Israel. The authors relate that "a Facebook event calling for a boycott of cottage cheese was created on June 14, 2011, demanding a price reduction from about 7 New Israeli Shekel (NIS) to 5 NIS per 250-gram container. The Facebook event was an instant success: a day after it started, nearly 30,000 Facebook users joined it; by June 30, the number surpassed 105,000.". On this specific example, it seems that the change in demand due to an intervention took place in a few days.

Following the aforementioned literature on firm response to demand shocks, one may wonder whether retailers would react to the new purchasing behaviour among affected consumers and how fast. For instance, [27] argues that the rather unforeseeable nature of hurricanes generates demand shocks that are very different from those observed during holidays, which explains why retailers tend to react more to the later. Thus, the intervention may be more likely to induce a price response if it is announced in advance and the size of the affected population can be forecast. As these conditions where met in the cottage cheese boycott, we should not be surprised that "the average price of cottage dropped by 24% virtually overnight". Still, other type of interventions might take longer to pay off.

How long can affected consumer stick to a purchasing behaviour that is unusual to them - in that it can involve refraining from consuming green products - before the price adjustment takes place ? Of course, they might be able to visit other retailers that offer the same green product at a better price, but they certainly occur some other monetary, transportation or cognitive cost by doing so. This leads to the question of the duration in which intervention-induced demand shocks can be sustained. Empirical studies of boycott movements typically observe substantial several weeks of demand shocks followed by a complete return to the normal in one month or two [28]. Consistent with these findings, "sales at the start of the [cottage cheese] boycott would have been 30% higher, but for the boycott. [...] After about six weeks, however, sales recovered and matched the expected demand at observed prices.". However, the cottage cheese boycott differs from usual examples in that its boycott rule was directly related to the price of the product. Bringing public attention on prices has durably affected price elasticities, so much that it had had a long-lasting impact on demand still observable six years after the boycott took place.

The last mechanism to discuss is the effect of the price decrease on non-affected consumers' green product purchase . As observed in our panel, the organic label is quite polarizing : most consumers (70%) never purchase organic, some rarely do so (20%), and a small number does so almost always (3%). While those who sometimes purchase organic eggs are likely to do so more often right after the price decrease, it might take longer before those who never purchase organic eggs react. As of today, they might not even include organic eggs in their consideration set or use heuristically the organic label as a proxy for expensiveness. The evolution of their representation of the organic label and the adaptation of the mental processes involved in the purchase decision might take years.

To summarize, a well-planned intervention may obtain substantial short-term effects on affected demand and green product prices. As compared to nudges or usual boycott movements studied in the literature, it is more likely that we observe long-lasting effects - on demand and prices - from an intervention aimed at increasing consumer price sensitivity. The price decrease will certainly increase green product share among occasional green consumers, but it is unlikely that the intervention changes anything on the short-run for those that never purchase green products. Thus, the benefits of the intervention might span over years, but could be estimated from elasticity changes observed after a few months.

6 Conclusion

In this paper, I argue that prices matter for the design and evaluation of non-price interventions - labelling schemes, environmental information campaigns - promoting the purchase of greener goods in imperfectly competitive retail markets. Raising consumer price sensitivity on green products could greatly contribute to the rise in environmental-friendly consumption on retail markets. The main mechanism is that making some green consumers more price-sensitive will constrain retailers to revise their margins on green products downwards, which in turn will increase sustainable consumption in general.

Similarly, lab and field experiments evaluating the potential of a behavioural intervention should anticipate the effect of the intervention on affected consumers attitude towards prices. Neglecting this aspect might lead to large prediction errors when the policy is implemented at scale. Overall, my results show that retailer price response matter and call for a more systematic investigation of the price-dependency in the purchasing behaviour that such interventions induce.

The main policy conclusion is that it is often better not to blindly raise consumer willingness to pay for green attributes. Instead, one might prefer to convey a sense of what a reasonable price for green product might be. Additional evaluation of past policies raising consumer price sensitivity would be interesting in order to put in perspective the results of the simulations.

Appendix

Formal statements, proofs and extensions of the theoretical results

6.0.1 Proof of Lemma 1

Lemma 1. *Whatever D_2^A, the market price p_2 is higher than p^{A^*} and the demand cannot exceed $D^N(p^{A^*}) + \epsilon$*

$$p_2 \geq p^{A^*} \textit{ and } D_2^A(p_2) \leq \epsilon + D^N(p^A)$$

Let me prove that the cut-off demand function with threshold price p^{A^*} is optimal. I want to show that the demand $D^N(p^{A^*}) + \epsilon$ cannot be exceeded, whatever the purchasing behaviour D_2^A in the affected population. Since D^N is decreasing and D_2^A is bounded by ϵ, it is sufficient to show that the optimal threshold price p^{A^*} is always smaller than the final equilibrium price p_2.

$$D_2(p_2) = D^N(p_2) + D_2^A(p_2) \leq D^N(p_2) + \epsilon \overset{?}{\leq} D^N(p^{A^*}) + \epsilon$$

Whatever D_2^A, the option of setting the price p^N is always available to the firm and generates a profit at least equal to $\Pi^N(p^N)$ - the maximal achievable profit in the absence of affected consumers. Thus, no intervention can induce a profit lower that this level.

$$\Pi^N(p^N) \leq \Pi^N(p_2) + \Pi_2^A(p_2) \leq \Pi^N(p_2) + \epsilon(p_2 - c)$$

From this inequality, I will show that $p^{A^*} \leq p_2$, which implies our conclusion $D_2(p^2) \leq D_2(p^{A^*})$. First, by construction of p^{A^*}, we have another expression for the leftmost term $\Pi^N(p^N)$ in the previous inequality

$$\Pi^N(p^{A^*}) + \epsilon(p^{A^*} - c) \leq \Pi^N(p_2) + \epsilon(p_2 - c)$$

Second, notice that the function $x \longmapsto \Pi^N(x) + \epsilon(x - c)$ is increasing on $[c, p^N]$ since Π^N is single-peaked in p^N. This concludes the proof in the case where $p_2 \leq p^N$. In the remaining case, $p^N \leq p_2$, hence $p^{A^*} \leq p_2$. We have proved Lemma 1.

Proof of Proposition 4

One can generalize some of the results to the case of a multi-product firm. This is interesting, for instance, to anticipate the effect of an intervention targeting a green product on the price of a closely-related brown product.

Let bold letters denote vector objects, such as prices $\mathbf{p}$ and demands $\mathbf{D}$, where each dimension corresponds to one of the K product sold by the monopolist. Then, Proposition 3 can be generalized in this setting.

Proposition 4 (Multi-product price effect of a marginal intervention)**.**

$$\mathbf{\Delta p} \underset{\epsilon \to 0}{\sim} (\mathbf{Hess}\ \Pi(\mathbf{p}_1))^{-1} \left(\nabla \Pi_1^A(\mathbf{p}_1) - \nabla \Pi_2^A(\mathbf{p}_1) \right)$$

Since Proposition 4 implies Proposition 3 (case of one product), I will prove only the former. Assume that Π^N, Π_1^A and Π_2^A are $\mathcal{C}^2$. Assume further that Π^N has a unique maximum p^*, that Hess $\Pi^N(p^*)$ is definite negative and $\nabla \Pi_2^A(\mathbf{p}^*) \neq \nabla \Pi_1^A(\mathbf{p}^*)$. I want to prove that

$$\Delta p \underset{\epsilon \to 0}{\sim} \left(\text{Hess } \Pi^N(\mathbf{p}^*) \right)^{-1} \left(\nabla \Pi_2^A(\mathbf{p}^*) - \nabla \Pi_1^A(\mathbf{p}^*) \right)$$

We can write the first-order conditions that translate the facts that the firm sets (1) $\mathbf{p_1}$ in order to maximize $\Pi_1(\mathbf{p_1})$ before the intervention and (2) $\mathbf{p_2}$ in order to maximize $\Pi_2(\mathbf{p_2})$ after the intervention.

$$\begin{cases} \nabla \Pi_1(\mathbf{p_1}) = \nabla \Pi^N(\mathbf{p_1}) + \nabla \Pi_1^A(\mathbf{p_1}) = \nabla \Pi^N(\mathbf{p_1}) + \nabla \underline{\Pi}_1^A(\mathbf{p_2}) \times \epsilon = 0 & (1) \\ \nabla \Pi_2(\mathbf{p_2}) = \nabla \Pi^N(\mathbf{p_2}) + \nabla \Pi_2^A(\mathbf{p_2}) = \nabla \Pi^N(\mathbf{p_2}) + \nabla \underline{\Pi}_2^A(\mathbf{p_2}) \times \epsilon = 0 & (2) \end{cases}$$

Notice that in both cases, when $\epsilon = 0$, the program of the firm consists in setting $\mathbf{p}$ in order to maximize $\Pi^N(\mathbf{p})$. It has been previously assumed that this problem had a unique solution $\mathbf{p}^*$. Thus, one can see these two program as mere perturbations parameterized by ϵ of this optimization problem. Since the profit functions Π_1 and Π_2 are $\mathcal{C}^1$ with respect to ϵ and Hess $\Pi^N(\mathbf{p})$ is definite negative, then for ϵ small enough equation (1) (resp. (2)) has locally a unique solution $\mathbf{p_1}$ (resp. $\mathbf{p_2}$). When ϵ goes to zero, both $\mathbf{p_1}$ and $\mathbf{p_2}$ tend to $\mathbf{p}^*$.

Since Π^N is assumed to be $\mathcal{C}^2$, then $\nabla \Pi^N$ is $\mathcal{C}^1$ and we can write its first-order Taylor expansion

$$\begin{cases} \nabla \Pi^N(\mathbf{p_1}) \underset{\epsilon \to 0}{=} \nabla \Pi^N(\mathbf{p}^*) + \text{Hess } \Pi^N(\mathbf{p}^*)\ (\mathbf{p_1} - \mathbf{p}^*) + o(1) \\ \nabla \Pi^N(\mathbf{p_2}) \underset{\epsilon \to 0}{=} \nabla \Pi^N(\mathbf{p}^*) + \text{Hess } \Pi^N(\mathbf{p}^*)\ (\mathbf{p_2} - \mathbf{p}^*) + o(1) \end{cases}$$

We can invert Hess $\Pi^N(\mathbf{p}^*)$ as it is definitive negative. Thus, we can isolate $\mathbf{p_2} - \mathbf{p_2}$ in the previous equation and use equation (1) and (2) to conclude.

$$
\begin{aligned}
\mathbf{p_2} - \mathbf{p_1} &\underset{\epsilon\to 0}{=} \text{Hess } \Pi^N(\mathbf{p}^*)^{-1} \left(\nabla \Pi^N(\mathbf{p_2}) - \nabla \Pi^N(\mathbf{p_1})\right) + o(1) \\
&\underset{\epsilon\to 0}{=} \text{Hess } \Pi^N(\mathbf{p}^*)^{-1} \left(\nabla \Pi^A_1(\mathbf{p_1}) - \nabla \Pi^A_2(\mathbf{p_2})\right) + o(1) \\
&\underset{\epsilon\to 0}{=} \text{Hess } \Pi^N(\mathbf{p}^*)^{-1} \left(\nabla \Pi^A_1(\mathbf{p}^*) - \nabla \Pi^A_2(\mathbf{p}^*)\right) + o(1) \\
&\text{(since } \Pi^A_2 \text{ is } \mathcal{C}^1, \nabla \Pi^A_2(\mathbf{p_1}) \underset{\epsilon\to 0}{\to} \nabla \Pi^A_2(\mathbf{p}^*) \text{ and } \nabla \Pi^A_2(\mathbf{p_2}) \underset{\epsilon\to 0}{\to} \nabla \Pi^A_2(\mathbf{p}^*) \text{)}
\end{aligned}
$$

Statement and proof of Theorem 2

Let me show that the results of section 2 can be extended to the case of symmetrical Nash-Bertrand oligopolists. I will start by introducing the notations, then state the main result - Theorem 2 - and finally prove it. Note that Theorem 2 implies Theorem 1.

Consider n symmetrical oligopolists with identical marginal cost c competing in prices. I will assume that the demand (D^N, D^A_1 and D^A_2) that they face before and after the intervention are symmetrical, meaning that two firms setting the same price also face the same demand and generate the same profit. When a firm sets a price p and all the others set a price p', I will denote the demand it faces by $D(p,p')$ and the profit it generates by $\Pi(p,p') = (p-c)D(p,p')$. Partial derivatives with respect to p refer to the first argument, the firm own price.

I focus on pure symmetrical price equilibria, that is to say prices p^* such that $\Pi(p^*,p^*) = \max_{p\in\mathbb{R}} \Pi(p,p^*)$. I assume that D^N and D^A_1 are smooth and that there exists before the intervention a unique symmetrical price equilibrium p_1. The fact that the size of the affected population is ϵ and the symmetry assumption implies that $D^A(p,p) \leq \epsilon/n$ and $\Pi^A(p,p) \leq (p-c)\epsilon/n$ for every price p.

Theorem 2 provides a lower bound for potential equilibrium prices following an intervention and shows that this optimum can be reached by inducing a specific purchasing behavior. I define the cut-off demand with threshold price p^A as

$$
D^A(p,p') = \frac{1_{(-\infty,p^A]}(p)}{1+(n-1)1_{(-\infty,p^A]}(p')} \times \epsilon
$$

This is a mere generalization of the one-dimensional cut-off function, in which the demand is split equally between all firms below the threshold price. Since we focus on the analysis of pure symmetrical equilibria, specifying $D(p,p')$ is sufficient - there is no need to define this function for every price vector $\mathbf{p}$.

I assume that for all $p' \in \mathbb{R}^+$, $p \mapsto \Pi^N(p,p')$ is single-peaked and I refer to the peak as $p^N(p')$. The second-order optimality condition entails that $\frac{\partial^2 \Pi^N}{\partial p^2}(p,p')$ must be non-positive, and I further assume that this quantity is negative for all p', so that $p^N(p')$ is continuous is p'. Finally, I assume that the following equation - which will be motivated later - has at most one solution p^{A^*} :

$$\Pi^N(p^N(p^{A^*}), p^{A^*}) = \Pi^N(p^{A^*}, p^{A^*}) + (p^{A^*} - c) \times \epsilon/n \quad (*)$$

There is no need to assume the existence of a solution to this equation, as this can easily be shown using the intermediate value theorem - noting that for $p^{A^*} = c$ the left-hand side of the equation is non-negative and the right-hand side null, while for $p^{A^*} = p^N$ the right-hand side is larger than the left-hand side. We are now able to state theorem 2.

Theorem 2. *For all symmetrical purchasing behaviour D_2^A such that there exists a pure symmetrical price equilibrium p_2, then $p_2 \geq p^{A^*}$ and $D_2(p_2) \leq D^N(p^{A^*}) + \epsilon$.*

Moreover, if D_2^A is a cut-off demand with threshold price p^{A^*}, then p^{A^*} is a pure symmetrical price equilibrium and $D_2(p_2) = D^N(p^A) + \epsilon$

I will start the proof by studying the case of the cut-off demand, and then prove that it is impossible to do better. Let me show that the price p^{A^*} introduced previously is indeed a symmetrical equilibrium price when D_2^A is a cut-off demand with threshold price p^{A^*}. When a firm faces a cut-off demand with threshold p^{A^*} from the affected population, the firm either sets the price p^{A^*}, or sets a price that is optimal when ignoring the affected population. In the first case, it generates a profit

$$\Pi^N(p^{A^*}, p^{A^*}) + \Pi_2^A(p^{A^*}, p^{A^*}) = \Pi^N(p^{A^*}, p^{A^*}) + \frac{\epsilon}{n}(p^{A^*} - c)$$

In the second case, it sets a price p that maximizes $\Pi^N(p, p^{A^*})$, which by definition must be $p^N(p^{A^*})$. Therefore, the firm generates in the second case a profit

$$\Pi^N(p^N(p^{A^*}), p^{A^*})$$

By equation (*) that defines p^{A^*}, the firm has no interest to deviate from p^{A^*} to p^N as both generate the same profit. Therefore, p^{A^*} is indeed a pure symmetrical price equilibrium and the corresponding demand is $D^N(p^A) + \epsilon$.

What remains to be shown is that these price and demand cannot be improved. Consider any symmetrical purchasing behaviour D_2^A such that there exists a symmetrical equilibrium price p_2. Since no firm has any interest to deviate from p_2,

$$\Pi^N(p_2, p_2) + \Pi^A(p_2, p_2) \geq \Pi^N(p^N(p_2), p_2) + \Pi^A(p^N(p_2), p_2)$$

I will show that the same price equilibrium can be obtained with a cut-off demand with threshold price p_2. As previously, it is sufficient to show that no firm has an interest to deviate to $p^N(p_2)$, that is to say

$$\Pi^N(p_2, p_2) + \frac{\epsilon}{n}(p_2 - c) \geq \Pi^N(p^N(p_2), p_2)$$

This comes directly by combining the previous inequality, the fact that $\frac{\epsilon}{n}(p_2-c) \geq \Pi^A(p_2, p_2)$ and that $\Pi^A(p^N(p_2), p_2) \geq 0$. Thus, the same price could have been obtained under a cut-off demand with threshold price p_2 in the affected population. Moreover, the equilibrium demand cannot be smaller with the cut-off demand than with D_2^A since

$$D_2^N(p_2, p_2) + \epsilon \geq D_2^N(p_2, p_2) + D_2^A(p_2, p_2)$$

It is now sufficient to compare cut-off demand functions with one another and find the lowest threshold price for which there exists a symmetrical equilibrium. Define T as the set of prices p such that p is a symmetrical equilibrium in presence of a cut-off demand function with threshold price p. Using the no-deviation condition found earlier, we have

$$T = \{p \in \mathbb{R}_+ \mid \Pi^N(p, p) + \frac{\epsilon}{n}(p - c) \geq \Pi^N(p^N(p), p)\}$$

By continuity of Π^N and p^N, T is a closed set, and since it has bounded from below $\inf T \in T$. Moreover, for the same reason, $\inf T$ satisfies the equation

$$\Pi^N(\inf T, \inf T) + \frac{\epsilon}{n}(\inf T - c) \geq \Pi^N(p^N(\inf T), \inf T)$$

By uniqueness of p^{A^*}, it must be that $\inf T = p^{A^*}$. In particular, for all $p \in T$, $p^{A^*} \leq p$ hence the final demand at the equilibrium p^{A^*} is higher than that at the equilibrium p. This concludes the proof.

Let me summarize quickly the rationale. For any purchasing behaviour D_2^A that leads to a symmetrical equilibrium price p_2, then the cut-off demand with threshold p_2 leads also to a symmetrical equilibrium price p_2 and the corresponding equilibrium demand is no lower than with D_2^A. Then, it suffices to ask what threshold price p^A generates the lowest price - hence, the highest demand. It has been shown that $p^A = p^{A^*}$ is the best possibility.

Likelihood and price sensitivities in a multinomial logit model with random coefficient

Let me start by providing formulas valid at the individual level, where α_i can be considered as a given constant. Denoting $\widetilde{U}_{ijt}$ the product-specific non-stochastic term in equation 2 - that can be directly computed from data and parameter values.

$$\widetilde{U}_{ijt} = \alpha_i \times p_{jt} + \beta \cdot \mathbf{x}_j + \gamma \times v_{ijt} \tag{10}$$

Since $\widetilde{U}_{ijt} = U_{ijt} + u_{ijt}$ and the stochastic noise terms u_{ijt} are independent and follow a Gumbel distribution, then the probability s_j that product $j \in J_{it}$ yields that highest utility as a function of the $\widetilde{U}_{ijt}$ writes

$$s_{ijt} \underset{\text{déf}}{=} P\left(U_{ijt} = \max_{k \in J_{it}} U_{ikt}\right) = \frac{\exp(\widetilde{U}_{ijt})}{\sum_k \exp(\widetilde{U}_{ikt})} \tag{11}$$

The derivative of s_j with respect to the price p_{kt} of product $k \in J_{it}$ has a simple expression, that will later be used in computing the Ω matrix.

$$\frac{\partial s_{ijt}}{\partial p_{kt}} = (\delta_i^j - s_{ijt}) s_{ikt} \tag{12}$$

The likelihood of the purchase choices at the household level, assuming α is known and product $j(i,t) \in J_{it}$ has been chosen by household i at period t

$$L = \prod_{i \in I} \int_{\mathbb{R}^+} \left(\prod_t \frac{\exp(\widetilde{U}_{ij(i,t)t})}{\sum_k \exp(\widetilde{U}_{ikt})} \right) \; f(\alpha_i \mid \theta_{LN}) \; d\alpha \tag{13}$$

Estimating the demand model consists in finding the values for the parameters β, γ and θ_{LN} that maximize this llikelihood. Numerically, we make use of the *apollo_estimate* function from the R *apollo* library. This function approximates the integral by a quasi Monte Carlo method, using 200 Halton points. More information are available in section 4.6 of the library user manual [29].

Bayesian posterior expectations at the household level

Estimating a multinomial logit model with random coefficient yields population-wide parameters estimates θ_{LN} for the price sensitivity α_i. Denoting $f(\alpha \mid \theta_{\text{LN}})$ the corresponding density, Bayes rule gives the density $g(\alpha \mid \theta_{\text{LN}}\ , \text{achats}_i)$ of the posterior distribution of the α coefficient conditionally on the estimated parameters θ_α of the population-wide distribution and the purchase choices achats_i made by household i.

$$g(\alpha \mid \theta_{\text{LN}}\ ,\ \text{achats}_i) = \frac{L(\text{achats}_i \mid \alpha)\ f(\alpha \mid \theta_{\text{LN}})}{\int_{\mathbb{R}+} L(\text{achats}_i \mid \alpha')\ f(\alpha' \mid \theta_{\text{LN}})\ d\alpha'} \tag{14}$$

The coefficient α_i^{BAYES} is then defined as the expectation of this conditional distribution $g(\alpha \mid \theta_{\text{LN}}\ ,\ \text{achats}_i)$

$$\alpha_i^{\text{BAYES}} = \frac{\int_{\mathbb{R}+} \alpha\ L(\text{achats}_i \mid \alpha)\ f(\alpha \mid \theta_{\text{LN}})\ d\alpha}{\int_{\mathbb{R}+} L(\text{achats}_i \mid \alpha')\ f(\alpha' \mid \theta_{\text{LN}})\ d\alpha'} \tag{15}$$

As for the likelihood function, These integrals are numerically approximated by quasi Monte Carlo using 200 Halton points, using the function *conditionals* from the *apollo* library. More information is available in section 9.14.1 from the *apollo* library manual [29].

Equilibrium search algorithm

Starting from $\mathbf{u_0} = \mathbf{p_1}$ the equilibrium price before the intervention, the algorithm iterates the rule

$$\mathbf{u_{k+1}} \longleftarrow \frac{1}{1-\tau}\left[\mathbf{c} - \mathbf{\Omega}(\mathbf{u_k})^{-1}\mathbf{D}(\mathbf{u_k})\right]$$

By continuity, if the sequence converges to $u_\infty \in \mathbb{R}^K$, then the first-order condition is satisfied by u_∞

$$\mathbf{\Omega}(\mathbf{u}_\infty)\left[(1-\tau)\mathbf{u}_\infty - \mathbf{c}\right] + \mathbf{D}(\mathbf{u}_\infty) = 0$$

In practice, the algorithm is stopped once the step of an iteration $\|\mathbf{u_{k+1}} - \mathbf{u_k}\|_\infty$ is smaller than 10^{-7} euros.

6.1 Illustration of the transformations

6.2 Robustness checks

The parameter values tested are $\Delta\alpha \in \{5, 20\}$, $\Delta\text{WTP} \in \{0.1, 0.4\}$, $\alpha_{\text{Target}} = \{-20, -30\}$ and $\text{WTP}_{\text{Target}} = \{0.4, 0.6\}$.

Please note that in the figure, dark and light colors in bars that are next to another correspond to the same type of intervention simulated twice, with the low version of the intervention parameters in the leftwards lighter one and the high version of the intervention parameters in the rightwards darker one. When it comes to two bars overlaid on each other, the darker bar represents the change in passive consumer demand while the lighter bar is the total demand change. This distinction allows to visually compare the the final demand change that is not driven by the demand from affected consumers. One can note that the price effect can account for nearly one half of the intervention effect in some settings.

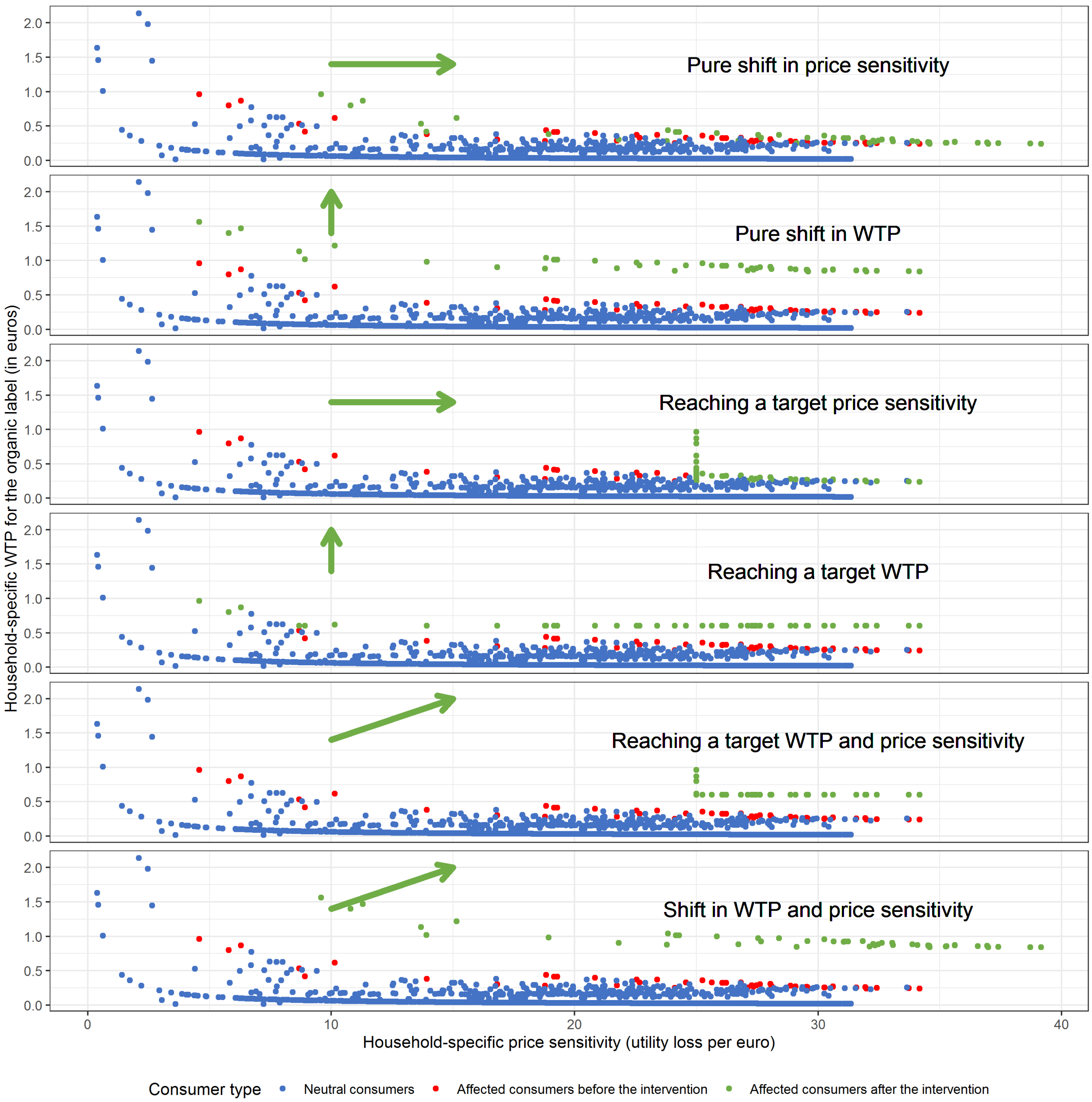


Figure 7: Comparing different non-price interventions

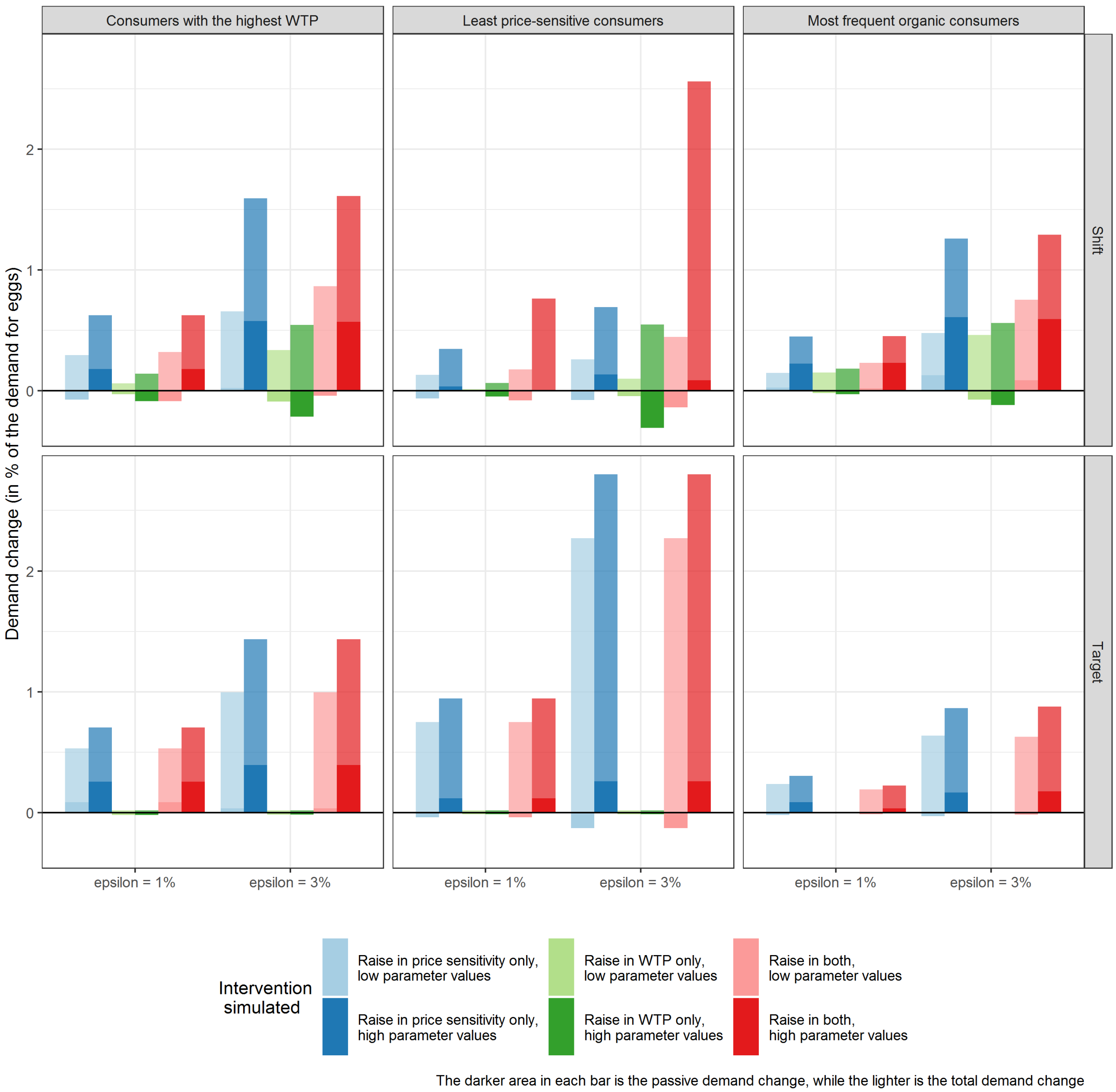


Figure 8: Simulation results for a chosen set of intervention parameters

The magnitude of the demand change following an intervention seems rather in line with the number of affected consumers : interventions involving 1% (resp. 3%) of the consumers can increase total demand by roughly 1% (resp. 3%). What is more surprising is that this increase is possible even when the affected population was almost consuming organic all the time. The visible part of the lighter bar in the high parameter case corresponds to the fact that the demand is fully saturated in the affected population. Of course, this leads to different bars depending on the affected population considered. In particular, the least price-sensitive consumers are also less prone to organic consumption than the two other groups before the intervention, hence their larger intervention effects.

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