Abstract
A portion cap rule is a limit on the maximum size at which a product can be offered in the market. The possible implementation of cap rules as a form of food retailing regulation is highly controversial and opponents imply that these restrictions negatively impact consumers’ well-being. I study the consumption and surplus impacts resulting from imposing a portion cap rule on one of two products offered by a seller facing demand from privately-informed heterogeneous buyers. Specifically, I look at the impacts caused by the cap rule on: i) consumption of the regulated component, ii) purchases of the unregulated item, and iii) consumer surplus. The hypotheses I derive using a standard multidimensional nonlinear pricing model predict reductions in consumption of the regulated component, changes in consumption of the unregulated product by some buyers, and mixed impacts on consumer surplus. With data from a laboratory experiment designed to test the model predictions, I find the following impacts attributable to the cap rule: i) all buyer types lower their consumption of the regulated good; ii) no significant changes in purchases of the unregulated product, and iii) surprisingly, the subset of buyers with low preference for the regulated item and high valuation for the unregulated good enjoy a larger surplus, while no buyer type is worse-off. The results have implications for food policy discussions around portion cap rules, where the assumption that these regulations negatively impact consumers’ well-being largely drives public debate.
1 Introduction

In this paper, I present an economic analysis of portion cap rules (caps). These are policies restricting the default quantities at which food products can be offered. In light of studies linking larger portion sizes to increased consumption, foods containing ingredients judged to have deleterious impacts on human health are common targets of proposed caps (Rolls et al. (2006), Ledikwe et al. (2005), and Flood et al. (2006)). One example of such policies is the so-called “New York City soda ban”. The advanced plan intended to prohibit food vendors regulated by the city of New York from selling sugar-sweetened beverages (SSBs) in containers exceeding 16 ounces (Kansagra, 2012). Ultimately, this proposal was struck down in court (New York Statewide Coalition of Hispanic Chambers of Commerce v. New York City Department of Health and Mental Hygiene, 2014). Nevertheless, discussions about possible implementations of similar policies in the food retail industry are ongoing and contentious.

Opponents to caps and similar measures argue that consumers’ freedom, choice, and well-being are infringed by these interventions. Some of them state that caps could disproportionately impact buyers that prefer to purchase larger quantities of SSBs (Grynbaum (2012); Grynbaum and Connelly (2012)). The implication is that diminishing default sizes will result in lower consumer welfare. This assumption is already shaping public policy, as exemplified by Mississippi’s Bill 2687 (2013). This bill interdicts against future restrictions of food sales within the state based upon the product’s nutrition information or upon its bundling with other items. However, because sellers engage in sophisticated pricing schemes, even if a regulation modifies consumption it does not necessarily follow that consumers are worse-off. In hope of informing future food policy design, my objective is to provide formal evidence of the short-term impacts on surplus generated by cap rules when sellers offer bundles of two products.

In this paper, I study a seller who offers packages containing quantities of two products serving heterogeneous buyers with private preferences over these goods. Throughout the paper, I refer to these goods as product A and product B. Suppose that product

As a reference, the “small”, “medium”, and “large” cup sizes typically found in popular American fast-food restaurants contain around 16, 21, and 32 ounces.
A is subject to a portion cap rule. The questions I aim to answer are: i) whether the intervention reduces consumption of the targeted item A, ii) what is the impact on the purchased sizes of the unregulated component B, and iii) what is the effect on consumer surplus, this is the gross utility from consumption net of the price paid also known as information rents. To provide answers to these questions, I concentrate on studying seller’s pricing behavior because changes in surplus distribution and consumption patterns are ultimately contingent on how the pricing scheme is modified following a regulation. My analysis of the seller’s response to the intervention has two parts: first, I generate predictions from a bi-dimensional nonlinear pricing model; second, I use data from a laboratory experiment to test the model’s hypotheses.

I refer to the quantity of a given product (A or B) as a “portion” and to specific combinations of quantity of A and quantity of B offered by the seller as “packages” or “combos”. In the theoretical model, one seller (she) designs a menu of package-price combinations. One buyer (he) with privately known preferences for A and B chooses his consumption from the menu of choices. There are four types of buyers characterized by their preferences over the products. Each product can be either highly (H) or lowly (L) preferred by the agents. The \(ij\)-type buyer has preference \(i\) for good A, and \(j\) for component B. The model predicts that without regulation, the seller offers “small-small”, “medium-large”, “large-medium”, and “large-large” A-B combos. Consumer surplus is the largest for the HH-type buyer, and lowest for the LL-type. When the medium HL and LH types’ surpluses are positive, they fall between these extremes. If a portion cap rule is enforced such that the seller is required to offer portions of A strictly lower than the “medium” unregulated size, the model predicts: i) all purchased sizes of A are reduced, including that of the “small” option; ii) consumption of the unregulated component B increases for the LL-type, and decreases for the HL-type, and iii) information rents for the HH-type are smaller, but they are larger for the LH-type. I conduct a laboratory experiment to test these predictions. In line with the hypotheses, I find that all consumers lower their consumption of the regulated component, and the LH-type buyer enjoys a larger surplus. On the other hand, contrary to the predictions I find no significant impacts neither on the consumption of product B, nor in the HH-type buyer’s earnings.
This research is important and timely because as obesity rates in the United States hover over 30% (Ogden et al., 2014), I expect campaigns against consumption of foods and ingredients associated with obesity and its health consequences to intensify. In effect, not only public health officials have proposed cap restrictions as a food policy tool, some voices within the private sector seem to recognize their potential as a cost-effective method to aid the abatement of obesity (Dobbs et al., 2014). At the same time and in parallel to an increase in the demand for consumption-curbing regulations, I also expect more campaigns opposing cap rules on the grounds of alleged potential reductions in consumer well-being. To help inform the discussion and design of effective food policies, a strong body of academic knowledge is essential. The academic community and policy officials are relatively well informed about the impacts of some policy tools used to regulate food consumption such as excise taxes. There is however, a relatively smaller literature on the economic consequences of portion cap rules. In this research I address this relative paucity by looking at the specific case of multi-product markets.

The multidimensional nature of the pricing problem I present in this paper is an important feature. Most food retailers are multi-product sellers that leverage the wide spectrum of available items they sell to implement sophisticated price-discriminating strategies. Importantly, they can engage in commodity bundling. Commodity bundling is the screening device wherein the price of a bundle containing various items in combination is lower than the sum of the prices for the stand-alone products. Alternatively, if two goods are always sold together in packages containing both components (the scheme known as pure bundling), they are said to be bundled if the variance in price across different packages is not entirely explained by differences in marginal cost of production. In this document, the seller implements a version of pure bundling. A and B are always consumed together, except in instances where she explicitly sets the quantity of one of the products to zero. This may appear to the reader as a restrictive assumption potentially dampening the predictive power of the model, and its parallelism with what it is observed in the field. I argue this assumption is not as restrictive as it appears because

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2For a formal discussion of pricing strategies in markets with imperfectly informed sellers, I refer the reader to Wilson (1993).
it simplifies experimental implementation and it can reflect pricing schemes of products we typically do not think of as bundles. For example, consider a soda or soft drinks manufacturer deciding sugar-water (A-B) combinations. In this case, the “package” is a bottle of soda with a particular sugar-water ratio. The model predicts that, without regulation, the seller decides to produce bottles of soda in different presentations: bottles with a one to one sugar-water formula in small and large options to cater to LL and HH-types (the small-small and large-large A-B combos); a “concentrated” formula with a high sugar-water ratio designed for the HL-type’s sweet taste (the large-medium A-B combo), and a “light” water-diluted presentation with low sugar-water ratio serving the health-conscious LH-type (the medium-large A-B combo). In this case, the portion cap takes the form of a restriction in the maximum quantity of sugar allowed in a bottle of soda.

In the model, the components offered by the seller are neither complements nor substitutes. This is to emphasize the tension between the multidimensional nature of the incentive-design problem. In doing so, I can argue that all the characteristics of the allocation outcomes before and after the regulations are solely due to the seller’s desire to segment demand; nothing else can influence the outcomes because potentially confounding factors (such as complementarity) are absent. In other words, I show that a cap rule changes allocation and consumer surplus even when the products are independent. Moreover, bundling of non-complements is not an uncommon practice even in the food retail sector; for example, several supermarkets engage in pricing strategies that tie gasoline price discounts with consumption of groceries.

In my analysis, I incorporate three stylized observations. First, buyers have private information regarding their preferences and these are taken as exogenous by the seller when designing the menu. It is fair to assume that food taste can be considered as exogenous and that sellers design incentive-compatible menus before any transaction occurs. Second, the seller offers more than one product. This reflects what is observed in the field, where most retailers are multi-product firms whose pricing strategies include bundling

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3 In this example, the reader can interpret the “water” ingredient to be the “all ingredients other than sugar” component needed when producing soda.

4 The reader can consult Wang (2015) for a study regarding this specific instance.
and combo-meal offers; and as in the “bottle of soda as a bundle” mentioned above, even single products can be thought as bundles of ingredients. Lastly, the seller decides the quantities and prices that characterize each package in the menu. In other words, she does not adopt a passive pricing scheme. Following a restriction in quantities, there is no reason to assume that seller will not try to endogenously modify the menu to accommodate the intervention in ways that will impact how seller and buyers divide gains from trade. I am confident these observations are fairly general and cover a wide spectrum of situations encountered in the field, particularly situations in the food retailing and supermarket industries. In the experiment, I allow for flexible contract design; i.e. instead of fixing the number of contracts a given seller can offer thereby limiting their tasks to merely specifying quantities and prices, my subjects taking the role of sellers are allowed to choose the number of bundles they want to offer, their mix of quantities, and their prices. This is consistent with how sellers are assumed to behave in standard screening models.

The rest of the document is organized as follows: in the next section, I succinctly describe the related academic literature; in section 3 I formally introduce the theoretical model and derive the theoretical hypotheses; in the fourth part, I present the experimental design; in section 5, I present the laboratory data and discuss the experimental results; the last section concludes.

## 2 Related literature

This paper contributes to the literatures on food policy design, applied industrial organization, and multidimensional nonlinear pricing.

Because my empirical project relies on the theoretical multiproduct nonlinear pricing literature, I present a brief review of the field. Stemming from screening theory, multidimensional nonlinear pricing is notorious for being a source of research queries easy to state but difficult to solve analytically. The early literature on bundling relied on stylized instances and the single-crossing assumption. Adams and Yellen (1976) uses a series of examples to show that mixed bundling is a preferred strategy for the seller when the valu-
ation for the item is negatively correlated. Armstrong (1999) shows that a monopolist can extract almost all possible surplus by price discrimination via a two-part tariff. McAfee et al. (1989) generalized the result of bundling as a preferred strategy by showing that the first order conditions necessary for component pricing to strictly dominate any alternative fail, therefore some form of bundling always does better when the distribution of types is continuous. A growing literature is exploring how robust the early outcomes are to simplifying assumptions. Even “null” results prove a significant contribution to the field; for example, without assuming single crossing, Carroll (2017) shows that when a seller faces a buyer with several dimensions of private information, and the seller knows the marginal distribution of each product of the buyer’s type but ignores the joint distribution, then it is in the seller’s best interest to engage in component pricing (as opposed to bundling). Venkatesh and Mahajan (2009) offer a review of the bundling literature and discuss how theoretical results are highly sensitive to assumptions on factors such as marginal cost of production, correlation of types, interactions between the components (complementarity, for example) and competition. Because of the complexity implied, Armstrong and Rochet (1999) point out that applied researchers hinder from studying problems where multidimensional screening provides the theoretical framework, despite of the several potential applications of the theory. This paper aims to contribute to the applied literature in multidimensional screening.

The topic of regulating price-discriminating sellers has been intensely studied in the field of industrial organization, although the specific intervention of maximum quantity caps in multi-dimensional screening models seems to be a contribution of mine. The existing literature tends to rely on theoretical predictions. Moreover, both analytical and empirical works either concentrate on the single-product case or rely on a multidimensional version of the single-crossing condition to facilitate the analysis. As a result of adverse selection, price-discriminating firms distort quantity downward along the type space. In a theoretical paper, Besanko et al. (1988) explore the effect of three regulatory measures intending to fix this distortion: minimum quality standards, maximum price regulation, and rate of return regulation. Besanko and co-authors derive conditions under which the rate of return regulation lowers quantity for the high-types; they also demonstrate
that maximum price interventions lower quantity for the high-types, while minimum quality standards do not modify the quantity consumed by the buyers with high valuation for the goods. Corts (1995) analytically studies the effect of imposing a price-cap on the lower level of quantity offered by a multi-product monopolist. Corts relies on a multidimensional version of the Spence-Mirrlees single crossing condition to analyze the multidimensional problem with a one-dimensional screening model. He finds mixed results regarding prices paid by different buyer types. In a numerical example where the multi-item single-crossing assumption is relaxed, Corts show how socially suboptimal unbundling may arise as consequence of the intervention. Amrstong et al. (1995) consider two forms of regulations: a cap on the seller’s average revenue, and a constraint that forces the seller to keep offering the option to buy a component at the uniform price. Armstrong and co-authors show that the average revenue constraint is preferred by the seller.

Moving to experimental research, Caliskan et al. (2007) and Hinloopen et al. (2014) are largely concerned with evaluating outcomes from the leverage theory of product bundling, where a multi-product firm competes in two markets, A and B. The firm is a monopolist in market A and faces fringe competitors in market B. The main concern of scholars studying tying is that the multi-product firm may leverage market power from market A to incur in extraordinary rents in market B. In this paper, I am concerned with learning about pricing strategies of a regulated multi-product monopolist with presence in a single market, thus my research speaks to a different, although closely related, literature. An experimental paper testing nonlinear pricing is Hoppe and Schmitz (2015) where the authors test the canonical adverse selection model wherein a seller makes a contract to try to separate a privately informed buyer who has preferences over a low and a high quality item.

More directly related to the topic of regulating food vendors, Wilson et al. (2013) conduct an interesting behavioral study. They aim to determine how a limit on sugary drink portions might affect consumption patterns. The authors put to the consideration of human subjects a hypothetical menu of options, and the subjects were asked to choose how much food they would like to consume. The authors contrast consumption choices made
under two types of menus: a baseline menu where the vendor offers soda cups without any regulation, and an active group where the seller replaces large cups (say of 32oz) with smaller containers (say of 16oz). Their main finding is that buyers decide to purchase more soda with the regulated menu featuring the portion cap rule. This study is useful since it provides an insight regarding potential framing effects that could alter subjects’ purchase decisions. My paper complements the work conducted by Wilson and co-authors in two dimensions. First, my analysis concentrates on the seller’s side of the story. A complete explanation of the consequences of an intervention ought to include analyses of reactions from buyers and sellers. Secondly, my experiment ties monetary rewards to subjects’ performance. That is, I reward subjects for taking actions that would make the hypothetical market player they are playing for better off.

My research is an extension of Bourquard and Wu (2016), and Balagtas et al. (2017). These papers analytically and experimentally study the impacts of portion cap rules with single-product sellers trading with privately-informed heterogeneous buyers. They report that a portion cap reduces consumption without affecting consumer surplus. The reason is that as the cap limits quantity, the seller adjusts prices accordingly so as to leave consumer rents unaffected. They also compare cap rules versus taxes and find that taxes do reduce consumer surplus.

3 Theory

In this section, I introduce a model largely based on the multidimensional screening model of Armstrong and Rochet (1999), though I simplify it to facilitate experimental implementation. To illustrate the main features of the theoretical model and how the regulation would be incorporated to the model, I present the characterization of the optimal price schedule before and after the cap. Following succinct discussions of the optimal solutions, I introduce a parametrization of the model.
3.1 Model

The seller is a monopolist producing goods A and B. She offers them in contracts \(\{q^A, q^B, p\}\), where \(p\) is the price charged for a package containing \(q^A\) and \(q^B\) units of components A and B, respectively. The buyers’ preference for each item remains private information. The \(ij\)-type buyer has preference \(i\) for good A, and \(j\) for B. For each item, buyers can have either high (H) or low (L) preference. There are four types of buyers, denoted HH, HL, LH, and LL. The \(ij\)-type buyer is characterized by the vector of taste parameters \((\theta^A_i, \theta^B_j)\) for \(i, j = H, L\). I assume \(\theta^A_H = \theta^A_L \equiv \theta_H^A\) and \(\theta^B_H = \theta^B_L \equiv \theta_L^B\), and \(\theta_H > \theta_L\). If the \(ij\)-type pays price \(p_{ij}\) for a package containing quantities \(q_{ij}^A\) and \(q_{ij}^B\), he earns consumer surplus:

\[
R_{ij} = \theta_i u(q_{ij}^A) + \theta_j u(q_{ij}^B) - p_{ij}
\]

The subindex in \(R, q^A, q^B\), and \(p\) indicates the type of consumer. I assume away interactions between the components. Thus, the two goods are neither substitutes nor complements. In this manner, I emphasize the relationship between the multidimensional incentive constraints and the seller’s pricing decisions. This assumption has advantages regarding experimental design that facilitate the interpretation of results. This simplification provides this study with a neutral background where changes across treatments can be confidently attributed to the impact of quantity restrictions on pricing behavior without the confounding effects that complementarity would bring about.

I assume \(u(\cdot)\) to be continuous, also \(u(0) = 0\), \(u'(q) > 0\) and \(u''(q) < 0\). Buyer’s preferences satisfy the Spence-Mirrlees single-crossing condition. Both, the seller and the buyers have reservation values of zero. I assume both goods to have the same differentiable, increasing and convex cost function \(c(\cdot)\) without interactions. Also, \(\theta_H u'(q) > c'(q)\) and \(\lim_{q \to \infty} \theta_H u'(q) < c'(q)\), so that trade is possible at least with the HH-type, and total quantity supplied is finite. \(\sum_{ij} \beta_{ij} = 1\), so \(\beta_{ij}\) represents the probability that a given buyer is of an \(ij\)-type. Lastly, let \(\beta_{HL} = \beta_{LH} = \beta\) so that instances HL and LH are equally likely. The seller’s expected profit is:

\[
\mathbb{E}[\pi] = \sum_{ij} \beta_{ij} \left[p_{ij} - c(q_{ij}^A) - c(q_{ij}^B)\right]
\]
It is useful to represent expected profit in terms of total and consumer surpluses:

\[
\mathbb{E}[\pi] = \sum_{ij} \beta_{ij} [\theta_i u(q_{ij}^A) + \theta_j u(q_{ij}^B) - c(q_{ij}^A) - c(q_{ij}^B)] - \sum_{ij} \beta_{ij} [\theta_i u(q_{ij}^A) + \theta_j u(q_{ij}^B) - p_{ij}] 
\]

(1)

Expected total surplus

Expected consumer surpluses

To successfully segment demand and extract as much surplus as possible, the seller must take into account a set of participation (PC), and incentive-compatibility (IC) constraints. The participation constraints ensure that all types are at least indifferent between participating and opting out from trade. These take the following general form:

\[
\text{PC: } R_{ij} \geq 0 \forall ij
\]

(2)

The set of incentive-compatibility constraints are self-selection conditions designed to provide incentives for higher types to choose packages with larger quantities. Separating higher types is beneficial to the seller because larger packages are associated with larger profit contributions. These incentive conditions ensure that the \(ij\)-type buyer does not find it advantageous to purchase a package originally intended to serve a \(kl\)-type buyer (where \(i \neq k\), and \(j \neq l\)). This implies that, at the optimum, quantities and prices are such that the \(ij\)-type buyer is weakly better-off by choosing contract \(\{q_{ij}^A, q_{ij}^B, p_{ij}\}\) over contract \(\{q_{kl}^A, q_{kl}^B, p_{kl}\}\). More precisely, the seller designs these two contracts such that the \(ij\)-type receives a temptation payoff known as information rents in the mechanism design and screening theory literature. These rents are exactly equal to the extraordinary rent the \(ij\)-type would have gained had he chosen the contract intended for the \(kl\)-type from a menu with linear prices. Formally, the IC constraints take the following general form:

\[
\text{IC: } R_{ij} \geq R_{kl} + u(q_{kl}^A)(\theta_i - \theta_k) + u(q_{kl}^B)(\theta_j - \theta_l) \quad \forall ij \text{ and } kl; i \neq k \text{ and } j \neq l
\]

(3)

Rent gained by the \(ij\)-type from posing as a \(kl\)-type

The complete optimization program includes 8 PC and 12 IC restrictions. The seller’s goal is to design a menu of contracts \(\{q_{ij}^A, q_{ij}^B, p_{ij}\}\) that maximizes expected profit (1)
subject to the set of constraints described in equations 2 and 3. The resulting pricing mechanism is incentive-compatible if it satisfies the following monotonicity conditions: $q_A^{HH} \geq q_A^{LH}$, $q_A^{HL} \geq q_A^{LL}$, $q_B^{HH} \geq q_B^{HL}$, and $q_B^{LH} \geq q_B^{LL}$. Intuitively, the monotonicity conditions say that the quantity of either good is weakly increasing with the corresponding valuation. Additionally, if in the resulting menu of contracts, the quantity of item $i$ increases with the preference for component $j$, the seller is said to implement commodity bundling.

Definition 1. In this model, the seller is said to implement **bundling** when, for a given menu of contracts, the quantity of product $i$ increases with preference for product $j$, i.e. when $q_A^{LL} < q_A^{LH}$, and/or $q_A^{HL} < q_A^{HH}$, and/or $q_B^{LL} < q_B^{HL}$, and/or $q_B^{LH} < q_B^{HH}$.

Bundling occurs when the probability mass function (PMF) of buyer types takes a specific form. The shape of the PMF depends on the correlation of preferences defined as $\rho = \beta_{HH} \beta_{LL} - \beta^2$. One of the main intuitions in the early screening literature is that it is in the seller’s best interest to bundle the two products whenever the correlation of preferences is weak enough (Armstrong and Rochet (1999), McAfee et al. (1989), and Adams and Yellen (1976)). In this model, bundling is profitable as long as $\rho < \frac{\beta^2}{\beta_{LL}}$. For this paper’s purposes, I will assume that $\rho < 0 < \frac{\beta^2}{\beta_{LL}}$, which is the case when the incentive to bundle is the strongest.

In a “relaxed” version of the problem, the seller ignores the possibility of lower types misrepresenting their preferences. In this version of the program, as long as the PC restriction for the LL-type is satisfied, she does not have to worry of the LL buyer purchasing any other package but his; thus, only the lowest participation constraint is relevant in the relaxed program. Additionally, in this simplified version of the problem, only the “downward” incentive restrictions are relevant. The seller does not consider the possibility of the HL-type choosing the packages intended for either the LH-type or the LL-types; similarly, she does not have to worry about the LH-type buyer choosing contracts designed to serve the HL and/or the HH-type. This problem is relaxed in the sense that it includes only a subset of all possible incentive and participation restrictions. In fact, only one participation and four incentive constraints are considered. The only important PC equation
is that of the LL-type buyer, and if \( R_{LL} \geq 0 \), then all buyer types’ PC constraints are satisfied. The relevant IC constraints are graphically depicted in figure 1. As I show later, the solution to the relaxed problem is the solution to the fully constrained program.

![Figure 1: IC constraints in the relaxed problem](image)

### 3.2 Optimal pricing without regulation

I now proceed to use the relaxed program to characterize the optimal menu of contracts both without and with portion cap. Without regulation, the seller’s problem is to design a menu of contracts to maximize expected profit (1) subject to the set of PC and IC restrictions listed in (4).

\[
\begin{align*}
R_{LL} &= 0 \\
R_{LH} &= u(q_{LL}^B)\Delta \\
R_{HL} &= u(q_{LL}^A)\Delta \\
R_{HH} &= \Delta[u(q_{LL}^A) + u(q_{LL}^B)] + \max\{[u(q_{LL}^A) - u(q_{LL}^L)]\Delta, [u(q_{HL}^B) - u(q_{LL}^B)]\Delta, 0\} \\
q_{HH}^A &\geq q_{LH}^A, q_{HL}^A \geq q_{LL}^L, q_{HH}^B \geq q_{HL}^B, q_{LH}^B \geq q_{LL}^B
\end{align*}
\]

Where \( \Delta \equiv \theta^H - \theta^L \). The first step in solving the seller’s problem is to find out the exact form of the incentive-compatibility constraint for the HH-type buyer. To provide
incentives to the HH-type to truthfully reveal his type, the seller must know which contract other than \{q^A_{HH}, q^B_{HH}, p_{HH}\} could attract the HH buyer strongly enough for him to choose it. Given the correct prices, the HH-type could feel inclined to purchase any of the other three contracts originally designed to serve the LH, HL, and LL-types. Intuitively, this is captured by the three arguments inside the brackets of the max expression in $R_{HH}$ among the equations in 4.

**Proposition 1.** The HH-type buyer incentive compatibility constraint is $R_{HH} = \Delta[u(q^A_{LL}) + u(q^B_{LL})] + [u(q^A_{LH}) - u(q^A_{LL})]\Delta + [u(q^B_{HL}) - u(q^B_{LL})]\Delta$.

Proof. First, because $\theta^A_i = \theta^B_i \equiv \theta_i$, for $i = H, L$, and the cost schedules of producing both components $c(\cdot)$ are identical, quantities will also be symmetric: $q_{HL} \equiv q^A_{HL} = q^B_{LH}$ and $q_{LL} \equiv q^m_{HH}$. Thus, the IC constraint for the HH-type can be written as $R_{HH} = 2\Delta u(q_{LL}) + \max\{[u(q_{LH}) - u(q_{LL})]\Delta, 0\}$.

Assume that $R_{HH} = 2\Delta u(q_{LL})$, this implies $0 \leq q_{LH} - q_{LL}$. Using this constraint, program 4 has the following First Order Conditions associated with $q_{LH}$ and $q_{LL}$:

$$[q_{LH}] : \theta_L u'(q_{LH}) = c'(q_{LH})$$

$$[q_{LL}] : \theta_L u'(q_{LL}) = \frac{c'(q_{LL})}{(1 - \beta + \beta_{HH} \frac{\Delta}{\theta^*})} > c'(q_{LL})$$

which imply $0 > q_{LH} - q_{LL}$, a contradiction. $\square$

In other words, because $\rho < 0$, the fraction of LL-types relative to all other buyer types is low. When this is the case, the quantities of A and B in the contract designed for the LL-type are simply too small for the HH-type to be tempted by this package. He would rather consider the other two packages. Because in this model taste is symmetric, the quantities of A and B in contracts $q_{HL} \equiv q^A_{HL} = q^B_{LH}$ and $q_{LL} \equiv q^m_{HH}$ are mirror images of each other and the packages are sold at the same price. The HH-type would find both of them equally luring. The seller must take this into consideration and increase the temptation payoff for the HH-type buyer accordingly.

The first order conditions characterizing the solution to the seller’s problem without regulation are in 5.
\[
\begin{align*}
[q^A_{HH}]: \quad & \theta_H u'(q^A_{HH}) = c'(q^A_{HH}) \\
[q^B_{HH}]: \quad & \theta_H u'(q^B_{HH}) = c'(q^B_{HH}) \\
[q^A_{HL}]: \quad & \theta_H u'(q^A_{HL}) = c'(q^A_{HL}) \\
[q^B_{HL}]: \quad & \theta_H u'(q^B_{HL}) = c'(q^B_{HL}) \\
[q^A_{LL}]: \quad & \theta_L u'(q^A_{LL}) = c'(q^A_{LL}) \\
[q^B_{LL}]: \quad & \theta_L u'(q^B_{LL}) = c'(q^B_{LL}) \\
\end{align*}
\]

(5)

Naturally, the solution characterized by the FOC above is only relevant if it is the solution to the fully constrained problem. Below, I propose and prove this is the case. This proof closely follows that in Armstrong and Rochet (1999).

**Proposition 2.** Maximizing 1 subject to 4 gives the solution to the seller’s fully constrained problem.

**Proof.** Proposition 2. Together, \( R_{LL} = 0 \), the monotonicity constraints, plus the four binding constraints in 1 imply the satisfaction of the following omitted incentive constraints:

- \( R_{LL} > R_{LH} + u(q_{LH})(\theta_L - \theta_H) \)
- \( R_{LL} > R_{HL} + u(q_{HL})(\theta_L - \theta_H) \)
- \( R_{LL} > R_{HH} + 2[u(q_{HH})(\theta_L - \theta_H)] \)

From the first order conditions in 5 it is straightforward to conclude that \( q_{HL} > q_{LH} \), thus:

- \( R_{LH} > R_{HL} + u(q_{HL})(\theta_L - \theta_H) + u(q_{LH})(\theta_H - \theta_L) \)
- \( R_{HL} > R_{LH} + u(q_{HL})(\theta_H - \theta_L) + u(q_{HL})(\theta_L - \theta_H) \)

Lastly, the single crossing condition implies:

- \( R_{LH} > R_{HH} + u(q_{HH})(\theta_H - \theta_L) \)
• $R_{HL} > R_{HH} + u(q_{HH})(\theta_L - \theta_H)$

In sum, without regulation, the quantities offered are such that:

• $q_{HL}^A = q_{LH}^B, q_{LH}^A = q_{HL}^B, q_{HH}^A = q_{HH}^B, q_{LL}^A = q_{LL}^B$. 

• The quantities $(q_{ij}^A, q_{ij}^B)$ purchased for each $ij$-type are: $(q_{HH}^A, q_{HH}^B), (q_{HL}^A, q_{LH}^B), (q_{LL}^A, q_{LL}^B)$, and $(q_{LL}^A, q_{LL}^B)$ for the HH, HL, LH, and LL-type respectively.

• The largest portions are $(q_{HH}^A = q_{HH}^B = q_{HL}^A = q_{LH}^B)$. The medium options are $(q_{LL}^A = q_{LL}^B)$. The small options are $(q_{LL}^A = q_{LL}^B)$.

• Let $q_{HL} \equiv q_{HL}^A = q_{LH}^B, q_{LH} \equiv q_{LH}^A = q_{HL}^B$, and $q_{HH} \equiv q_{HH}^m, q_{LL} \equiv q_{LL}^m$, for $m = A, B$, the seller’s value function is $E[\pi(\cdot)^*]$, expressed in 6.

• Consumer rents are: $R_{LL} = 0, R_{LH} = \Delta u(q_{LL}^A), R_{HL} = \Delta u(q_{LL}^A)$, and $R_{HH} = \Delta[u(q_{LL}^A) + u(q_{LL}^B)] + [u(q_{LL}^A) - u(q_{LL}^B)]\Delta + [u(q_{LL}^A) - u(q_{LL}^B)]\Delta$.

• Because of the symmetry in the outcomes and to economize in space, I use the nomenclature $q_{HH}^*, q_{HL}^*, q_{LL}^*$ to denote the large, medium, and small unregulated options.

\[
E[\pi(\cdot)^*] = 2 \left\{ \beta_{HH}[\theta_Hu(q_{HH}^*) - c(q_{HH}^*)] + \beta_{LL}[\theta_Lu(q_{LL}^*) - c(q_{LL}^*)] \\
+ \beta[\theta_Lu(q_{LL}^*) + \theta_Hu(q_{HH}^*) - c(q_{HH}^*) + c(q_{LL}^*)] - \Delta[(2\beta + \beta_{HH})u(q_{LL}^*) + \beta_{HH}u(q_{HH}^*)] \right\} 
\]

The profit-maximizing seller offers a menu of four package-price contracts, each of these targeting a specific type of buyer. That is, it is optimal to fully separate buyers by offering four options tailored to the taste of the four consumer types. To visualize this screening strategy and to ease with the comprehension of the model’s results, I graphically represent the separating scheme in figure 2. In this diagram, the solid black dots represent the buyers and their preferences can be inferred by their coordinates. For example, the lower-left dot represents the LL-type buyer, while the upper-right dot denotes
the HH-type consumer. Different background colors represent different contracts. The figure thus shows that each buyer type purchases one of the four tailored packages.

![Figure 2: Optimal segmentation without regulation](image)

To further aid with interpretation and comprehension of the theoretical hypotheses, in figures 3 and 4, I correspondingly show consumption (of both A and B) and consumer surplus by buyer type. I omit scale labels along the vertical axis of both figures because the specific values of these variables depend on the parametrization of the model. For some parameter combinations, for example, the LL-type is excluded from participation, and rents for the LL, LH, and HL types are null. However, the essence of the result remains. That is, consumption increases with type, bundling is observed in the form of larger sizes of product $i$ when preference for good $j$ rises, and consumer surplus increases weakly with buyers’ preferences.

### 3.3 Optimal pricing with portion cap rule

Without loss of generality, suppose that a cap is to be enforced on product A. The seller is not allowed to offer quantities of A larger than $\bar{q}$. Now, the seller’s objective is to maximize 1 subject to the traditional participation (2) and incentive-compatibility (3) constraints, plus the following quantity cap (QC) restriction:

$$\text{QC: } q_{ij}^A \leq \bar{q} \text{ for } i, j = L, H$$  \hspace{1cm} (7)
Figure 3: Graphical description of consumption by types (Theory) - Baseline

Figure 4: Graphical description of consumer surplus by types (Theory) - Baseline
Restriction QC means that the seller is not allowed to sell quantities larger than $q$ of product A to any $ij$-type buyer. A restriction where $q \geq (q^*_{HH} = q^*_{HL})$ would be innocuous because it would not have an impact on the seller’s optimal pricing scheme. Varying on restrictiveness, there are three economically interesting levels of severity at which the cap can be set:

1. Mild restriction: $(q^*_{HH} = q^*_{HL}) > q \geq q^*_{LH} > q^*_{LL}$.
2. Moderate restriction: $(q^*_{HH} = q^*_{HL}) > q^*_{LH} > \bar{q} \geq q^*_{LL}$.
3. Harsh restriction: $(q^*_{HH} = q^*_{HL}) > q^*_{LH} > q^*_{LL} > \bar{q}$.

Taking the unregulated quantities as benchmarks to design the policy, the regulation on the portion of good A can be: 1) mild if the limit is set below the larger quantity available without regulation but above the quantity of the medium unregulated alternative; 2) moderate if the cap is set below the medium unregulated option but above the quantity contained in the smallest regulation-free alternative, or 3) harsh if the limit on quantity is set at a level lower than the small alternative without the cap. In this paper, I study the impact of a moderate restriction. The moderate restriction approximates the design of the portion cap rule proposed in 2012 in New York City, since the common small, medium, and large portion choices of soda normally found in American fast-food restaurants are 16, 21, and 32 ounces respectively; the proposed intervention would have enforced a maximum size of 16 ounces.

Equation 3 shows the general form of the IC restrictions and from this equation, using this equation, it can be shown that as the regulation causes both $q^A_{HH}$ and $q^A_{HL}$ to become smaller, the extraordinary information rent that the LH-type would gain from posing as either HH or HL increases. In other words, as the quantity of product A becomes smaller due to more restrictive cap rules, the seller has to be aware of the possibility of the LH-type misrepresenting himself as an HL-type and increase the temptation payoff accordingly. With a moderate cap, the incentive constraint preventing unfaithful representation of the LH-type buyer as an HL-type is binding. This modification renders the downward incentive constraints involving the HH-type redundant. In other words, if the downward
incentive constraints for the LH-type buyer are satisfied, the HH-type buyer will not purchase neither of the two contracts intended to serve the HL-type and the LL-type buyers. I graphically show the new set of IC conditions in figure 5. With a cap then, the seller maximizes her expected profit (8), subject to the LL-type buyer’s PC, the set of incentive constraints listed in 9, and the moderate quantity constraint \( q_{HH}^* = q_{HL}^* > q_{LH}^* > \bar{q} \geq q_{LL}^* \).

The first order conditions that characterize the solution to this problem are in 10.

\[
\mathbb{E}[\pi] = (\beta_{HH} + \beta)[\theta_L u(q) - c(q_{LH})] + \\
\beta[\theta_H u(q) - c(q_{HL})] + \\
\beta_{LL}[\theta_L u(q_{LL}) + \theta_L u(q_{HL}) - c(q_{LH}) - c(q_{HL})] - \\
\beta(R_{LH} + R_{HL}) - \beta_{LL} R_{LL}
\]

\[
R_{LL} = 0 \\
R_{HL} = \Delta u(q_{LL}^A) \\
R_{LH} = \Delta u(q_{HL}^B) + \Delta u(q_{LL}^A) - \Delta u(\bar{q}) + \Delta u(q_{HL}^B) \\
R_{HH} = 2[\theta_H u(\bar{q}) - \theta_H u(q_{LH}^B)] - \Delta[u(q_{HL}^B) + u(q_{LL}^A) + u(q_{HL}^B)]
\]

Figure 5: IC constraints in the relaxed problem with a portion cap
\[
\begin{align*}
[q] : & \quad \theta_H u'(q) = c'(q) \frac{\beta_{HH} + 2\beta}{\frac{\alpha}{T_H}(\beta_{HH} + \beta) + \beta(1 + \frac{\Delta}{\theta_H})} \\
[q_{BH}] : & \quad \theta_H u'(q_{BH}) = c'(q_{BH}) \\
[q_{HL}] : & \quad \theta_L u'(q_{HL}) = \frac{c'(q_{HL})}{1 - \frac{\Delta}{\theta_L}} \\
[q_{HL}] : & \quad \theta_L u'(q_{HL}) = \frac{c'(q_{HL})}{1 - \frac{\Delta}{\theta_L}} \\
[q_{LL}] : & \quad \theta_L u'(q_{LL}) = \frac{c'(q_{LL})}{1 - \frac{\Delta}{\theta_L}} \\
\end{align*}
\]

Let the endogenous variables that solve the conditions in 10 be referred to with the double star (***) superscript. The results of a cap are:

- The HH-type, and LH-type buyers purchase the same contract with quantities \(q^{***}, q_{BH}^{***}\). The HL, and LL types consumer get quantities \(q^{***}, q_{HL}^{***}\), and \(q_{LL}^{***}, q_{LL}^{***}\).
- Importantly, it can be shown that: \(q_{BH}^{***} = q_{BH}^{***}\); \(q_{HL}^{***} < q_{HL}^{***}\); and \(q_{LL}^{***} > q_{LL}^{***}\).
- \(q_{LL}^{***} < q; q_{LL}^{***} < q_{HL}^{***} < q_{LL}^{***}\).
- Consumer rents compare as follows: \(R_{LL}^{***} = R_{LL}^{***}\); \(R_{HL}^{***} = R_{HL}^{***}\); \(R_{HL}^{***} > R_{HL}^{***}\), and \(R_{HH}^{***} < R_{HH}^{***}\).
- The seller’s value function is \(E[\pi(\cdot)^{**}]\), expressed in 11. It can be shown that \(E[\pi(\cdot)^{**}] < E[\pi(\cdot)^{*}]\)

\[
E[\pi(\cdot)^{*}] = (\beta_{HH} + \beta)[\theta_L u(q) + \theta_H u(q_{BH}) - c(q) - c(q_{BH})] + \\
\beta[\theta_H u(q) + \theta_L u(q_{HL}) - c(q) - c(q_{HL})] + \\
\beta_{LL}[\theta_L u(q_{LL}) + \theta_L u(q_{LL}) - c(q_{LL}) - c(q_{LL})] - \\
\beta(R_{LH} + R_{HL}) - \beta_{LL}R_{LL}
\]

The resulting optimal segmentation strategy with a moderate cap is depicted in figure 6. The portion cap results in bunching of HH and LH-type buyers; these type of customers purchase the same contract. This differs from the baseline environment with no regulation where the LH and HH-types are offered the same large portion of product B, but different quantities of product A.
Because in the model the two products are neither complements nor substitutes, it is surprising to find that the theoretical results suggest changes for the quantity of the unregulated product B purchased by the HL and LL-type buyers. According to the theoretical outcomes associated with a moderate restriction, the HL-type buyer is offered less of product B, while the LL receives more of it. This result stems from the nature of the incentive-design problem faced by the seller. Once the cap is implemented, her desire to price-discriminate continues and the restriction merely reduces her choice space. To accommodate the policy while at the same time continue to adopt a profit-maximizing segmentation strategy, the seller has to modify all of the endogenous variables to her disposal, including the quantities of product B. I continue with a brief explanation of the forces driving these adjustments.

I first discuss the adjustments made to the small package designed to serve the LL-type buyer. In essence, these changes are driven by the LL-type’s participation constraint and the need to provide positive rents to the LH-type for him to purchase his own package. Without regulation, information rents for the LH-type take the form of a larger quantity of product A compared to the level received by the LL-type buyer. With a moderate cap on A, the LH-type (as well as the HL, and HH types) consumes less of the regulated product A. However, the profit-maximizing seller still needs to provide positive information rents to the LH-type in order to make sure that this buyer will not purchase the small combo designed to serve the LL buyer. Because there is an external limit on A, the only way the
seller can increase the difference in quantity of A offered to the LL and LH types is by decreasing the quantity of A served to the LL-type buyer. Thus, the LL ought to receive less product A. To maintain the satisfaction of the LL-type’s participation constraint, the seller increases the quantity of component B served to this type. This explains the change in the mix of A and B served to the LL-type consumer.

I now turn to explain the modifications in the package sold to the HL-buyer. In essence, these are explained by the changes in the smallest package (served to the LL-type consumer), and the fact that the need to separate the HL from the LL-type remains, but the incentives need not be as strong under regulation. Due to the cap, the seller is unable to offer the first best quantity of product A to the HL-type buyer. Indeed, because the cap is of moderate nature, the HL buyer purchases considerably less compared to the baseline. The seller still needs to provide incentives to the HL-type in the form of a larger portion of product B compared to the LL package. Because the quantity of product A contained in the smallest package (that serving the LL-type) is low and indeed smaller compared to the baseline unregulated case, the extra amount of product B granted to the HL-type consumer to generate information rents need not be as large. This explains the reduction in consumption of product B from the HL-type buyer.

Regarding the impacts on buyers’ surplus, the model predicts two main impacts on consumer surplus contingent on the type of the buyer: a reduction in the rents granted to the HH-type ($R_{HH}$) and an increase in the surplus earned by the LH-type ($R_{LH}$). The reason behind the reduction of the HH-type’s surplus is straightforward. The HH-type buyer is worse-off because he is receiving significantly less of a product he values highly and the reduction in price is not large enough to compensate for the diminished size of the package. The intuition behind the increase in the LH-type’s well-being is the following. In the unregulated baseline, the LH-type is purchasing a “medium” portion product A for which he has a low preference. The LH buyer would prefer a “small-large” A-B combo which is not available in the baseline menu of choices. The portion cap rule moves the choice set closer to ideal for this buyer type because it reduces the quantity of product A he is offered. Therefore, this buyer purchases less of the product for which he has a low preference, while still consuming a large portion of the product he values highly.
To help with the interpretation of the theoretical outcomes, I include figures 7 and 8 which correspondingly depict consumption and consumer surplus patterns when under a moderate portion cap rule enforced on product A. In figure 7 the horizontal red line indicates the maximum-quantity limit on product A. In figure 8, the purple and blue horizontal lines indicate the baseline levels for HH-type and LH-type consumer surplus, respectively. In both figures, I omit the scale in the vertical axis because the point value of each column is contingent on the model’s parametrization. In some cases, for example, the LL-type is excluded from participation, and rents for the LL, and HL types are null. However, the essence of the result remains: the model predicts that a severe enough cap on A will reduce consumption of A; increase consumption of B by the LL buyer; decrease consumption of B by the HL type; increase consumer surplus for the LH-type, and reduce consumer rents for the HH-type.

3.4 Hypotheses

The subsections above characterize the effects of the cap as predicted by a standard multi-dimensional nonlinear pricing model. I summarize these results in the hypotheses below. These constitute the set of hypotheses I will test in a controlled experiment.

**Hypothesis 1.** Consumption of good A. Following the implementation of a portion cap rule on product A, all buyer types reduce their consumption of the regulated product A.

**Hypothesis 2.** Consumption of good B. Implementing a portion cap rule on product A will result in the following impacts on consumption of good B: i) the LH and HH-type buyers do not reduce their consumption of the unregulated product B; ii) the HL-type purchases less of B, and iii) the LL-type buyer consumes more of product B.

**Hypothesis 3.** Expected profit and consumer rents. Imposing a cap on product A will cause the following impacts on surplus: i) the seller’s expected profit is smaller; ii) the LH-type receives more consumer surplus; iii) the HH-type buyer earns a smaller consumer rent, and iv) the LL and HL-type’s consumer surpluses remain unaffected.

The next step before conducting an experiment to test these predictions is to choose a parameter constellation for the model. In table 1, I display the parameters I use during
Figure 7: Graphical description of consumption by types (Theoretical) - Cap

Figure 8: Graphical description of consumer surplus by types (Theoretical) - Cap
the experiment. With this parametrization, without a cap, the optimal scheme excludes the LL-type and offer distinct options to each of the other buyer types. The chosen probability combination of buyer types is fairly generic, its properties are not particular and can be considered to be fairly representative of other probability-combinations with negative correlation. In figure 9, the 2-simplex in the upper panel shows all possible combinations of probabilities I could have selected. The coordinates within the lightest area correspond to values where $0 < \frac{\beta^2}{\rho_{LL}} < \rho$, and the seller has no incentive to engage in bundling. Coordinates in the second lightest area of the 2-simplex correspond to values of probabilities where $0 < \rho < \frac{\beta^2}{\rho_{LL}}$, thus the incentive to bundle is “weak”. The incentive to bundle is the strongest in the dark blue area where $\rho < 0 < \frac{\beta^2}{\rho_{LL}}$. The red line highlights “symmetric” combination of probabilities where $\beta_{HH} = \beta_{LL}$. The combination of probabilities I chose is generic and lies relatively far from “border” and corner regions in the 2-simplex. Moreover, since it is symmetric (the probability of the buyer being a LL-type is the same with the probability of being an HH-type) and it can be expressed with probabilities with only one decimal, this distribution reduces the complexity of the experimental instructions.

Table 1: Parameter values used in this study

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\beta_{HH}$</td>
<td>0.1</td>
<td>Probability of the buyer being a HH-type</td>
</tr>
<tr>
<td>$\beta$</td>
<td>0.4</td>
<td>Probability of the buyer being a HL-type</td>
</tr>
<tr>
<td>$\beta_{LL}$</td>
<td>0.1</td>
<td>Probability of the buyer being a LL-type</td>
</tr>
<tr>
<td>$\theta_H$</td>
<td>15</td>
<td>Taste parameter when preference is high</td>
</tr>
<tr>
<td>$\theta_L$</td>
<td>10</td>
<td>Taste parameter when preference is low</td>
</tr>
<tr>
<td>$\theta_iu(q)$</td>
<td>$\frac{\theta_i}{\sqrt{q}}$</td>
<td>Buyer’s gross utility</td>
</tr>
<tr>
<td>$c(q)$</td>
<td>$q^2/500$</td>
<td>Seller’s cost of producing $q$ units of a given good</td>
</tr>
<tr>
<td>$q_A$</td>
<td>75</td>
<td>Maximum-quantity cap on good A in the cap treatment</td>
</tr>
</tbody>
</table>

The probability of the buyer being an LH-type is also $\beta$.

4 Experimental design

In total, 82 subjects were randomly assigned to one of two experimental treatments. I refer to the treatments as either Baseline or Cap depending on their policy environment. There were three sessions per treatment with 12 to 14 subjects each. Sessions were conducted
Figure 9: Chosen probabilities of buyer types between October and November of 2017 at Purdue University’s Vernon Smith Experimental Economics Laboratory. Payoff functions and the ranges of choice variables given to the subjects can be seen in table 2. Subjects were recruited via ORSEE (Greiner, 2015). The experimental interface was designed with oTree (Chen et al., 2016). The instructions were read aloud by a computer using Google’s text to speech application programming interface gTTS 1.2.2. No subject participated in more than one session.

Table 2: Experimental treatments

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Payoffs</th>
<th>Choice variables: ranges</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>$p - \frac{(q_A)^2 + (q_B)^2}{500}$</td>
<td>$\theta^i \sqrt{q_A} + \theta^j \sqrt{q_B} - p$</td>
</tr>
<tr>
<td>Cap</td>
<td>$\frac{(q_A)^2 + (q_B)^2}{500}$</td>
<td>$\theta^i \sqrt{q_A} + \theta^j \sqrt{q_B} - p$</td>
</tr>
</tbody>
</table>

In all sessions, subjects play “trading periods” in which the seller submits a menu of
choices and the buyer makes consumption decisions. Subjects play 6 “training periods” with no financial consequences which allows them to become familiar with the interface and the periods’ structure. Following the training phase, each subject plays 11 paying “trading periods”. Every menu of choices submitted and the corresponding purchase decision constitute an observation in my database. Excluding training periods, the final database contains 902 observations, 440 from the Baseline group and 462 from the Cap treatment. All subjects are assigned to the role of a seller and did not interact with any other human subject in the room. The role of the buyer was taken by a computer program behaving as a rational utility-maximizing buyer. The buyer type was randomly and independently assigned each trading period. Throughout the experiment, earnings were denominated in points. Final earnings were converted into cash at the exchange rate was 31 points per US Dollar. All sessions had the same structure: first, subjects answered a pre-experimental quiz; second, there were six “training” non-paying trading periods; then, eleven “effective” trading rounds were played; lastly, subjects answered a post-experimental survey. Four out of the eleven effective periods were randomly selected to determine subjects’ final payoff consisting of the sum of points earned in the chosen periods. Subjects were informed of all the above plus the profit and information rents functions before the beginning of the session. I append the computer interface’s screens and instructions for the Cap treatment at the end of the paper.

The game in each trading period closely mirrors the screening problem I describe in the previous sections. At the beginning of each trading round, the seller chooses to offer a number of packages, from one to four; she can also choose not to offer any package at all. Next, the seller specifies quantities and prices. Thus, the seller is designing a menu consisting of up to four packages, each with three arguments: quantity of product A, quantity of product B, and price. Following the design of the menu, the offer is submitted to the computerized buyer for consideration. The buyer can purchase only one package per period. The buyer chooses the package that maximizes his payoff, but rejects the entire menu if all packages resulted in earnings lower than the reservation value of zero. If more than one packages results in the same non-negative earnings for the buyer, then the first of these packages (in the order they were submitted by the seller) is chosen. The
seller and buyer payoffs in points are determined using the purchased package, if any. If no menu is submitted or if the buyer rejects the entire menu, both parties receive zero points. At the end of each trading period, the seller is shown the terms of the menu she offered, the choice made by the seller and her period earnings in points. Subjects also have access to a calculator during the menu-design phase of the trading periods. With this calculator, subjects can experiment with different quantities-price combinations and learn how these would translate into profit, cost of production, and consumer surplus per buyer type.

The sum of points earned in four out of the eleven effective trading periods determined the final experimental earnings for the seller. These were randomly chosen via the following protocol. Labeled from 1 to 330, the experimenter had a list with all possible combinations of four periods. A computer application that randomly chooses numbers between 1 to 330, all equally likely. The application was activated three times. The number that appeared the third time represented the label of the selected combination of paying periods. This was done before subjects started to answer the pre-experimental quiz. The selected paying combination was shown to each subject after they finished with all of their tasks. If the sum of the four randomly selected periods was negative, the earnings of the subject was set to zero.

5 Results

5.1 Descriptive overview

Before introducing the main results of the study, I first offer an overview of the general patterns found in the data. I present evidence suggesting that subjects submit offers consistent with nonlinear pricing theory. This would grant a degree of confidence that my experimental design appropriately captures the essence of the theory, and that subjects understood the instructions.

Specifically, the theory predicts that, without regulation, sellers engage in bundling when facing privately informed buyers where the distribution of types is negatively cor-
related. If I take all of the menus with one or more packages submitted during the baseline treatment, order the packages within a menu by the sum of their quantities, and average across menus, the result is figure 10. Remember that bundling is said to exist if the quantity of product \( j \) increases with preference for component \( i \), and this is graphically confirmed in figure 10, assuming that the smaller, and second smaller packages target LL and LH types, while the largest and the second largest target HH and HL types, respectively. This is a crude approximation to the sellers’ pricing scheme in the sense that it is not immediately obvious which of the two “medium” packages (the options between the smallest and the largest) would be consumed by either the HL or the LH type. Moreover, it ignores the possibility that some sellers engaging in bunching (serving more than one type with a single package), and exclusion. However, it is not one of my objectives to formally test the theory of multidimensional screening. Therefore, I consider the pattern of offered quantities shown in figure 10 to be evidence of sellers attempting to bundle.
I now turn to the way in which the characteristics of the menus evolved across periods and look at the possibility of learning. Evidence of learning during the experiment would provide a degree of confidence on the data because it would indicate that the subjects not only understood the instructions, but they took non-random decisions and increased their pricing accuracy as the experiment progressed.

To elicit segmentation and price discrimination, subjects were informed that they were going to be matched with a single buyer each trading round but the type of the buyer would change across periods according to a known vector of probabilities. From the submitted menus, I can infer which packages would each type of buyer would have purchased had he been presented with the submitted menu. These packages and their associated payoffs are the data I use to test hypotheses during the rest of this document. Tables 3, and 4 show average price and quantities of the packages purchased by each buyer type in the baseline and cap treatments, correspondingly. In both treatments, price and quantities are larger in later periods.

Table 3: Average paid prices and purchased quantities per buyer type: Baseline treatment

<table>
<thead>
<tr>
<th>Buyer type</th>
<th>LL</th>
<th>LH</th>
<th>HL</th>
<th>HH</th>
</tr>
</thead>
<tbody>
<tr>
<td>All periods:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean price</td>
<td>160.14</td>
<td>209.66</td>
<td>211.35</td>
<td>218.80</td>
</tr>
<tr>
<td>Mean $q^A$</td>
<td>93.42</td>
<td>98.32</td>
<td>117.15</td>
<td>114.10</td>
</tr>
<tr>
<td>Mean $q^B$</td>
<td>90.42</td>
<td>112.93</td>
<td>97.11</td>
<td>109.76</td>
</tr>
<tr>
<td>First 5 periods:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean price</td>
<td>145.49</td>
<td>197.63</td>
<td>200.18</td>
<td>204.39</td>
</tr>
<tr>
<td>Mean $q^A$</td>
<td>85.15</td>
<td>92.07</td>
<td>112.38</td>
<td>106.13</td>
</tr>
<tr>
<td>Mean $q^B$</td>
<td>83.47</td>
<td>107.98</td>
<td>91.26</td>
<td>103.69</td>
</tr>
<tr>
<td>Last 6 periods:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean price</td>
<td>173.66</td>
<td>219.69</td>
<td>220.75</td>
<td>230.57</td>
</tr>
<tr>
<td>Mean $q^A$</td>
<td>101.06</td>
<td>103.53</td>
<td>121.16</td>
<td>120.60</td>
</tr>
<tr>
<td>Mean $q^B$</td>
<td>96.83</td>
<td>117.05</td>
<td>102.03</td>
<td>114.71</td>
</tr>
</tbody>
</table>

The evolution in prices and quantities would be evidence of a greater degree of pricing sophistication if buyers’ information rents are lower in later periods and seller’s per-period payoffs are larger later in the experiment. Tables 5 and 6 show that this is generally the case. As the experiment progresses, subjects seem to learn to more precisely price their
Table 4: Average price and quantities per buyer type: Cap treatment

<table>
<thead>
<tr>
<th>Buyer type</th>
<th>LL</th>
<th>LH</th>
<th>HL</th>
<th>HH</th>
</tr>
</thead>
<tbody>
<tr>
<td>All periods: Mean price</td>
<td>128.97</td>
<td>179.61</td>
<td>169.74</td>
<td>184.22</td>
</tr>
<tr>
<td>Mean $q^A$</td>
<td>41.43</td>
<td>48.57</td>
<td>56.44</td>
<td>55.32</td>
</tr>
<tr>
<td>Mean $q^B$</td>
<td>95.21</td>
<td>119.98</td>
<td>96.89</td>
<td>117.19</td>
</tr>
<tr>
<td>First 5 periods: Mean price</td>
<td>121.30</td>
<td>170.59</td>
<td>161.18</td>
<td>177.25</td>
</tr>
<tr>
<td>Mean $q^A$</td>
<td>37.50</td>
<td>45.45</td>
<td>53.73</td>
<td>52.97</td>
</tr>
<tr>
<td>Mean $q^B$</td>
<td>88.67</td>
<td>113.75</td>
<td>91.81</td>
<td>112.22</td>
</tr>
<tr>
<td>Last 6 periods: Mean price</td>
<td>136.26</td>
<td>187.14</td>
<td>176.79</td>
<td>190.03</td>
</tr>
<tr>
<td>Mean $q^A$</td>
<td>45.16</td>
<td>51.19</td>
<td>58.67</td>
<td>57.28</td>
</tr>
<tr>
<td>Mean $q^B$</td>
<td>101.43</td>
<td>125.19</td>
<td>101.07</td>
<td>121.33</td>
</tr>
</tbody>
</table>

Table 5: Average per-period earnings: Baseline treatment

<table>
<thead>
<tr>
<th>Number of observed packages</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>All periods:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>#Obs/Total (Share)</td>
<td>4/440 (0.9)</td>
<td>251/440 (57.0)</td>
<td>170/440 (38.6)</td>
<td>15/440 (3.4)</td>
</tr>
<tr>
<td>Mean $R_{LL}$</td>
<td>0</td>
<td>10.96</td>
<td>8.51</td>
<td>8.01</td>
</tr>
<tr>
<td>Mean $R_{LH}$</td>
<td>0</td>
<td>40.25</td>
<td>33.81</td>
<td>36.51</td>
</tr>
<tr>
<td>Mean $R_{HL}$</td>
<td>0</td>
<td>41.48</td>
<td>34.04</td>
<td>36.60</td>
</tr>
<tr>
<td>Mean $R_{HH}$</td>
<td>0</td>
<td>90.44</td>
<td>79.59</td>
<td>74.73</td>
</tr>
<tr>
<td>Mean payoff seller</td>
<td>0</td>
<td>142.33</td>
<td>144.51</td>
<td>140.93</td>
</tr>
<tr>
<td>Mean $E[\pi]$</td>
<td>0</td>
<td>107.15</td>
<td>110.39</td>
<td>117.62</td>
</tr>
<tr>
<td>First 5 periods:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>#Obs/Total (Share)</td>
<td>4/200 (2.0)</td>
<td>111/200 (55.5)</td>
<td>76/200 (38.0)</td>
<td>9/200 (4.5)</td>
</tr>
<tr>
<td>Mean $R_{LL}$</td>
<td>0</td>
<td>16.70</td>
<td>8.10</td>
<td>8.95</td>
</tr>
<tr>
<td>Mean $R_{LH}$</td>
<td>0</td>
<td>48.44</td>
<td>33.76</td>
<td>39.25</td>
</tr>
<tr>
<td>Mean $R_{HL}$</td>
<td>0</td>
<td>49.52</td>
<td>33.53</td>
<td>39.84</td>
</tr>
<tr>
<td>Mean $R_{HH}$</td>
<td>0</td>
<td>96.49</td>
<td>78.13</td>
<td>77.96</td>
</tr>
<tr>
<td>Mean payoff seller</td>
<td>0</td>
<td>136.68</td>
<td>142.38</td>
<td>134.61</td>
</tr>
<tr>
<td>Mean $E[\pi]$</td>
<td>0</td>
<td>102.34</td>
<td>109.46</td>
<td>121.51</td>
</tr>
<tr>
<td>Last 6 periods:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>#Obs/Total (Share)</td>
<td>0/220 (0.0)</td>
<td>140/220 (63.6)</td>
<td>94/220 (42.7)</td>
<td>6/220 (2.7)</td>
</tr>
<tr>
<td>Mean $R_{LL}$</td>
<td>0</td>
<td>6.41</td>
<td>27.9</td>
<td>6.61</td>
</tr>
<tr>
<td>Mean $R_{LH}$</td>
<td>0</td>
<td>33.76</td>
<td>33.85</td>
<td>32.40</td>
</tr>
<tr>
<td>Mean $R_{HL}$</td>
<td>0</td>
<td>35.10</td>
<td>34.45</td>
<td>31.74</td>
</tr>
<tr>
<td>Mean $R_{HH}$</td>
<td>0</td>
<td>85.65</td>
<td>80.77</td>
<td>69.88</td>
</tr>
<tr>
<td>Mean payoff seller</td>
<td>0</td>
<td>146.81</td>
<td>146.23</td>
<td>150.41</td>
</tr>
<tr>
<td>Mean $E[\pi]$</td>
<td>0</td>
<td>110.96</td>
<td>111.14</td>
<td>111.78</td>
</tr>
</tbody>
</table>
Table 6: Average per-period earnings: Cap treatment

<table>
<thead>
<tr>
<th>Number of packages</th>
<th>All periods:</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>#Obs/Total (Share)</td>
<td>2/462 (0.4)</td>
<td>300/462 (64.9)</td>
<td>121/462 (26.2)</td>
<td>39/462 (8.4)</td>
<td></td>
</tr>
<tr>
<td>Mean $R_{LL}$</td>
<td>0</td>
<td>15.69</td>
<td>9.85</td>
<td>5.10</td>
<td></td>
</tr>
<tr>
<td>Mean $R_{LH}$</td>
<td>0</td>
<td>52.18</td>
<td>36.68</td>
<td>34.75</td>
<td></td>
</tr>
<tr>
<td>Mean $R_{HL}$</td>
<td>0</td>
<td>35.29</td>
<td>27.9</td>
<td>25.47</td>
<td></td>
</tr>
<tr>
<td>Mean $R_{HH}$</td>
<td>0</td>
<td>87.13</td>
<td>72.34</td>
<td>62.26</td>
<td></td>
</tr>
<tr>
<td>Mean payoff seller</td>
<td>0</td>
<td>126.00</td>
<td>135.33</td>
<td>134.41</td>
<td></td>
</tr>
<tr>
<td>Mean $E[\pi]$</td>
<td>0</td>
<td>95.93</td>
<td>100.83</td>
<td>117.38</td>
<td></td>
</tr>
<tr>
<td>First 5 periods:</td>
<td>1/210 (0.5)</td>
<td>133/210 (63.3)</td>
<td>58/210 (27.6)</td>
<td>18/210 (8.6)</td>
<td></td>
</tr>
<tr>
<td>Mean $R_{LL}$</td>
<td>0</td>
<td>17.75</td>
<td>12.17</td>
<td>3.24</td>
<td></td>
</tr>
<tr>
<td>Mean $R_{LH}$</td>
<td>0</td>
<td>53.60</td>
<td>41.71</td>
<td>34.66</td>
<td></td>
</tr>
<tr>
<td>Mean $R_{HL}$</td>
<td>0</td>
<td>36.50</td>
<td>33.22</td>
<td>25.02</td>
<td></td>
</tr>
<tr>
<td>Mean $R_{HH}$</td>
<td>0</td>
<td>87.31</td>
<td>76.13</td>
<td>62.23</td>
<td></td>
</tr>
<tr>
<td>Mean payoff seller</td>
<td>0</td>
<td>117.70</td>
<td>127.62</td>
<td>144.21</td>
<td></td>
</tr>
<tr>
<td>Mean $E[\pi]$</td>
<td>0</td>
<td>92.17</td>
<td>102.82</td>
<td>120.87</td>
<td></td>
</tr>
<tr>
<td>Last 6 periods:</td>
<td>1/252 (0.4)</td>
<td>167/252 (66.3)</td>
<td>63/252 (25.0)</td>
<td>21/252 (8.3)</td>
<td></td>
</tr>
<tr>
<td>Mean $R_{LL}$</td>
<td>0</td>
<td>14.05</td>
<td>7.71</td>
<td>6.70</td>
<td></td>
</tr>
<tr>
<td>Mean $R_{LH}$</td>
<td>0</td>
<td>51.05</td>
<td>32.04</td>
<td>34.83</td>
<td></td>
</tr>
<tr>
<td>Mean $R_{HL}$</td>
<td>0</td>
<td>34.32</td>
<td>23.05</td>
<td>25.85</td>
<td></td>
</tr>
<tr>
<td>Mean $R_{HH}$</td>
<td>0</td>
<td>86.99</td>
<td>68.85</td>
<td>62.29</td>
<td></td>
</tr>
<tr>
<td>Mean payoff seller</td>
<td>0</td>
<td>132.61</td>
<td>142.43</td>
<td>126.01</td>
<td></td>
</tr>
<tr>
<td>Mean $E[\pi]$</td>
<td>0</td>
<td>98.92</td>
<td>99.00</td>
<td>114.39</td>
<td></td>
</tr>
</tbody>
</table>
Table 7: Market coverage: Participation by buyer type

<table>
<thead>
<tr>
<th></th>
<th>Base</th>
<th>Cap</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>All periods:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LL-type</td>
<td>221/440 (50.23)</td>
<td>≈ 246/462 (53.25)</td>
</tr>
<tr>
<td>LH-type</td>
<td>431/440 (97.95)</td>
<td>&lt;* 459/462 (99.35)</td>
</tr>
<tr>
<td>HL-type</td>
<td>429/440 (97.50)</td>
<td>≈ 443/462 (95.89)</td>
</tr>
<tr>
<td>HH-type</td>
<td>436/440 (99.09)</td>
<td>≈ 460/462 (99.57)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>First 5 periods:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LL-type</td>
<td>106/200 (53.00)</td>
<td>≈ 120/210 (57.14)</td>
</tr>
<tr>
<td>LH-type</td>
<td>196/200 (98.00)</td>
<td>≈ 209/210 (99.52)</td>
</tr>
<tr>
<td>HL-type</td>
<td>196/200 (98.00)</td>
<td>≈ 200/210 (95.24)</td>
</tr>
<tr>
<td>HH-type</td>
<td>196/200 (98.00)</td>
<td>≈ 209/210 (99.52)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Last 6 periods:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LL-type</td>
<td>115/240 (47.92)</td>
<td>≈ 126/252 (50.00)</td>
</tr>
<tr>
<td>LH-type</td>
<td>235/240 (97.92)</td>
<td>≈ 250/252 (99.21)</td>
</tr>
<tr>
<td>HL-type</td>
<td>233/240 (97.08)</td>
<td>≈ 243/252 (96.43)</td>
</tr>
<tr>
<td>HH-type</td>
<td>240/240 (100.0)</td>
<td>≈ 251/252 (99.60)</td>
</tr>
</tbody>
</table>

= P ≥ 0.10, * P < 0.10, ** P < 0.05, *** P < 0.01.
packages and extract more surplus from the buyers as a result.

Subjects do not seem to explore with different segmentation strategies, rather they seem to adopt a strategy and increase their sophistication for that scheme. If subjects were switching their segmentation schemes, I would expect the participation of buyers (especially the lowest type) to vary as subjects may decide to exclude them some times and cover them during other trading rounds. Table 7 shows that within and across treatments, the market coverage patterns observed in the early part of the experiment are also appreciated later on. That is, the fraction of menus that cover a given buyer type remained stable during the experimental sessions and the market coverage profile observed in the baseline group closely approximates the appreciated in the cap treatment. In addition to the results shown above supporting increased surplus extraction in later periods, This suggests that, on average, subjects did not switch between segmentation strategies, rather they choose a segmentation pattern increased their pricing accuracy as the sessions progressed.

5.2 Major results

I now continue with the paper’s main research objectives, namely finding what are the impacts that a moderate cap on product A has on quantity consumed of both products and on consumer surplus by buyer type. For all menus of contracts that subjects submitted during the trading periods, I infer which package each type of buyer would have purchased; how much they would have paid; the seller’s expected profit; the information rents for all buyers, and the associated experimental payoffs in points. I use these quantities in the estimations below.

I start by looking at the impacts on quantity purchased by type of buyer. In table 8, I show econometric estimates of the portion cap’s impact on quantities purchased by each buyer type. I find significant reductions in consumption of A by all buyer types. I do not find statistically significant evidence of a change in consumption of product B by any of the consumer types. These are the main two findings regarding impacts on consumption.
Table 8: Estimates: impact of the quantity cap on per-period quantities purchased per buyer type

<table>
<thead>
<tr>
<th></th>
<th>(q^A_{HH})</th>
<th>(q^B_{HH})</th>
<th>(q^A_{HL})</th>
<th>(q^B_{HL})</th>
<th>(q^A_{LH})</th>
<th>(q^B_{LH})</th>
<th>(q^A_{LL})</th>
<th>(q^B_{LL})</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cap dummy</strong></td>
<td>-58.992***</td>
<td>8.418</td>
<td>-61.200***</td>
<td>0.469</td>
<td>-49.206***</td>
<td>7.454</td>
<td>-44.174***</td>
<td>10.061</td>
</tr>
<tr>
<td><strong>Period</strong></td>
<td>1.639***</td>
<td>1.600***</td>
<td>1.284***</td>
<td>1.684***</td>
<td>1.541***</td>
<td>1.500***</td>
<td>1.880***</td>
<td>2.044***</td>
</tr>
<tr>
<td></td>
<td>(0.399)</td>
<td>(0.464)</td>
<td>(0.228)</td>
<td>(0.362)</td>
<td>(0.462)</td>
<td>(0.440)</td>
<td>(0.399)</td>
<td>(0.674)</td>
</tr>
<tr>
<td><strong>Constant</strong></td>
<td>104.360***</td>
<td>99.129***</td>
<td>109.087***</td>
<td>86.499***</td>
<td>88.453***</td>
<td>103.415***</td>
<td>72.4927***</td>
<td>69.600</td>
</tr>
<tr>
<td><strong>Observations</strong></td>
<td>896</td>
<td>896</td>
<td>872</td>
<td>872</td>
<td>890</td>
<td>890</td>
<td>467</td>
<td>467</td>
</tr>
</tbody>
</table>

* P < 0.10, ** P < 0.05, *** P < 0.01. Regressions estimated using multi-level random effects at the session and subject levels. Robust standard errors clustered at the session level in parentheses. Cap dummy takes a value of 1 if the observation belongs to the cap treatment, 0 otherwise.
Main Result 1. According to hypothesis 1, compared to the unregulated baseline, all consumers reduce their consumption of product A.

Main Result 2. According to hypothesis 2, the cap rule does not impact the quantity of product B purchased by the HH and LH-type buyers. In opposition to hypothesis 2, the HL-type buyer does not reduce his consumption of B. Although the LL-type’s consumption of B is estimated to have the predicted sign, it is not statistically significant.

As stated in result 1, all buyer types reduced their consumption of product A. The estimate on the impact of the cap on consumption of B by the LL-type has the predicted sign, however it is not statistically significant. The data do not support the theoretical hypothesis of a reduction in the consumption of B by the HL-type. Indeed, I do not find evidence of a statistically significant change in purchases of product B by any consumer type.

I turn now to the distributional impacts of the portion cap rule. I show the econometric estimates of the impact on producer and consumer surpluses in table 9. The main hypotheses are that the LH-type is better off after the cap, while the HH is worse off. To complement the analysis the table also shows the impact on seller’s expected profit and per-period profit (observed profit).

Main Result 3. In opposition to hypothesis 3: expected profit is not significantly smaller with a cap, and the reduction in consumer surplus earned by the HH-type buyers is not statistically significant either. In alignment with hypothesis 3, on the other hand, the LH-type buyer earns a larger surplus, while the HL and LL-type’s surpluses remain unchanged.

As predicted by the model, the LH-type is better off after the cap. Intuitively, this buyer is no longer pressed to buy more of the product he has a low valuation for in order to get the large portion of the good he values the most. The cap moves the set of options closer to the ideal for this buyer’s preferences. Contrary to the hypotheses derived from the model, the HH-type buyer is not impacted by the cap. The main reason can be found in table 10. The HH-buyer is buying less of A a good he values largely, however he is also paying less for the package he is purchasing, the reduction in price compensates for the reduction in consumption.
Table 9: Estimates: impact of the quantity cap on per-period earnings

<table>
<thead>
<tr>
<th></th>
<th>Seller’s earning</th>
<th>Buyers’ earnings</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( \mathbb{E}[\pi] )</td>
<td>Observed profit</td>
<td>( R_{HH} )</td>
<td>( R_{HL} )</td>
<td>( R_{LH} )</td>
<td>( R_{LL} )</td>
<td></td>
</tr>
<tr>
<td>Period</td>
<td>1.057***</td>
<td>2.108***</td>
<td>-0.509</td>
<td>-0.966***</td>
<td>-1.071***</td>
<td>-0.796***</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.391)</td>
<td>(0.358)</td>
<td>(0.406)</td>
<td>(0.357)</td>
<td>(0.344)</td>
<td>(0.214)</td>
<td></td>
</tr>
<tr>
<td>Constant</td>
<td>101.558***</td>
<td>129.345***</td>
<td>87.950***</td>
<td>43.866***</td>
<td>43.703***</td>
<td>14.592***</td>
<td></td>
</tr>
<tr>
<td>Observations</td>
<td>902</td>
<td>902</td>
<td>902</td>
<td>902</td>
<td>902</td>
<td>902</td>
<td></td>
</tr>
</tbody>
</table>

* P < 0.10, ** P < 0.05, *** P < 0.01. Regressions estimated using multi-level random effects at the session and subject levels. Robust standard errors clustered at the session level in parentheses. Cap dummy takes a value of 1 if the observation belongs to the cap treatment, 0 otherwise.
To put the empirical results in perspective, it is useful to compare them with the non-linear pricing model’s predictions. The first theoretical hypothesis I turn to is that of the changes in the quantities purchased by the LL-type buyer. For the LL buyer, the model predicts a reduction in the portion of A and an increase in the portion of B. As shown in table 8, I do observe a statistically significant reduction in quantity of product A purchased by the LL-type buyer ($q^A_{LL}$), which aligns with the hypothesis. On the other hand, although the estimated coefficient on the change of consumption of good B by this buyer type ($q^B_{LL}$) is positive as predicted, it is not statistically significant. As predicted by the model however, these changes in the mix of quantities consumed by the LL-type result in a null impact on his consumer rents (table 9). Because the price paid by this buyer type remained unaffected across treatments, as can be seen in table 10, the LL-type’s rents are held constant via modifications in quantities, as opposed to a drop in price.

Recall that the model predictions regarding the consumption choices made by the HL-type are that this buyer would reduce his consumption of both products when the cap is enacted compared to the unregulated baseline. The empirical estimates displayed in table 8 suggest that this buyer does reduce his consumption of product A ($q^A_{HL}$), but do not modify his purchases of product B ($q^B_{HL}$). The nonlinear pricing model predicts a null impact on the information rents earned by this buyer and this what I find in the data (see table 9). Because the cap limits the consumption of the product for which this consumer has a high valuation, in order to keep his consumer surplus unchanged, the seller must

<table>
<thead>
<tr>
<th></th>
<th>$p_{HH}$</th>
<th>$p_{HL}$</th>
<th>$p_{LH}$</th>
<th>$p_{LL}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cap dummy</td>
<td>-34.163*</td>
<td>-42.081**</td>
<td>-29.17</td>
<td>-18.345</td>
</tr>
<tr>
<td></td>
<td>(19.122)</td>
<td>(19.758)</td>
<td>(18.541)</td>
<td>(15.219)</td>
</tr>
<tr>
<td>Period</td>
<td>3.355***</td>
<td>3.291***</td>
<td>3.269***</td>
<td>3.596***</td>
</tr>
<tr>
<td></td>
<td>(0.680)</td>
<td>(0.572)</td>
<td>(0.624)</td>
<td>(0.792)</td>
</tr>
<tr>
<td>Constant</td>
<td>198.185***</td>
<td>191.023***</td>
<td>189.076***</td>
<td>118.163***</td>
</tr>
<tr>
<td>Observations</td>
<td>896</td>
<td>872</td>
<td>890</td>
<td>467</td>
</tr>
</tbody>
</table>

* $P < 0.10$, ** $P < 0.05$, *** $P < 0.01$. Regressions estimated using multi-level random effects at the session and subject levels. Robust standard errors clustered at the session level in parentheses. Cap dummy takes a value of 1 if the observation belongs to the cap treatment, 0 otherwise.
decrease the price of the package she offers to him. According to table 10, this is what subjects in the laboratory did.

The surprising result of an increased surplus earned by the LH-type buyer following a cap is also documented by the data, as the reader can see in table 9. Looking at the estimates in tables 8 and 9, I conclude that the increase in surplus is entirely explained by the reduction in the portion of product A acquired by this buyer \( q_{LH}^A \) the product for which this buyer has a low valuation). This is because only the consumption of good A changed; neither the quantity consumed of the product B \( q_{LH}^B \) for which this buyer has a higher valuation changed nor the price paid per package registered statistically significant changes.

The nonlinear pricing model generated the following hypotheses regarding the HH-type consumer’s consumption and surplus: lower quantity of A \( q_{HH}^A \), no effect on consumed quantity of B \( q_{HH}^B \), and therefore a lower consumer surplus \( R_{HH} \). In the experimental data I find support for the predictions involving quantities (see table 8). Surprisingly, however, there is not a significant reduction in the surplus earned by this customer, as the reader can see in table 9. This is because, during the experiment, this buyer paid lower prices (see table 10) and the reduction is large enough to keep his information rents constant compared to the unregulated treatment.

6 Conclusion

In this paper, I present an economic analysis of a form of regulation that limits the maximum default quantity of one of the goods a multiproduct seller offers. In the context of food policy design, such interventions are known as portion cap rules. Cap rules are an alternative tool for policy makers to regulate the consumption of certain foods and ingredients judged to have deleterious impacts on human health when consumed liberally. To analyze the economic outcomes of the regulation I look at a two-product seller facing demand from privately-informed buyers. When implemented, the cap is enforced on only one of the goods offered by the seller. I use a bi-dimensional nonlinear pricing model to derive predictions about the effects of the cap on the consumption of both items,
consumer surplus, and expected profit. In the model, there are four types of privately-informed buyers in the market. The $ij$-type buyer has preference $i$ for good A, and $j$ for B. Preferences for a given product can be either high (H) or (L). The seller designs a menu of packages crafted to maximize her expected profit in this market characterized by adverse selection.

In the unregulated baseline, the model predicts the seller offers each of the products in “small”, “medium”, and “large” sizes. The menu of packages is designed such that the LL, LH, HL and HH buyers consume the following corresponding combination of goods A and B portions: small-small, medium-large, large-medium, and large-large. The consumers’ information rents weakly increase with their valuation for the products. The pricing model predicts that a portion cap rule limiting the quantity of A to be below the “medium” unregulated portion but larger than the “small” alternative would result in: i) less consumption of the regulated product for all buyers; ii) increased consumption of the unregulated product for the LL-type buyer; iii) reduced consumption of the unregulated product for the buyer with high preference for the regulated good and low preference for the unregulated good; iv) larger consumer surplus for the buyer with low preference for the regulated item and high preference for the unregulated good, v) lower consumer rents for the buyer type with high preference for both products, and vi) no change in consumer surplus for the other buyers. The experimental data confirms the reduction in purchased portions of good A, the increase in buyer surplus by the HL-type consumer, and the null impact on the consumer surplus earned by the LL and HL-type buyers. There is no significant changes in consumption of product B for any buyer type. All buyer rents, with the exception of the LH-type’s surplus, remain unaffected.

Thus, the experimental evidence suggests that a moderate portion cap rule would be successful at reducing consumption of the targeted product from all consumer types, with neither increased consumption of the unregulated component nor negative impacts on consumer well-being. Indeed, one type of buyer is better-off as a result of the policy, namely the consumer with low valuation for the regulated product A and high preference for good B. If available, this buyer would prefer a price-discounted “small-large” A-B package; the closest option for them in the unregulated baseline is a price-discounted
“medium-large” combo; the “small-small” alternative has too little of product B, while the “large-large” package is just too expensive for this buyer. A portion cap rule on good A shapes the set of contracts such that the package designed by the seller to serve the buyers with low-high valuation, is closer this buyers’ ideal contract. The buyer with high-high valuations for the A-B goods are surprisingly not worse-off after the policy, this is because during the experimental sessions, this type of buyer paid lower prices for the packages he purchased, the reduction in per-package price is significant and would have left information rents for this buyer unmodified after the cap.

These results have implications for food policy discussions around portion cap rules and similar measures. The assumption that portion cap rules negatively impact consumer well-being is an important driver of public discourse surrounding food policy and at it is already shaping public policy, as demonstrated by Mississippi’s bill 2687 (2013). I show that these worries are not justified. A portion cap can increase consumer well-being for some buyers. The benefited buyers have low valuation for the regulated product but high preference for the unregulated goods. Absent a portion cap rule, the seller has an incentive to engage in commodity bundling and offer to these buyers information rents in the form of a relatively larger quantity of the product he values lowly. The cap reduces the extent to which bundling can be leveraged as a sorting device.

Future work would expand the model and experiment with situations where complementarity or substitutability between the package components is allowed. A formal comparison between the impacts of quantity limits and other popular food policy measures such as excise taxes seems to be a natural extension.
References


Appendix A: Experimental interface

Pricing/packaging phase - **Effective** trading period 1 of 11.

Figure 11: Experimental interface: Menu choice

Pricing/packaging phase - **Effective** trading period 1 of 11.

Figure 12: Experimental interface: Quantity and price choice
Figure 13: Experimental interface: Quantity and price choice

Figure 14: Experimental interface: Offer submitted

Figure 15: Experimental interface: Feedback
Appendix B: Instructions for the *cap* treatment

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**Experimental Instructions**

This is an experiment in the economics of pricing decisions. You are entitled to a $5.00 USD show-up fee which will be paid to you at the end of the experiment. In addition, a clear understanding of these instructions will help you to increase your chances of earning an appreciable amount of money that will be paid to you in cash, in private, at the end of the experiment. During the experimental session, you are not allowed to talk, laugh, or exclaim out loud. Please, remain silent during the entire session. If you have any questions, or need assistance of any kind, raise your hand and an experimenter will help you out. All written information is for your private use only. Do not share information with other participants. Be sure to keep your eyes on your screen only. Turn off your electronic devices (such as phones, tablets, etc.) now and put them away during the experiment. Violations of these rules may force us to stop the experiment.

Anybody that violates any of these rules will be asked to leave the laboratory and will not be paid. We appreciate your cooperation.

**Agenda**

1. We will go over the instructions.
2. There will be a quiz with 10 questions to make sure everybody understands the experimental instructions. You will earn 0.20 USD for each question you answer correctly. All questions will be displayed on your computer's screen. You will have one chance to answer the questions. The correct answers will be displayed in the page following the quiz. Studying the questions you got wrong might help improve your performance during the experiment.
3. After the quiz, you will be working with a fictitious currency called Points. Points will convert to cash at the end of the experiment at the rate of 31 points = 1 USD. The next section of the experiment is divided into two parts:
   - First, there will be a set of training trading periods that will allow you to practice without incurring financial risk.
   - Next, there will be a set of effective trading periods. Your performance in these periods will determine your final earnings.
4. You will be asked to answer a post-experimental survey.

**Description of the Experiment**

In this experiment, there will be sellers and buyers. You and every subject in the room are assigned the role of a seller. You will not interact with any other human subject participating in this experiment. You will interact only with the computer assigned to you. Your computer takes on the role of a buyer. You will perform trades. You will retain your role of seller during the entire session. The decisions you make do not affect in any form the results of other participants in the room.

In this market, there are two products: product A and product B. The seller will design packages containing quantities of these products. The seller will also specify the prices of each package. These packages are then offered to one potential buyer. The seller and the buyer can obtain earnings from trades. Trades will occur within trading periods. There will be many trading periods throughout the course of this experimental session.

In general, the seller's earnings increase with price. Also, the seller's earnings diminish with the quantities of the products contained in the package. This is because it is costly to produce quantities of any product. On the other hand, the buyer's earnings increase with the quantities. However, the earnings made by the buyer decrease with the price paid for the package. In short, the buyer benefits from high quantity at low prices, while the seller benefits from high prices at low production cost.

The buyer has a preference for product A and a preference for product B. The buyer can have either a "high" or a "low" preference for each product. How much each product affects the buyer's earnings depends on his type. In general, the buyer benefits from purchasing both products, however, the buyer benefits more from purchasing larger quantities of the product for which he has a "high" preference. There are four possible types of buyers:
Type-III buyer: This buyer has "high" preference for both products A and B.
Type-HL buyer: This buyer has "high" preference for product A and "low" preference for product B.
Type-LH buyer: This buyer has "low" preference for product A and "high" preference for product B.
Type-LL buyer: This buyer has "low" preference for both products A and B.

In a given period, the type of the buyer will be one of the listed above. The seller will never be informed about the type of buyer she or he is trading with. After the seller has designed the menu of packages, the buyer will be presented with the options. The buyer can decide to either buy one package or not to buy any package at all. The package agreed upon will determine the earnings for the trading period.

How is the buyer type assigned?
During each trading period you will encounter one buyer. The buyer will be randomly assigned to be of a certain type. This is true for every single trading period. At the beginning of the period, the buyer will be assigned his type according to the following probabilities:

- Probability of type-III: 10%
- Probability of type-HL: 40%
- Probability of type-LH: 40%
- Probability of type-LL: 10%

Note that the buyer type is not fixed across periods. You will not know for certain the type of buyer you are trading with. You will only know that the buyer is assigned a type according to the probabilities listed above. The computer will behave like a buyer who knows his type.

Specific Trading Instructions. Each period will be divided into the following phases:

1. Pricing/packaging phase. You will be asked to design your menu of packages.
   - Menu choice: You will be asked to decide whether to offer one, two, three or four packages. You can also choose not to offer any package at all.
   - Quantity - Price choice: For each package you decided to offer, you will need to specify: 1) quantity of product A; 2) quantity of product B, and 3) the price you would like to charge for the package. The quantity of product A can be any integer number between 0 and 75. The quantity of product B can be any integer number between 0 and 250. The price of the package can be any integer number between 0 and 500. If you decide not to offer a package for the period, this step will be skipped. This is an image of the interface used to input the quantities and the price for a package.

   - Package 1:
     - Product A: (0 to 75)
     - Product B: (0 to 250)
     - Price: (0 to 500)
• You can set the desired levels of product A, product B and price by either adjusting the corresponding vertical slider, or by typing into the box right below the corresponding slider. To interact with one of the vertical sliders, you only need to click and hold on its handle, then move your mouse up or down to adjust the handle to the desired level. You can also click on any part of the slider to quickly set the handle at the desired level. You can also use the arrow keys on your computer’s keyboard to move the handle one unit at a time. Additionally, below each slider there will be a rectangular box. You can type the desired number of units into the box.

2. Purchase phase: If the seller decided to offer at least one package, the computerized buyer will be presented with the menu of options and will have the following alternatives: either purchase one of the packages or reject them all. The buyer cannot buy more than one package per trading period. The buyer compares packages with respect to the earnings he would obtain from buying them. The buyer will choose the package that yields the highest earnings for him. If the buyer does not buy any package, he earns zero points. The buyer will not buy a package that would result in negative earnings for him. If two or more packages yield the same earnings to the buyer, and they are tied as the most beneficial for the buyer, he will choose the option that appears first in the menu (for example: imagine you offered four options. Suppose that, from the buyer’s point of view, packages one and two are tied, and both generate more earnings than packages three and four; then the buyer chooses package one). If the most beneficial package to the buyer results in exactly zero earnings, he will purchase it. In short, the buyer will purchase the package that maximizes his earnings.

At the end of the period, you will be presented with a screen displaying the following information: the characteristics of the packages you offered; which package was purchased, and your period earnings. It is recommended to document your performance in the earnings-tracking sheets we provided to keep track of your strategies and performance.

How are earnings calculated?
Prior to making an offer, you will have access to an on-screen calculator where you can compute, for a given quantities-price combination, the following: the earnings that the seller would obtain if the package were purchased, the seller’s cost of production, and the earnings that each type of buyer would gain. This calculator appears during the pricing/package phase. So you can try different package designs before submitting an offer. The following is how the calculator would appear on-screen:

- Enter quantities and price information (integers only):
  - Product A  Enter quantity (from 0 to 79):
  - Product B  Enter quantity (from 0 to 299):
  - Price  Enter price (from 0 to 500)

- Compute

Potential outcomes if this package were purchased:
  - Seller’s earnings if purchased:
  - Seller’s cost of production:
  - Type-HH buyer earnings:
  - Type-HL buyer earnings:
  - Type-LH buyer earnings:
  - Type-LL buyer earnings:

In each period, if the seller decides not to offer any package or if the buyer rejects all options in the menu, then both seller and buyer earn zero points. If you are curious as to how payoffs are affected by quantities and price, keep in mind that the buyer benefits from high quantity at low prices while the seller benefits from high prices at low production cost.

For those of you interested in even more details, we explain the equations that define the earnings. Suppose you offered one package containing q_A units of product A and q_B units of product B. Your earnings in points are:
Points earned from one sold package = price \[ - \left( \frac{\text{number of buyers} \times (\text{price per buyer}) \times (\text{distance})}{100} \right) \]

Notice that “cost” is determined by the last term. The buyer earnings depend on his type. Notice that you may lose points from selling a package for which the cost of production is higher than its price.

The buyer’s earnings are determined by the sum of the valuations gained from consuming each product minus the price he pays:

\[
\begin{align*}
\text{Type-III earnings} &= (15 \times \sqrt{\theta}) + (15 \times \sqrt{\psi}) - \text{price} \\
\text{Type-II earnings} &= (15 \times \sqrt{\theta}) + (10 \times \sqrt{\psi}) - \text{price} \\
\text{Type-I earnings} &= (10 \times \sqrt{\theta}) + (15 \times \sqrt{\psi}) - \text{price} \\
\text{Type-LL earnings} &= (10 \times \sqrt{\theta}) + (10 \times \sqrt{\psi}) - \text{price}
\end{align*}
\]

Note from the above that the buyer has a much higher valuation for the good he has a “high” preference for compared to the good he has a “low” preference for (\(15 \times \sqrt{\theta}\) versus \(10 \times \sqrt{\psi}\)).

**How many trading periods will there be?**

The trading part of the experiment will be divided in two parts:

1. **First part:** There will be 6 non-paying periods. We will call these “training” periods. This part provides trading opportunities for you to become familiar with the trading screens and to develop strategies without financial consequences.

2. **Second part:** The second part begins following the training periods. There will be 11 periods in this part. We will call these periods “effective” trading periods. Each effective trading period can potentially influence your final earnings. Four out of the eleven effective trading periods will be randomly chosen. The sum of points that you earned in these four randomly selected trading periods will be converted into cash and paid to you at the end of the experiment.

**How do the paying effective periods get selected?**

Labeled from 1 to 330, the experimenter has a list with all possible combinations of four effective periods. These are listed with no particular order. On the laboratory’s projection screen, you can see a computer interface that randomly chooses numbers between 1 and 330, all equally likely. The experimenter will activate this interface three times. The number that appears the third time will indicate the label of the combination of paying effective trading periods. This label will be displayed on the projection screen during the entire session. On the list, the experimenter will mark the combination associated with the selected label. He will put the list into a yellow envelope, close the envelope, and leave it on the desk below the projection screen. **Only the experimenter is allowed to open the envelope.** The set of paying effective periods will remain secret until the end of the experiment. Only at the end of the experiment, right before you are paid, the experimenter will privately show you the list of all combinations and the selected combination.

Then, the experimenter will proceed to sum the earnings obtained in the randomly selected periods in order to determine your final payoff. If the sum of the four randomly selected effective periods is negative, your trading earnings will be set to zero.
Appendix C: Pre-experimental quiz for the *Cap* treatment

- Question 1: Suppose that you did not make an offer during the trading phase. How many points do you earn for this period?

- Question 2: Suppose that you offer a single package of size 16 at a price of 3920 points. The buyer accepts your offer. How many points did you earn for this period?

- Question 3: Suppose that you offer a menu of two packages. The first package is size 15 at a price of 9000, and the second package is size 9 at a price of 2200 points. The buyer accepts the smaller package. How many points did you make this period?

- Question 4: Suppose that the buyer is a low-valuation buyer and the buyer rejected the seller’s offer. How many points did you make for this period?

- Question 5: Suppose that for this period, the buyer is a high-valuation buyer and decided to accept your offer of a package size of 10 at a price of 2500 points. How many points did the buyer make this period?

- Question 6: Suppose that for this period, the buyer is a low-valuation buyer and you offered a menu of two packages. The first package is size 16 at a price of 6200 points. The second package is size 9 at a price of 2100. Which package yields the highest amount of points to the buyer?
  - choices:
  - The first (larger) package: The first (larger) package
  - The second (smaller) package: The second (smaller) package

- Question 7: Suppose that trading periods are about to start. What is the probability of your buyer being assigned to be a high-valuation buyer for the first period?

- Question 8: The type of the buyer (high-valuation or low-valuation) is randomly assigned every period. Select one.
  - choices:
– True
– False

• Question 9: You will not be informed about the type of buyer (high-valuation or low-valuation) you are trading with. Select one.
  – choices:
  – True
  – False