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Insensitivity to Prices in a Dictator Game*

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Abstract

In this paper we examine the relationship between prices and violations of the Generalized Axiom of Revealed Preference (GARP) in dictator games. Using new experimental data and a new algorithm that adjusts budget prices to eliminate GARP violations, we introduce a new measure of consistency of choices, and we identify a systemic relationship between prices and violations. We find that pushing prices away from extremes tends to eliminate the violations of most subjects, a phenomenon that we call "price insensitivity".

Keywords: Revealed Preference, GARP, Measures of Rationality, Dictator Game.

Codes JEL/JEL Codes: C90, D11, D12.

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1 Introduction

In this paper we introduce a new measure of the consistency of choices with revealed preference axioms. We introduce an algorithm that first identifies the choices that are most frequently involved in violations of the axioms, and then determines a set of prices at which all violations are eliminated. We apply our algorithm to a new experimental data set consisting of choices in dictator games. We calculate a price-adjusted consistency index, a measure that summarizes the degree to which choices are consistent with the axioms. We then estimate a price weighting function, which maps actual prices into adjusted prices. The parameters of the price weighting function reveal heterogeneity in patterns of violations, something that has not been possible before.

Empirical literature testing choice data against axioms of revealed preference requires measures of choice consistency with the Generalized Axiom of Revealed Preference (GARP).[1] Current measures quantify either the cost of eliminating violations (the critical cost efficiency index, by Afriat, 1967 and 1972, and the money pump index, by Echenique et al, 2011), or the number of violations (the HM-index by Houtman and Maks, 1985, and the violation rate by Famulari, 1995), or both the cost and the number of violations (the minimum cost index, by Dean and Martin, 2015).[2] Our complementary approach quantifies the choice alternatives under the budget set that become unavailable after adjusting the prices of inconsistent choices to prices that support consistency.

Most existing measures of choice consistency treat violations as choices with errors made

[1] A large empirical literature has developed testing revealed preference theory in various contexts. They are based on consumption data (e.g., Blundell et al, 2003, Beatty and Crawford, 2011, Dean and Martin, 2015, and Echenique et al., 2013) and data from laboratory experiments (e.g., Battalio et al., 1973, Sippel, 1997, and Fevrier and Visser, 2004). Studies varied subject populations (e.g., Mattei, 2000, Harbaugh et al., 2001, and Burghart et al., 2013) and assumptions on preferences (Cox, 1997). Revealed preference has also been used to experimentally study rationality of behavior where the good is an allocation of a surplus between two people using dictator games (e.g., Andreoni and Miller, 2002, and Fisman et al., 2007). Choi et al. (2007) applied revealed preference tests to study behavior under uncertainty. See Dean and Martin (2015) for a review of these and other studies.

[2] Apesteguia and Ballester (2014) and Dean and Martin (2015) provide detailed reviews of these measures.

in response to actual prices (Varian, 1985; Gross, 1995). It is possible, however, that choices that cause violations are actually consistent choices made in response to prices that are different from those observed in the data. Echenique et al. (2011) propose an index of choice consistency that captures the notion that in scanner data consumers respond to not only prices but also unobserved transaction costs. People may also respond to subjective prices due to a reference price (Thaler, 1985). Reference prices, closely related to anchoring (see Ariely et al., 2003; Sakovics, 2011; and Mazar et al., 2014 and references therein), capture the notion that price perceptions are affected by a variety of factors, from prior experience with prices for the good to completely unrelated information. Other sources of subjective prices include price thresholds (the notion of a range of acceptable prices for a good), and the concept of a "fair price", which could be determined, among other things, by the price history (Monroe, 1973).

We render the choice data rationalizable through an algorithm that finds a set of supporting prices that make choices consistent with GARP.[3] From the set of supporting prices we compute an adjusted price to which the choice appeared to be in response. Since responding to adjusted prices while facing actual prices reduces the set of alternatives available under the budget, we are able to compute a new measure of consistency, which is interpretable as the proportion of consumption alternatives at the intersection of the actual and adjusted budget sets. We call this measure the Price-Adjusted Consistency Index (PACI). Ours is the first attempt to use this evidence to quantify the role of prices in violations of revealed preference.

The adjusted prices provide an additional opportunity beyond the computation of an index, until now unexplored. We compute a price weighting function, which maps actual prices into adjusted prices. We use the parameters of the price weighting function to identify price

[3] Technically, we test for the Weak Generalized Axiom of Revealed Preference (WGARP), which is equivalent to testing for GARP in a two-dimensional good space (Banerjee and Murphy, 2006). Testing for WGARP reduces computational complexity relative to GARP.

adjustment tendencies in our choice data. One parameter of the price weighting function reflects the situation where decisions would appear rational if all prices were lower (higher) than they actually are; we call this price discounting (price inflating). A second parameter reflects the situation where decisions would appear rational if prices were pushed toward the middle of the price range (pushed toward the extremes); we call this price insensitivity (price oversensitivity). These price adjustments appear to have analogues in the theory of probability weighting: price discounting is analogous to pessimism, price inflating is analogous to optimism, price insensitivity is analogous to likelihood insensitivity, and price oversensitivity is analogous to likelihood oversensitivity (Tversky and Wakker, 1995, and Hertwig et al., 2004).

We apply the price-adjustment algorithm to choices in a dictator game. We chose a dictator game because of its two-dimensional choice space and clearly defined "goods": a dictator's allocation and a recipient's allocation.[4] In our experiment, subjects faced 41 different budget constraints, randomly ordered in presentation, designed for high power for the purposes of identifying violations. As with any laboratory experiment, a dictator game is administered in a controlled environment and within a short time span, so it is not affected by various unobserved factors specific to field data, such as scanner data, that require additional assumptions due to unobserved influences on choices.

We find a substantial number of subjects who commit violations of GARP. Using existing methods to quantify the violations, we find that our results are in line with past experimental results, taking into account the power of our experimental design. We compute adjusted prices for the violations and we present two main results. First, we show that the PACI usefully summarizes choice consistency in our data. Second, we find for the first time evidence

[4] Note that our method can be applied to any choice data with two goods (e.g., data from Choi et al, 2007, on choices under uncertainty), subject to the data set containing budget constraints that lend sufficient power to the test (Andreoni, Gillen, and Harbaugh, 2013). Alternatively, choice data with more than two goods can often be usefully reduced to two groups of goods including a good of interest and a composite of the remaining expenditure (Gross and Kaiser, 1996). We know of no reason that our method cannot be extended to multi-dimensional cases, however this is outside the scope of this paper.

that price-adjustments exhibit patterns. While we document the existence of several price adjusting tendencies, price insensitivity is the most prevalent. We show that our procedure uncovers substantially different behavior between subjects with identical scores on current indices. Our paper is the first to provide such evidence.

Applying our procedure to two previous studies, we show evidence for price insensitivity in those studies, one a dictator game and one an individual choice under uncertainty, thus the effect is not an artifact of our experiment or our particular game. We also show that price insensitivity can vary by experimental treatment. Finally, we demonstrate our procedure as a new tool to explore behavior, using it to show that our data are not inconsistent with the notion of reference pricing.

Revealed preference theory is one of the most fundamental concepts in economics. If choices conform to revealed preference theory, then a well-behaved utility function can rationalize them. The importance of revealed preference has led to a rich empirical literature that seeks to devise new methods, to use better data sets, to more precisely characterize the number and severity of violations of the theory, as well as to better apply it (see Andreoni, Gillen, and Harbaugh, 2013, and the references therein). Our algorithm provides a new lens through which to view violations of revealed preference, and our results suggest that price-adjusting is a useful avenue through which to interpret those violations.

2 Violations of demand theory

We briefly review the core axioms of revealed preference, which are based on Afriat (1967), Houthakker (1950), Samuelson (1938), and Varian (1982). For a vector of prices p and consumption choices x, x^t is *directly revealed preferred* to x^s ($x^t R^d x^s$) if x^s is affordable when x^t is chosen (i.e., $p^t x^t \geq p^t x^s$). Choice x^t is *strictly directly revealed preferred* if the inequality is strict. Taking into account transitivity of preferences, x^t is *indirectly revealed* *preferred* to x^s (x^tRx^s) if there is a chain of directly preferred choices between x^t and x^s. The following two definitions summarize the core axioms.

Definition 1. Weak Axiom of Revealed Preference (WARP): If x^t is directly revealed preferred to x^s, then x^s is not directly revealed preferred to x^t.

Definition 2. Strong Axiom of Revealed Preference (SARP): If x^t is revealed preferred to x^s, then x^s is not revealed preferred to x^t.

Definition 3. General Axiom of Revealed Preference (GARP): If x^t is indirectly revealed preferred to x^s, then x^s is not strictly directly revealed preferred to x^t.

GARP is the fundamental test of rationality in choice data: if choices satisfy GARP then they can be rationalized by a utility function (Varian, 1982). In the two-goods consumption space considered in this paper, Rose (1958) showed that WARP implies SARP. Banerjee and Murphy (2006) propose the Weak General Axiom of Revealed Preference (WGARP) and show that with two goods WGARP implies GARP. Therefore, with two goods it is sufficient to test choices for WGARP.[5]

Definition 4. Weak General Axiom of Revealed Preference (WGARP): If x^t is directly revealed preferred to x^s, then x^s is not strictly directly revealed preferred to x^t.

To illustrate, consider a data set consisting of (p^0, x^0), (p^1, x^1), (p^2, x^2), and (p^3, x^3) depicted on Figure 1 and described in Table 1. A pairwise comparison of choices identifies two pairs of violations in this data set: x^0 with x^1 and x^0 with x^2. Both pairs violate WARP, which implies a violation of WGARP. Choice x^3 is not involved in a WARP or WGARP violation with the rest of the choices, but because of violations among the rest of the choices, x^3 is involved in GARP violations (e.g., $x^3R^dx^0R^dx^2R^dx^1R^dx^3$).

[5] Unlike testing for WGARP, which requires pairwise comparisons of choices, testing for GARP requires testing chains of choices. Therefore, testing for WGARP substantially reduces computational burden and eliminates a range of other difficulties. We thank an anonymous referee for bringing this to our attention.

	p_{x_1}	p_{x_2}	x_1	x_2
x^0	4	2	0.5	5
x^1	5	1	1.8	1
x^2	6	1	1.5	1
x^3	9	1.1	0.3	7.6

Table 1: Prices and choices: example.

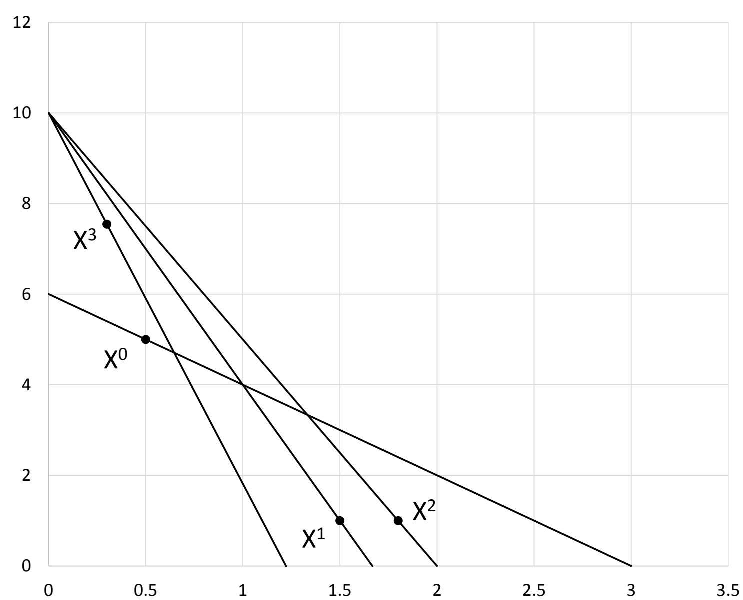


Figure 1: Violations of revealed preference

2.1 Price adjustment algorithm

We introduce our price adjustment algorithm (PAA) that eliminates violations in choice data by adjusting prices until all choices are consistent. The PAA has two steps: 1) identify prices that need adjustment, and 2) adjust prices identified in step 1. We provide the details of both steps below.

2.1.1 Step 1: Identification of prices for adjustment

To identify prices to be adjusted, we determine which choices are most frequently involved in violations. To do so, we use the notion of a consistent subset (CS) and a violator subset (VS) initially proposed by Gross (1995). The CS consists of all choices that are consistent with revealed preference axioms, and the VS is a complement subset.[6] Selecting the maximal sized CS is conservative in the sense that it assumes maximal consistency from the data evidence.

We use the algorithm of Gross and Kaiser (1996), which is a graph-theoretic approach that partitions the data into CS and VS in a two-dimensional consumption space. Each choice is treated as a node of a graph, each violation is an edge of a graph, and choices in a violation share edges (i.e., they are adjacent). The degree of a node is the number of adjacent nodes, that is, the number of violations associated with the choice. Nodes with the highest degrees are considered serious violators and are iteratively eliminated from the set with special attention given to nodes with the same degree adjacent to each other. The partitioning algorithm proceeds until there are no adjacent nodes. The remaining nodes form the CS, and the eliminated nodes form the VS. Gross and Kaiser (1996) report that finding a consistent subset of maximal size is NP-complete. In the two-goods space, where only direct revealed preference relations are assessed, the computational time is proportional to n^2. We

[6] The idea is based on the HM-index (Houtman and Max, 1995) that determines the maximal subset of the data consistent with the axioms.

take the approach of their approximate algorithm, which in some rare circumstances makes an extra removal compared to the exact algorithm, but requires less computational time for large data sets.[7]

2.1.2 Step 2: Adjustment of prices

To adjust the prices identified in step 1, we determine prices at which all choices in the VS are consistent. To do so, we use the notion of supporting prices proposed by Varian (1982), a set of prices at which a choice can be demanded such that it is consistent with the rest of the data. To determine supporting prices for a choice in the VS set, we solve a system of inequalities constructed using choices in the CS that have been revealed preferred to the choice in question (hereafter referred to as the RP set). The intuition behind the system of inequalities is that the choice demanded at prices that solve the system is never revealed preferred to choices in the RP set, guaranteeing consistency of this choice with the rest of the data. Varian (1982) shows that by Afriat's theorem supporting prices always exist for any choice. We perform this procedure for every choice in the VS.[8]

2.1.3 Illustration of the PAA

To illustrate both steps of the PAA, consider again the four choices presented in Figure 1. The first step of the PAA partitions choices into the CS and the VS. Three out of four choices are involved in violations of WGARP. Choice x^0 is involved in two violations, one with x^1 and one with x^2. Choices x^1 and x^2 are involved in one violation each, both times with x^0.

[7] Gross and Kaiser (1996) note that in some cases the CS and the VS are not unique. The authors suggest that sensitivity of results can be assessed by performing the algorithm repeatedly. We applied the algorithm repeatedly to our data and found negligible differences between runs.

[8] When the data contain a large VS, it is possible for choices in the VS to become inconsistent with each other at their new supporting prices, even though they are consistent with the CS. We recommend applying the algorithm by forming a new VS with the offending choices at the adjusted prices and repeating step 2. This procedure is guaranteed to eventually terminate due to the fact that in the worst case it will find supporting prices for one item in the VS at a time until none are left. The need for this procedure was rare in our data.

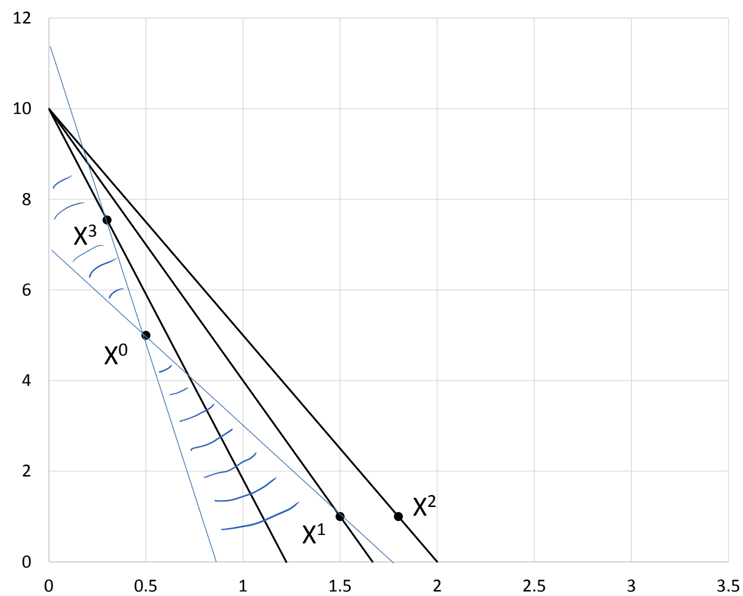


Figure 2: Price-adjustment to eliminate violations

That is, if we remove choice x^0, all violations will be eliminated. Thus in this example, the CS consists of x^1, x^2, and x^3, and the VS consists of x^0.

The second step of the PAA determines supporting prices of the choices in the VS. The intuition is the following. If we were to observe only choices x^1, x^2, and x^3, we would conclude that the data are consistent with the axioms. Suppose now that in addition we were given choice x^0, which was previously unobservable. Suppose further that we were not given the price at the new choice. The set of supporting prices answers the question at what prices would a consistent consumer make choice x^0?

The RP set of x^0, $RP(x^0)$, consists of x^1, x^2, and x^3. That is, choice x^0 is affordable when both x^1, x^2, and x^3 are chosen, and we can write $x^1 R^d x^0$, $x^2 R^d x^0$, and $x^3 R^d x^0$. Therefore, supporting prices of x^0 should make x^1, x^2, and x^3 unaffordable when x^0 is chosen. Figure 2 illustrates these prices graphically: they should be no flatter than a line going through choices x^0 and x^1 and no steeper than a line going through choices x^0 and x^3.[9] Therefore, the shaded area in Figure 2 represents the set of supporting prices of choice x^0.

More formally, supporting prices of choice x^0 are solutions to the following system of linear inequalities

$$\begin{aligned} p^0x^0 &\leq p^0x^1 \\ p^0x^0 &\leq p^0x^2 \\ p^0x^0 &\leq p^0x^3. \end{aligned}$$

In the two-good example in Figure 2, the solution is easy to obtain: the set of supporting prices for choice x^0 consists of budgets with relative prices ranging from 4 to 12.7.[10] From this interval of prices, we have to choose a price as the adjusted price.

The data provide no evidence with regard to which price in the interval shown in Figure 2 is the most likely adjusted price, thus we treat every price in the interval as equally likely. One way to view this problem is to consider two fundamental alternatives: the price at the midpoint of the price interval between 4 and 12.7, or a price on either end of the price interval. The price at the midpoint of the interval is attractive for at least two reasons. First, it is analogous (but not identical to) a mean price or a point estimator. Second, we can characterize the decision to move in either direction, higher or lower, from the midpoint as simply biasing the adjusted prices higher or lower. Since there is no theoretical or data evidence to bias our inference one way or the other from the midpoint, and since we can easily characterize the consequences of doing so, we selected the midpoint relative price as the adjusted price.

Selecting this price is also convenient computationally because it is straightforward to identify by dividing the interval into two equal parts by making use of the fact that in a

[9] Since we assumed that x^0 is observed without prices, the corresponding budget is not displayed.

[10] Note that Varian (1982) normalizes income to equal 1 (i.e., $px = 1$). In what follows, we normalize $p_2 = 1$ instead, and perform all analyses in terms of relative prices.

two-goods consumption space, budget sets are right-angled triangles. This allows us to use simple trigonometric rules to determine a slope of a ray that divides the angle formed the supporting price interval into two equal parts. In the example depicted in Figure 2, the midpoint relative adjusted price is 6.13. In what follows, we describe our results using the midpoint relative adjusted price.

2.2 Price-adjusted consistency index

We next introduce our index of choice consistency, which we call the Price-Adjusted Consistency Index (PACI). The main idea behind the PACI is to quantify the degree of similarity between the adjusted budget constraint and the actual budget constraint. There is a geometry that is involved with our measure that does not exist with the cost measures due to the fact that our adjusted budget constraints rotate, rather than simply move in toward the origin. The good news is that once we account for that, our index has an intuitive interpretation that can be applied to the cost indices as well.

The degree of similarity between actual and adjusted budget constraints depends on how steeper or flatter the adjusted budget constraint is compared to the actual budget constraint. We measure this similarity using the area of the actual budget set that remains available under the adjusted prices, that is, using the area that is common to both budget constraints.[11] A consistent choice does not require a price adjustment, and therefore the entire actual budget set remains available. To aggregate over all choices of a subject, we divide the total area of the available budget sets by the total area of the actual budget sets:

$$PACI = \frac{\sum_i Area\ of\ available\ budget\ set_i}{\sum_i Area\ of\ actual\ budget\ set_i} \tag{1}$$

For a subject with no violations, and hence no price adjustments, the area of each actual budget set remains available, which results in the maximum value of PACI equal to 1. For a

[11] Heufer (2008) proposes a geometric measure of choice consistency, which uses the area of the budget set revealed preferred by the inconsistent choice. Our measure of consistency relies on the area of the actual budget set that is preserved by the price adjustment.

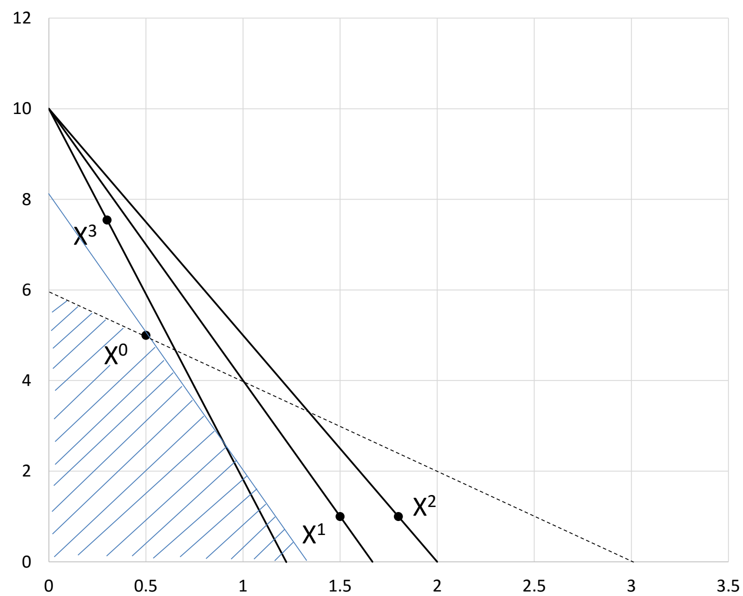


Figure 3: Available budget set under the actual and adjusted prices of x^0

subject with violations at extreme allocations, and hence either vertical or horizontal budget lines, the area of the available budget can reach 0, which results in the minimum value of PACI equal to 0.

To illustrate, Figure 3 depicts the same three consistent choices and their budgets and choice x^0 with its actual relative price (dashed line) and its adjusted relative price (thin gray line). The shaded area is the available budget set under the two budgets formed by the actual and the adjusted relative prices. The size of the shaded area is equal to 4.8. The area under the actual budget set for choice x^0 equals 9. For choices x^1, x^2, and x^3 the areas of the available budget sets also equals their actual budget sets (10, 8.3, and 6.1, respectively). Hence, we can compute PACI as follows:

$$PACI = \frac{10 + 8.3 + 4.8 + 6.1}{10 + 8.3 + 9 + 6.1} = 0.87$$

Our new measure both has an intuitive interpretation and is comparable to existing cost measures. The PACI measures the proportion of the aggregate budget that remains available to the decision maker after accounting for violations. Referring back to Figure 3, our measure interprets the choice at x_0 as having the consequence of reducing the alternatives available to the decision maker from the total area under the dashed line to the shaded area. The shaded area is a subset of the set of alternatives available at the actual price and income. The index thus reflects the fact that, although the decision appears as if made at an adjusted price, the actual price is applied to the choice set. Violations restrict alternatives. Our measure quantifies this restriction.

Notice that all of the cost measures can be viewed with the same interpretation: shifting the budget curve in towards the origin also restricts the set of alternatives. In fact, it is easy to show that squaring a cost measure results in the same units as our measure. In practice, this is unnecessary to the extent that one is typically interested in the distribution of the measure around some cut-off to determine the degree of rationality or consistency in the data. Monotonically transforming the measure would move the cut-off with the index calculations and thus fail to alter conclusions drawn from the data.

2.2.1 Comparison with other consistency measures

In this section we compare our measure, PACI, with the CCEI (Critical Cost Efficiency Index), MPI (Money Pump Index), and MCI (Minimum Cost Index), where the severity of violations is based on their cost. The CCEI, first proposed by Afriat (1972), is based on the fraction of the budget that needs to be removed to eliminate the most severe violation in the data set. Graphically, this is equivalent to shifting budgets in toward the origin. The larger the CCEI (the smaller the budget wasting), the closer the choices to consistency with the axioms.

The MPI, proposed by Echenique et al. (2011), is based on the mean or median total cost of breaking all violation cycles in the data. The index quantifies the amount of money that can be extracted from a consumer who makes inconsistent choices. The smaller the MPI, the closer the choices to consistency with the axioms. The MCI, proposed by Dean and Martin (2015), is based on the minimum cost of breaking all cycles of violations in the data. The index quantifies the cost of the cheapest violation cycle for each choice. The smaller the MCI, the closer the choices to consistency with the axioms. Our PACI is based on the area of the budget set preserved by price adjustments. The index quantifies consumption possibilities that were not eliminated by adjusting prices. The higher the PACI, the closer the choices to consistency with the axioms.

The three already existing indices measure the severity of the violation using its cost. Echenique et al. (2011) show that the CCEI may sometimes be unaffected by violations caused by choices further away from the budget crossing because the CCEI picks up the smaller budget wasting in a pair of choices. To the contrary, both the MPI and the MCI would be affected if choices involved in violations move further away from the budget crossing because that would result in higher costs of violations. The PACI is also sensitive to such choices as it deems them less consistent and results in a lower value of the index. To illustrate, consider again choices in Figure 1 and imagine choice x^0 located at a point further away from the crossing of the budgets, say, (0.25, 5.5). The set of the adjusted prices for this choice would be wider, the midpoint price would be steeper, and the preserved area of the budget would be smaller. That is, if x^0 at (0.25, 5.5) is a more severe violation, the PACI would be smaller.

Out of the three indices, only the MCI takes into account both the number of violations and consistent choices. Our PACI is most similar to the MCI in the sense that it also takes into account both the severity and the number of violations, as well as choices that were not resulting in violations. In a sense, both the PACI and the MCI reward subjects for consistent decisions because they aggregate over all choices. To illustrate, consider again choices x^0, x^1, x^2, and x^3 in Figure 1. Choice x^3 is involved only in GARP violations because of WARP violations among other choices in the data. The CCEI is only concerned with choices x^0, x^1, and x^2, and is affected by the worst budget wasting out of the violations formed by these choices. Therefore, the CCEI will remain the same regardless of whether x^3 is or is not in the data set. The MPI sums costs over all cycles formed by violations in which a choice is involved. Therefore, if choice x^3 is in the data, the cost of its involvement in GARP violations will be included into the MPI. That is, with choice x^3 in the data the MPI would be higher than without it.

Both the MCI and the PACI account for all choices. Therefore, if we remove choice x^3 from the data set, both the PACI and the MCI would change. The MCI would be higher because its denominator would be lower without the cost of choice x^3 (since the MCI measures the cost of violations relative to the total expenditure, a higher value of the MCI suggests higher severity of violations). The PACI would be lower because both its nominator and denominator would be lower by the same amount. In addition, without choice x^3 the interval of supporting prices for choice x^0 would be wider, and hence the available portion of the budget set for x^0 would be smaller, which would reduce the nominator even more. Therefore, without choice x^3 in the data, both the MCI and the PACI would deem the decision maker as less consistent.

Finally, in terms of computational complexity the PACI is similar to the MCI and the MPI because it is NP-complete. To summarize, we reproduce a table of index comparisons from Dean and Martin (2015) for the three indices we considered in this section and extend it to include our PACI (see Table 2).

Measure	Violation severity	Violation aggregation	Complexity
Minimum Cost Index	Minimum cost	Sum	NP
Critical Cost Efficiency Index	Minimum cost	Maximum	P
Money Pump Index	Total cost	Median or mean	NP
Price-Adjusted Consistency Index	Preserved budget subset	Sum	NP

Table 2: Comparison of measures.

2.3 Price weighting function

The PAA produces rich information that can be used beyond computing a measure of choice consistency. In particular, it determines which prices had to be adjusted and by how much in order to rationalize the data. It is possible to exploit this information to explore heterogeneity in adjusted prices. In what follows, we use the set of adjusted prices to describe this heterogeneity in our data. We estimate a price weighting function that maps a logarithm of the actual relative price into a logarithm of the adjusted price:

$$\log(AP_i) = \alpha + \beta \log(P_i) + \varepsilon_i, \tag{2}$$

where AP_i is the adjusted price of choice i and P_i is the actual price of choice i.[12]

We chose this functional form because the slope and the intercept of the regression are informative about the type of relationship between adjusted prices and actual prices. The intercept coefficient, α, captures the shift in the adjustment along the y-axis. It indicates whether the price adjustment occurs similarly for prices below 1 and prices above 1 ($\alpha = 0$) or whether the price adjustment is predominantly upward or downward ($\alpha \neq 0$). The slope coefficient, β, captures the rotation of the regression line. It indicates whether prices are adjusted in the same direction for all prices and hence the regression line never crosses the 45-degree line ($\beta = 1$), or whether prices are adjusted in different directions for low versus high prices and hence the regression line crosses the 45-degree line ($\beta \neq 1$).

The estimated coefficients α and β thus summarize patterns of price-adjusting of each individual in the following manner. First, note that if $\alpha = 0$ and $\beta = 1$, the regression line coincides with the 45-degree line. Next, $\alpha > 0$ represents a shift of the regression line everywhere upward, that is, an upward shift of all prices, a pattern we call price inflating. A coefficient value of $\alpha < 0$ identifies an everywhere downward shift we call price discounting. Finally, $\beta < 1$ signifies a rotation of the function such that low prices are inflated and high

[12] The log transformation results in a symmetric distribution of prices around the relative price of 1. The relative price of 1 has a special meaning that prices of both goods are equal.

prices are discounted; we call this price insensitivity. A coefficient value of $\beta > 1$ marks the opposite rotation, that is, low prices discounted and high prices inflated; we call this price oversensitivity.

3 Experimental design and procedures

We presented subjects in a dictator game with 41 budget constraints of the form $px_d + x_r = m$, where x_d is the amount of money allocated to the dictator, x_r is the amount allocated to the recipient, p is the relative price of keeping money by the dictator (i.e., the recipient's price is normalized to 1), and m is the normalized income. For each budget constraint, the level of income was such that the maximum amount allocated either to a dictator or a recipient was an even amount between \$2 and \$20. The price for each budget constraint varied from relatively expensive to relatively inexpensive for the dictator to keep the money (i.e., the relative price p was below or above 1).

Figure 4 presents the budget constraints. The legend in the top right corner of the figure indicates the income (m) and the dictator price (p) for each of the 41 budget constraints. In the figure, the dictator's own allocation of money is presented on the x-axis, and the recipient's allocation is located on the y-axis. The budget constraints cross frequently, which guarantees a high power of the test to reveal violations.[13]

All subjects made decisions as if they were dictators. Subjects were informed that only one subject in a randomly-matched pair would be randomly chosen to actually be the dictator. The subject who was not chosen as the dictator was effectively the recipient in the resulting dictator game. Thus, subjects played the dictator game using the strategy method, where they reported what they would do in every case if they were to be chosen as the dictator. This method eliminates allocations that are chosen to distribute payments across both

[13] The Bronars's measure of the power of the test for these budgets is equal to 1 (Bronars, 1987). Other measures for the power of revealed preference tests can be found in Andreoni et al. (2013).

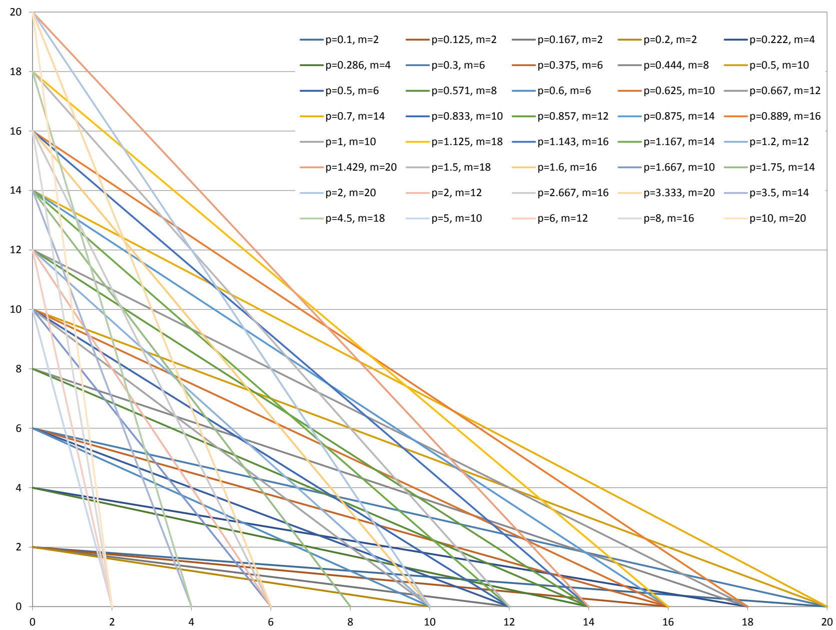


Figure 4: Experimental budgets in the dictator game

roles.

Subjects entered their decisions into a computer interface, which displayed the price and the income of the current budget constraint. The screen contained a calculator, which computed and displayed amounts that both the dictator and the recipient would earn for each choice. Subjects made their final decisions in a different box on the screen and clicked on an OK button to confirm the choice. The experiment was programmed and conducted with the software z-Tree (Fischbacher, 2007).

Eighty subjects participated in 4 sessions conducted at a university-based experimental economics laboratory. There was an equal number of men and women, and all subjects were between 25 and 34 years of age. The subjects were paid for two randomly chosen decisions in the 2-hour session and a brief survey, and earned on average \$22 plus a show-up fee of \$10. On average, dictators allocated \$9 to recipients, or 22% of their income, which is comparable to the numbers reported in other studies (e.g., Andreoni and Miller, 2002).

4 Experimental Results

4.1 Consistency of choices

Out of 80 subjects in the experiment, 65 subjects (81%) had at least one violation of WGARP. In total, these 65 subjects committed 878 WGARP violations, or 13.5 violations per subject. The vast majority of subjects who violated WGARP (41 subjects) did so 10 times or less, and the largest number of violations was 44 for one subject.[14]

4.1.1 CCEI efficiency of choices

Figure 5 presents the severity of the revealed preference violations in the choice data measured with the Afriat's CCEI. In the figure, the black bars represent the distribution of the index for experimental subjects, and the white bars represent the index for 10,000 simulated subjects. Simulated choices were based on budget shares drawn randomly from the uniform distribution for the same 41 budgets that were presented to the experimental subjects.

The figure shows that the distribution of the CCEI for the simulated subjects is substantially different from that of the experimental subjects. The cost efficiency of choices for the experimental subjects is overall higher than that of simulated subjects. The range of the CCEI in the experimental data is wide: from 0.17 to 1 (i.e., some subjects "waste" over 80% of their budget), with the mean CCEI among experimental subjects with violations is 0.84, which is comparable to other studies with a large number of choices (e.g., Fisman et al, 2007, and Choi et al, 2007). Using the value of the CCEI equal to 0.8 as a threshold,

[14] Note that in this experiment the number of violations per subject is larger than in other studies only in absolute terms. Relative to the maximum number of violations that can be committed with 41 budget constraints (i.e., 820), the proportion of violations per person is comparable to other studies.

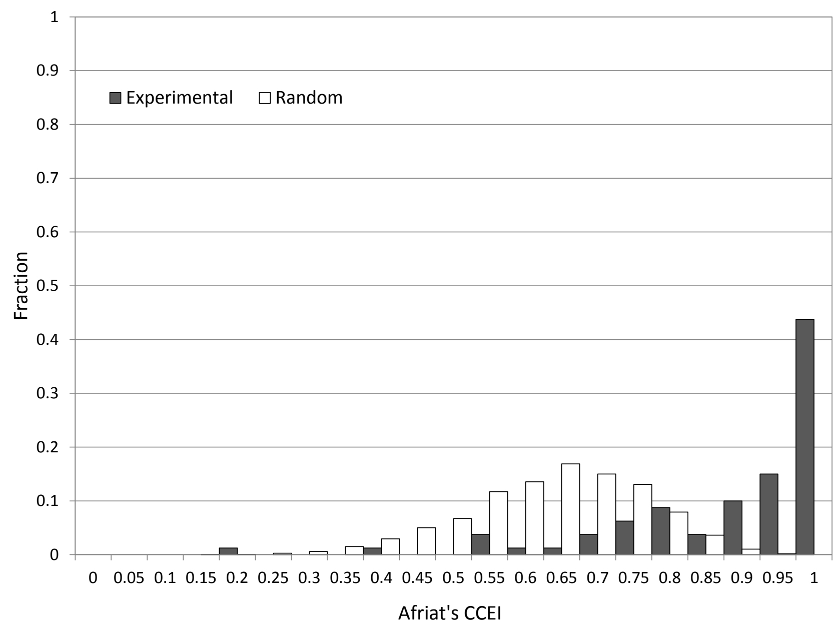


Figure 5: Distribution of the CCEI for experimental and simulated subjects

81.5% of all our subjects demonstrate rational or almost rational choices.[15]

Note that the efficiency of choices in our data is comparable to that reported in Fisman et al. (2007). Although it is true that in our data fewer subjects pass the threshold of 95% (67% in their data vs. 56% in our data), the numbers are comparable at the threshold of 80% (85.5% in their data and 81.5% in ours). And the threshold of 80% is exactly what Fisman et al. (2007) used to judge the severity of violations in their data. Moreover, the most severe cases in our data are similar to theirs: the lowest CCEI is around 20% and it characterizes around 1% of subjects in both data sets.

[15] We used the notion of power loss measure (Heufer, 2011) to identify the threshold of the CCEI for the power loss of 5%. This useful benchmark is based on simulated random shares drawn from the uniform distribution along the experimental budget constraints. The method computes the power loss associated with accepting observations violating the axioms as close enough to rational. The procedure is general to be applied to compare different indices.

4.1.2 PACI consistency of choices and price adjustment

We applied the PAA to our data as described in Section 2.1 and report our results in this section.[16] The first step of the PAA identifies prices that need adjustment and, as a result, produces the CS, the VS, and the HM-index. The values for the HM index among the 65 subjects with WGARP violations range from 0.71 to 0.98. The average value of the HM index is equal to 0.88, which implies the average size of the CS equal to 36 and the average size of the VS equal to 5.

Results show that choice consistency as measured by the PACI at first glance appears different than with the CCEI. The values of the PACI among the 65 subjects with violations ranges from 0.74 to 0.99, with the mean value of 0.96. Figure 6 presents the distribution of individual values of the PACI calculated using the adjusted prices. The values of the PACI for the experimental subjects are plotted together with the values of the PACI for the simulated subjects. The range of the simulated PACI is wider than that for our experimental subjects (0.64 - 0.97) with the average value of 0.84. As with the CCEI we use the threshold for the power loss of 5%, which is equal to 0.91 in our data, to make the comparison. The threshold of 0.91 is passed by the total of 53 out of 65 subjects who had violations, in addition to the 15 subjects who did not have violations (i.e., 85% of all subjects). Note that although the magnitude of the PACI is higher than that of the CCEI, this does not mean that the PACI deems our subjects more rational than the CCEI as the two indices are not directly comparable (recall that the CCEI has to be squared to be comparable with the PACI). With regard to the two measures, 81.5% of the subjects passed the rationality threshold for CCEI and 85% passed for PACI, a seemingly insignificant difference. However, the variance of the distribution of the two indices are different, with the variance of the PACI being smaller due

[16] We implemented the PAA in MATLAB. The total time for the entire procedure, including the Gross-Kaiser partitioning and supporting price adjustment, was under 0.2s for the total of 80 subjects with 41 choices per subject. Our codes are available upon request. Heufer and Hjertstrand (2015) provide an alternative implementation of the Gross-Kaiser partitioning.

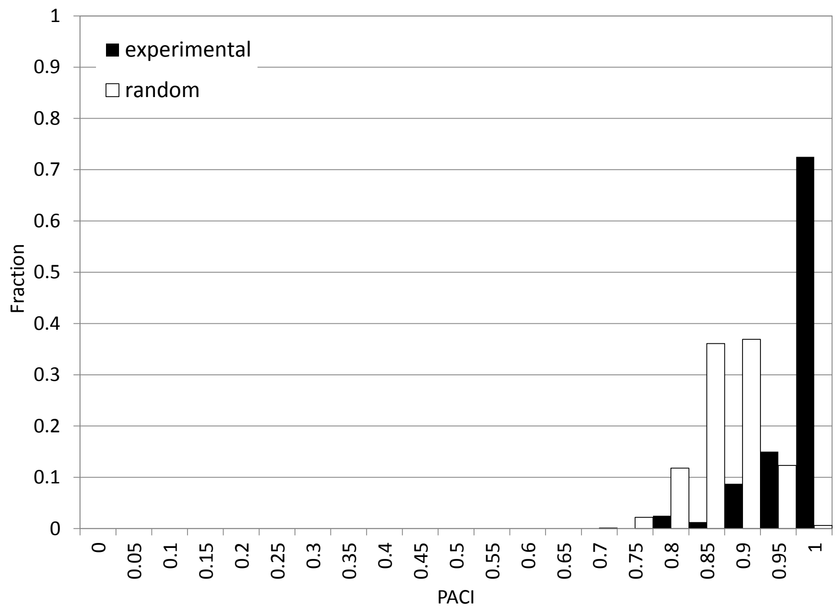


Figure 6: Distribution of PACI for experimental and simulated subjects

to its aggregation over all choices.

We next discuss the adjusted prices in relation to the actual prices for the 65 subjects with violations. Figure 7 presents a scatter plot of the adjusted prices against the actual prices (in logarithms).[17] The graph suggests that, overall, prices are adjusted over the entire price interval, and there is both price-inflating and price-discounting in the aggregate data. This finding is confirmed by the parameters of the price weighting function fitted to the aggregate data for all 65 subjects. We obtained the estimate of α equal to 0.02, different from 0 at 0.08, and the estimate of β equal to 0.88, different from 1 at less than 0.0001. These results suggest that the aggregate data exhibit price insensitivity that occurs to a similar extent for actual prices below and above 1 (i.e., the adjusted prices appear "pushed" toward to relative price of 1).

[17] Note that the overall pattern of the scatter plot is partially affected by the experimental design (i.e., budget constraints and their crossing points) and partially by choices of subjects with violations.

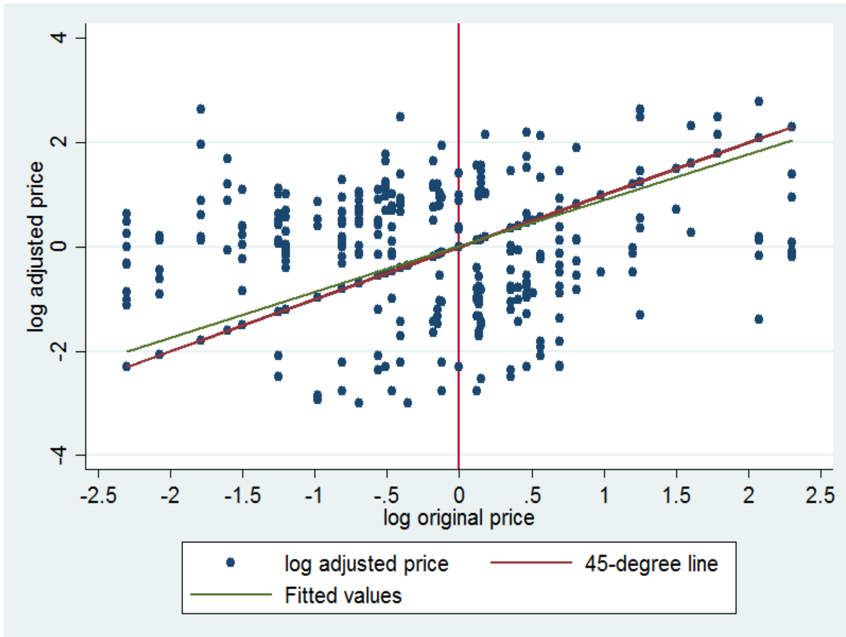


Figure 7: Adjusted versus original relative prices

4.1.3 Individual price adjustment

Turning to individual heterogeneity, we report estimates of the parameters of the price weighting functions for each of the 65 subjects with WGARP violations. We used all 41 observations per subject, including prices that did not have to be adjusted. The values of coefficients estimates are useful to describe the tendencies of individual price adjustments. Due to the log transformation of prices, positive log prices correspond to relative price above 1, which are less favorable to the dictator, and negative log prices correspond to relative prices below 1, which are more favorable to the dictator.

Individual regressions confirm the richness of the heterogeneity implied by the histogram of individual parameter estimates for α and β presented in Figure 8. The first observation is that the majority of subjects have a value of β less than 1, implying price-insensitive behavior. That is, to resolve their violations of WGARP we must raise the dictator price when it is low and to lower the dictator price when it is high. For about half of price-insensitive subjects, α is positive implying that there is more price adjustment occurring for low dictator prices than for high dictator prices. Note that inflating low prices makes them less desirable for the dictator than they really are, whereas discounting high prices increases their favorability to the dictator. For the other half of price-insensitive subjects, α is negative implying that there is more price adjustment occurring for high dictator prices than for low dictator prices.

Note that $\alpha \neq 0$ may also indicate that the relative price of 1 had to be adjusted upward or downward. In the context of the dictator game this observation may be of special interest since the classical dictator game implies the dictator price of 1. This may suggest that without observing dictators' choices at other prices, and hence being unable to assess their rationality, one may mistakenly attribute choices to selfishness or altruism, whereas the subject may have acted as if the relative price was higher or lower than it really was.

Figure 9 shows adjusted prices and the fitted price weighting function for four different subjects. Subjects 117, 135, and 159 have values of β less than 1 and hence exhibit price insensitivity. Subject 117 inflates low and moderate dictator prices more than s/he discounts high dictator prices (i.e., $\alpha = 0.34$). Subject 135 also demonstrates price insensitivity but does so by mostly discounting moderate and high prices (i.e., $\alpha = -0.33$). Subject 159 has the highest value of β of these three subjects, 0.83, which suggests the lowest degree of price insensitivity because all price adjustments occur for moderate prices. For this subject, prices are adjusted proportionately but in different directions for prices above 1 and below 1 ($\alpha = 0.01$). Finally, Subject 90 exhibits no pattern in price adjustment that could be picked up by α and β. Neither parameter for this subject is statistically significantly different from 0 and 1, respectively, and the graph shows adjusted prices scattered on both sides of the 45-degree line.

Note that in addition to the overall heterogeneity in behavior, the parameters of the

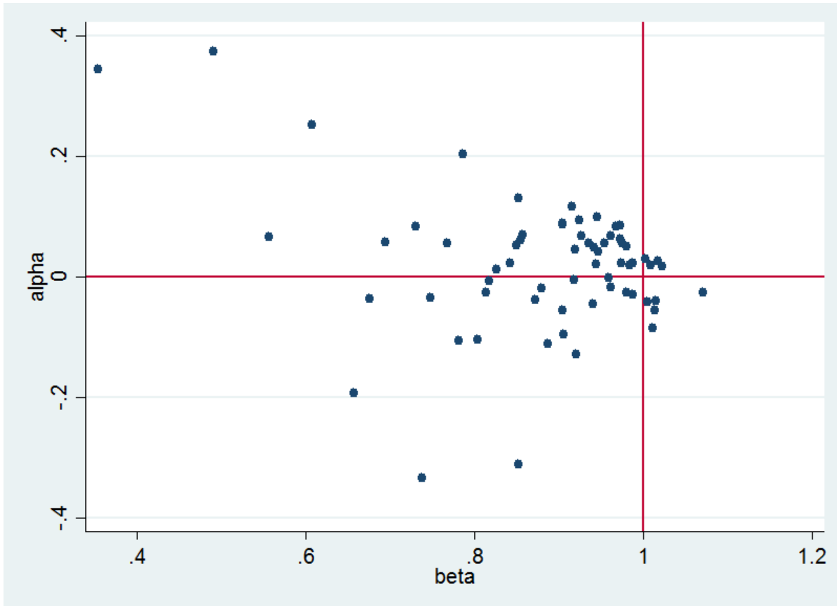


Figure 8: Distribution of parameter estimates

price weighting function allow interesting comparisons of subjects with the same degree of rationality as measured by traditional indices. For example, notice that subjects 117 and 135 have identical values of the HM-index equal to 0.71, which is the lowest value in the data set. The standard approach would not have distinguished between these two subjects and would have discarded their data as being far from rational (note their low values of the CCEI as well: 0.58 and 0.38, respectively). Our price weighting function allows distinguishing between different types of patterns in violations of these two subjects. Subject 117 inflates low dictator prices and Subject 135 discounts high dictator prices. That is, the price weighting function crosses the 45-degree line to the right of the price of 1 for Subject 117, but does so to its left for Subject 135. These are distinctly different types of price weighting that may suggest different subjective behaviors toward dictator prices.

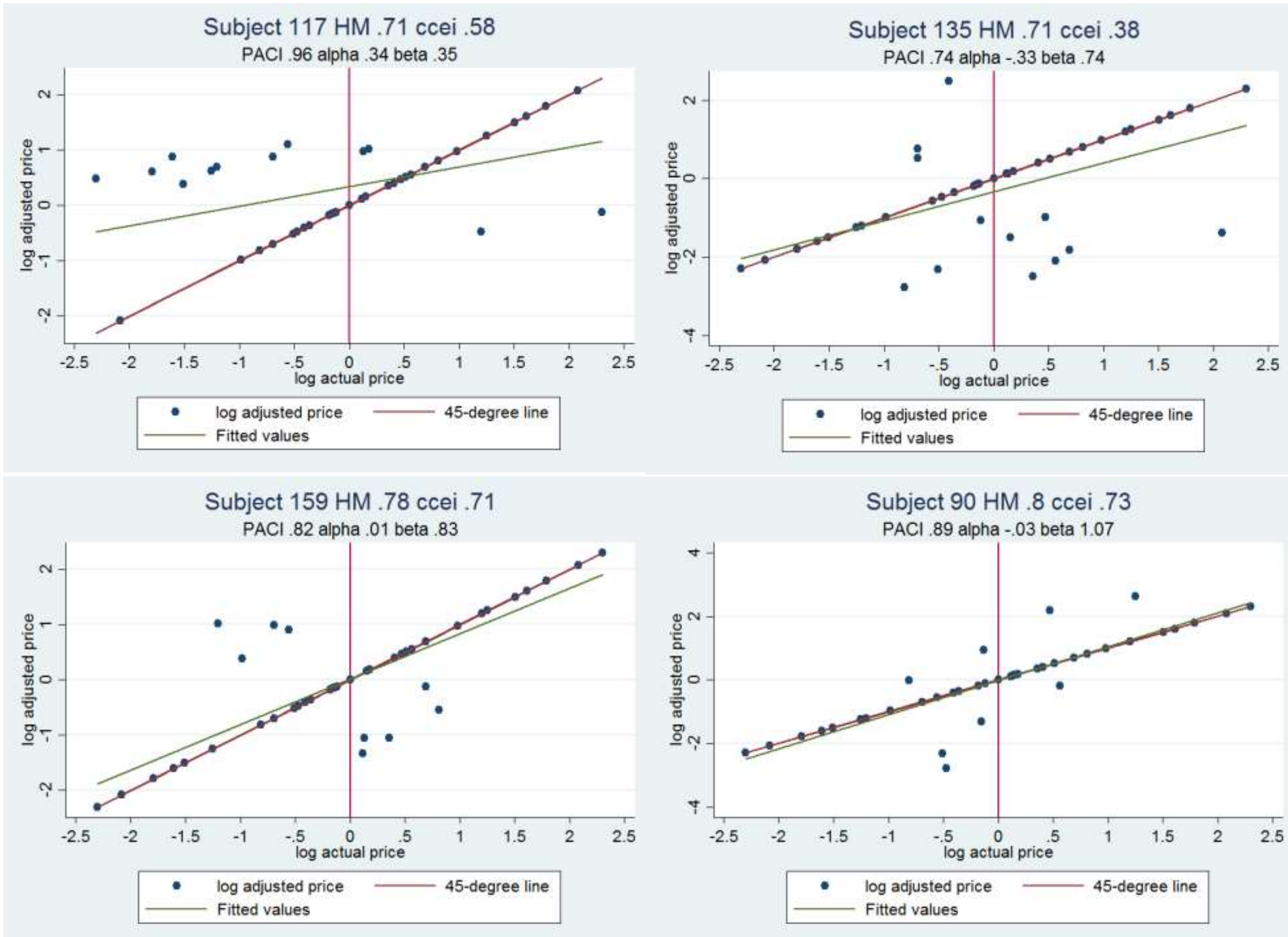


Figure 9: Examples of individual types of price weighting

5 Discussion

Do people actually respond to weighted prices? Our experiment provides evidence that they do; however, more work needs to be done to understand the mechanism behind price adjustments. In this section we provide further evidence with a more detailed look at one of our results, an analysis on two previous experimental studies, as well as a preliminary investigation into the details of price adjustment in our data. Our analysis shows that price weighting is not an artifact of our data, and that our procedure contains the promise of unlocking new inference even on our own data.

First, to demonstrate the intuition behind the price weighting function, we revisit the price weighting function of Subject 117 in Figure 9 analyzed in the previous section because it illustrates well the intuition behind the adjusted prices. The subject's choices resulted in a strong case of price insensitivity ($\beta = 0.35$) as well as price inflating ($\alpha = 0.34$). There is strong inflation of low relative dictator prices and somewhat less discounting of high dictator prices in this weighting function.

Notice in the scatter plot all of the adjusted prices lying above the fitted line, all but two of which are to the left of the log zero actual price line (i.e., all but two of which are favorable prices to the dictator). All of these choices represent allocations that are so generous to the recipient that they cannot be explained by her preferences, no matter what they are, revealed by the choices in the consistent set. Notice also the two data points below the fitted line at high prices. These represent allocations so stingy that they cannot be explained by any preferences. Our procedure makes these choices rationalizable by inflating the low prices and discounting the high prices. The price weighting function shows the resulting relationship between the adjusted and actual prices. It is important to note that the evidence we use to compute this relationship comes from choices that do not correspond to any preference with respect to the consistent set.

We call this relationship price insensitivity. It is important to ask what else it could be.

We doubt that transaction costs are at work here because our data comes from a laboratory experiment. We also doubt that choice errors are at play here since adjusted prices occurred mostly for choices at budgets with low prices, and our experimental design made sure that violations at low price budgets are as easily detected as violations at high price budgets. Moreover, if the errors were due to the experimental design, we would have observed the same price weighting for all subjects with violations, which is not the case (e.g., Subject 135 and 159 from Figure 9). Finally, we exclude that these violations were due to learning because the budgets at which they occurred were presented at different points throughout the experiment.

One candidate explanation could be different preferences over low and high prices, that is, a type of unstable preference. We doubt this is the most likely explanation due to the large number of data points on the 45-degree line at low prices. Another candidate explanation could be a reference point, which moves prices up to the left of the log price of about 0.5 (the fixed point on the graph) and down at prices to the right of 0.5. We are unaware of any alternative explanations.

Whatever explanation turns out to be the most likely, pure price weighting, unstable preferences, or reference prices, our new lens through which to view these data opens the question. Answering the question requires further research. Our experimental design cannot directly observe price weighting. It indirectly observes GARP violations, then we exploit the relationship between prices and violations to better understand the data. We doubt that price weighting is a phenomenon to which subjects have cognitive access. We believe that more focused experimental designs that first cleanly elicit preferences and then, given the preferences, elicit the weighting function are called for.

Second, to see the complementarity between our measure and existing measures of choice consistency, we applied our procedure to data from two papers: Choi et al. (2007) on choices under risk and Fisman et al. (2007) on choices in a dictator game. Briefly, Choi et al. (2007)

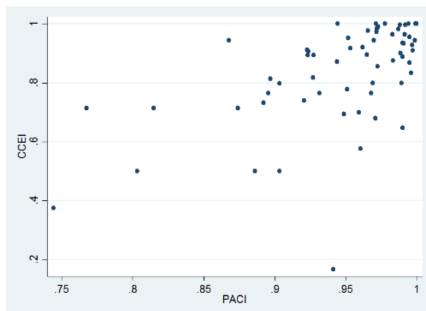
tasked subjects with allocating fixed wealth between two accounts x_1 and x_2, and presented subjects with a budget constraint $p_1x_1 + p_2x_2 = 1$. There were two states of nature s_1 and s_2. If s_1 occurred, the subject was paid x_1 and if s_2 occurred, the subject was paid x_2. In their symmetric treatment $p(s_1) = 1/2$, and in their asymmetric treatment $p(s_1) = 1/3$ or $p(s_1) = 2/3$. Fisman et al. (2007) studied a dictator game.

We constructed scatter plots from an analysis on the aggregate data, placing our index on the horizontal axis and the CCEI on the vertical axis, and we present them in Figure 10. The scatter plots reveal a positive (and significant) correlation between the two measures in all three cases, suggesting that with regard to choice consistency the two measures are complementary. The degree of correlation appears to depend on the experimental design: the dictator games appear qualitatively similar, whereas the distribution of the parameters in the risky choice task appears less scattered. This leads us to examine what additional information we may acquire through our new measure.

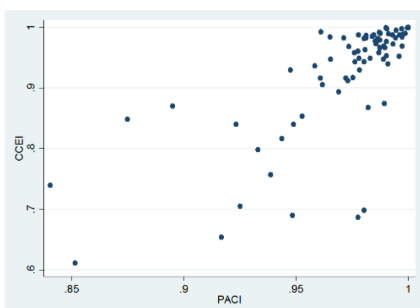
We also compared parameters of the price weighting functions applied to the data from all three studies. On scatter plots of α and β coefficients in Figure 11, data points above the red horizontal line indicate price inflating, while data points below indicate price discounting. Data points to the left of the vertical red line indicate price insensitivity, while data points to the right of the red line indicate price oversensitivity.

The results from the dictator game (ours and Fisman et al., 2007) visually appear similar with regard to the distribution of the two parameters. The majority of subjects are price insensitive in both cases (most data points to the left of the vertical red line), while there may be more subjects for whom $\beta = 1$ in Fisman et al. (2007). The two plots share the quality of roughly equal price inflating (above the horizontal red line) and price discounting (below the horizontal red line).

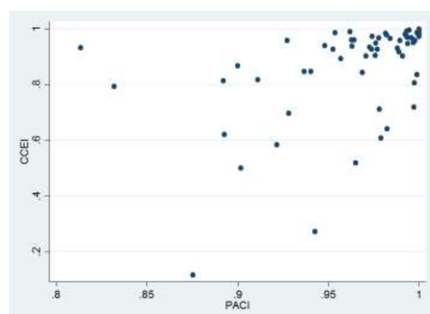
There is a potential indication that parameters are distributed differently with regard to price insensitivity in the Choi et al. (2007) data: there may be more price oversensitivity



a) Our data (dictator game)

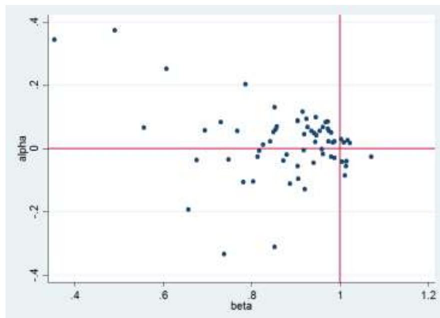


b) Fisman et al. (2007) (dictator game)

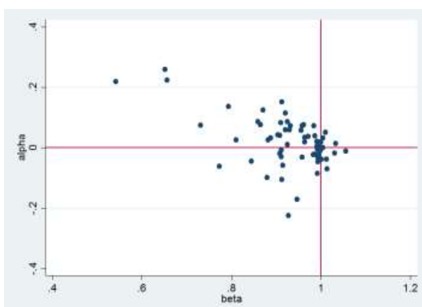


c) Choi et al. (2007) (choice under risk)

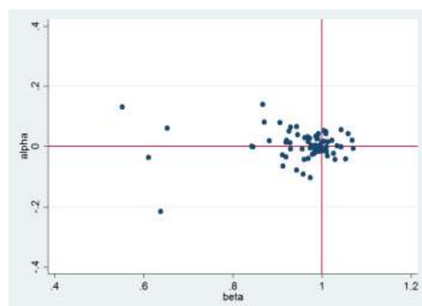
Figure 10: CCEI versus PACI calculated for data from three different experimental studies



a) Our data (dictator game)



b) Fisman et al. (2007) (dictator game)



c) Choi et al. (2007) (choice under risk)

Figure 11: Parameters of the price weighting function calculated for data from three different experimental studies

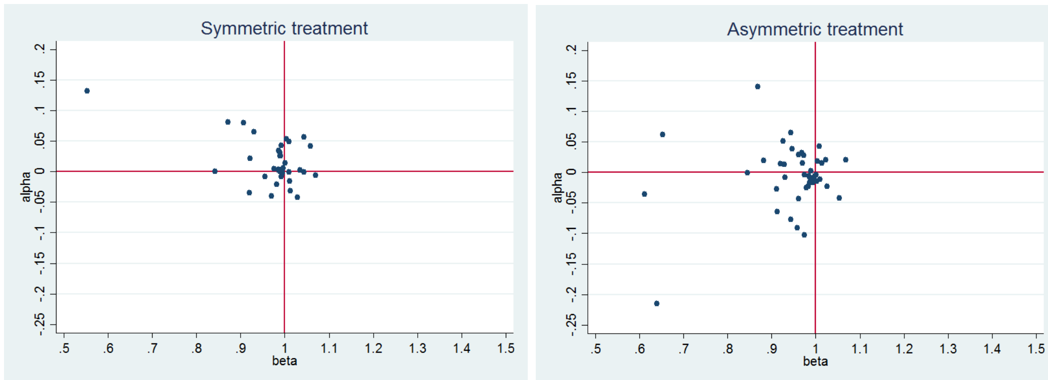


Figure 12: Comparisons by treatment with data from Choi et al. (2007)

than in the other two data sets, and the coefficients may be distributed more tightly around the crossing point of the two red lines that indicates where adjusted prices equal actual prices. The clustering of the data points appears tighter than in the dictator games.[18]

To investigate this further, we disaggregated the data from Choi et al. (2007) into their symmetric and asymmetric treatments. Those results are presented in Figures 12. In the symmetric treatment, parameters α and β are scattered fairly symmetrically around the crossing of the two red lines. In the asymmetric treatment, relative to the symmetric treatment, there appears to be a shift in the direction of price insensitivity. It is difficult to be precise, but price discounting may be stronger as well. The point is that viewed through the lens of our measure, there is evidence for a difference between treatments that until now we were not aware of.

Third, to illustrate our method as a tool for exploring behavior we used the adjusted prices in our data to explore whether they are consistent with the notion of reference level pricing. Sakovics (2011) proposes that "the price function should capture the empirically

[18] We thus find similar price adjustments in an existing data set. Note that, unlike in our experiment, incomes were normalized in both studies, thus it is difficult to conclude that mis-perception of income is driving these results.

established and sensible idea that the subjective effect of a reference price is to make a price that is higher than it seem (even) higher (a negative “sticker shock”); and a price that is lower than it seem (even) lower (a “positive sticker effect”).”[19] Such price perception may well be consistent with price insensitivity.

To see this, suppose a subject experiences a price (say, equal to 5) that is lower than her reference price (say, equal to 10). Due to the sticker shock she may perceive the price of 5 to be even lower than it is, say, equal to 2. Hence, her subjective price (or adjusted price in our paper) equals to 2. Our algorithm would adjust the price of 5 down to 2, which results in the discounting of a high price. A similar example can demonstrate inflating of low prices. Hence, positive and negative sticker shocks may well be behind price insensitivity.

Variable	Coefficient
price at t less than price at $t-1$	0.783
	(0.373)*
log(price)	2.254
	(0.309)*
decision period	-0.003
	(0.014)
constant	-0.163
	(0.349)
Observations	259
Pseudo R^2	0.35
LR $\chi^2(3)$	124.28

Note: standard errors in parentheses; * indicates significance at 5%

Table 3: Estimates from a logit regression.

For evidence of possible sticker shocks in our data, we estimated a logistic regression of an indicator that the adjusted price is lower than the actual price on an indicator that the actual price is lower than the price in the previous period. We also included as regressors both the logarithm of the actual price and the period number to control for any trends. We used the price of previous decision as a possible reference price. If sticker shocks are present, then we expect a positive coefficient on the indicator that the current price is lower than the previous price. That is, experiencing a lower price in the current period compared to the

[19] We thank an anonymous referee for this reference.

previous period makes it more likely that the adjusted price is lower than the current period price. We ran this regression on all choices whose prices were adjusted.

The results are shown in Table 3. We obtained a positive and significant coefficient on the indicator that today's price is less than the previous price of 0.783. Thus, not only is our finding of price insensitivity not inconsistent with the price model of Sakovics (2011), it would not have been possible to investigate this (reference prices are unobservable in these data) without use of the adjusted price as the dependent variable in the regression.

6 Conclusion

In this paper we investigated the role of prices in violations of revealed preference axioms by introducing the notion of price adjustment, which answers the question what prices must look like for observed choices to be consistent with a utility function. We designed a price adjustment algorithm, which determines a set of budget prices that renders the choice data rationalizable. With the adjusted prices we computed a new measure of price-adjusted consistency of choices (PACI). We fit a price weighting function that maps actual prices into adjusted prices. The parameters of the price weighting function revealed heterogeneity in patterns of violations that we call price discounting, price inflating, price insensitivity, and price oversensitivity.

We applied our method to new data from a dictator game experiment. Our analysis suggested complementarity between our PACI and existing measures of choice consistency. We found heterogeneity in price weighting, with price insensitivity being prevalent. That is, many dictators systematically inflated low dictator prices and discounted high dictator prices. It appeared as if they pushed extreme prices toward a price in the middle of the interval when making their decisions. By adjusting the actual prices in this manner, choices became consistent with revealed preference.

We thus introduced a new and complementary method to examine choice consistency with respect to revealed preference. With this approach comes the unavoidable behavioral interpretation that allocation decisions may be in response to adjusted prices rather than to actual prices. Using an example found in our data we showed the intuition behind the price adjustments and discussed alternative explanations of behavior.

We tested the robustness of our findings on previous data both in a dictator game context and in a context of choices under risk, finding similar results in the dictator game, and presenting evidence of a possible treatment effect. We used our new method as a tool to investigate our own data, and showed that price insensitivity is consistent with reference pricing, where the price reference is established by the price history experienced by the subject.

Our new method provides a new lens through which to view violations of GARP, and providing an alternative interpretation of the violations. For example, when a subject allocates too much of the good to the recipient in the dictator game, relative to her other choices, if it is in response to an adjusted price, it may not be an altruistic decision. This fact does not suggest that a re-evaluation of behavior in these games is required due to this result: it is based solely on violations of GARP, that is, decisions that are inconsistent with other decisions in the choice set, not on consistent choices that reveal preferences. It does suggest a fruitful avenue of exploration in the future.

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