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A Computational Theory of Exchange:

Willingness to pay, willingness to accept
and the endowment effect

Pete Lunn & Mary Lunn^a

Abstract. We present a theory of exchange that provides an alternative explanation for the endowment effect. Unlike standard neoclassical theories and Prospect Theory, our approach is not based on preference structure, but on adaptive responses to the problem of exchange when value is uncertain. We combine assumptions from perceptual and economic theory into a highly generalised model. Agents who maximise surplus but perceive uncertainty in the value of goods, set willingness to accept (WTA) above willingness to pay (WTP). The disparity increases with the perceived uncertainty of value. We show also how feedback over repeated exchanges may have heuristic value in learning to set optimal WTA and WTP. Our model receives some support from empirical studies of exchange.

Keywords: Endowment effect, willingness to accept, willingness to pay, exchange, uncertainty

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1. Introduction

Exchange of ownership is a fundamental economic process. Yet numerous studies suggest that people approach simple exchanges in a manner that defies neoclassical economic theory. Devising an alternative or additional theory that can adequately account for behaviour in exchanges is therefore of fundamental importance. We present a theory that departs from prevailing explanations by emphasising the difficulties inherent in the process of exchange, rather than viewing exchange behaviour as wholly determined by the structure of preferences.

For several decades it has been noted that attempts to elicit private valuations of environmental and public goods (“contingent valuation” studies) often result in large disparities between the prices people give when asked to state the maximum they are willing to pay (WTP) for a good and those they give when asked to state the minimum they are willing to accept (WTA) to give up the same good. It is rare, of course, that environmental and public goods are exchanged. But beginning with Kahneman, Knetsch and Thaler (1990) and Knetsch (1989), similar results have been recorded in laboratory experiments in which subjects are invited to trade ordinary consumption goods such as mugs, pens and chocolate bars. Typically, mean WTA is greater than mean WTP by a factor of two or three, and subjects are unwilling to trade goods they own for goods they would prefer if offered a binary choice. Following Thaler (1980), this finding is known as the “endowment effect”.¹

For economic theory, the endowment effect is no small matter. Most straightforwardly, the lack of an agreed explanation implies that, as economists, we do not understand the process of simple exchange. The effect also questions the validity of theoretical staples such as Hicksian consumer theory and the Coase

¹ There is some confusion in the literature as to whether the term “endowment effect” refers to a type of empirical finding in which items owned appear to be valued more highly than items not owned, or to the theoretical claim that agents change their preferences according to ownership. We use the term “endowment effect” to refer only to empirical phenomena.

Theorem (Kahneman et al., 1990), and raises the possibility that many agents in markets may miss out on beneficial trade. An alternative theoretical perspective to the neoclassical one is provided by Prospect Theory (Kahneman and Tversky, 1979; Tversky and Kahneman, 1991), which holds that individual preferences are “reference dependent”, meaning that they change according to endowments. Specifically, Prospect Theory asserts that preferences display “loss aversion”, such that reductions in utility associated with giving up goods are larger than increases in utility associated with equivalent gains (see also Bateman et al., 1997).

These implications for economic theory depend, however, on the robustness of the empirical findings and the extent to which they are echoed beyond the laboratory, both of which have been recently called into question. With respect to robustness, Plott and Zeiler (2005, 2007) provide evidence that certain combinations of changes in experimental procedures can cause the endowment effect to disappear. Regarding relevance to the real economy, List (2003, 2004) used a series of field experiments to show that the endowment effect is stronger for (and perhaps confined to) less experienced traders at collectors’ trade fairs. These findings, to which we return in the light of our own model, are hard to explain if the endowment effect is caused by changes in preferences coinciding with ownership, without additional assumptions about when and for whom such changes in preferences take place.

Yet the endowment effect remains to be explained. Numerous studies have reported it in a wide range of circumstances. There are also findings relating to exchange in the real economy that appear to be more consistent with Prospect Theory than conventional neoclassical theory (Camerer, 2000).² Furthermore, there are empirical regularities regarding the strength of the endowment effect and the context in which valuations are sought. One of these regularities we find particularly suggestive. Horowitz and McConnell (2002) reviewed empirical studies of the disparity between WTA and WTP, including laboratory experiments and contingent valuation studies. They noted a systematic relationship between the type of good being valued and the strength of the effect, and concluded from this pattern that the endowment effect increases with the uncertainty surrounding people’s valuations of the good.

² Prospect Theory also receives support from much empirical literature on “risky choice”, or choice over lotteries. In this paper, we consider only what is often termed “riskless choice”, meaning choice over goods rather than lotteries. We do not use the term “riskless choice”, because our approach emphasises that what appears to be a riskless choice may in fact not be.

Valuation is a complex perceptual task. The association between the strength of the endowment effect and the difficulty of making accurate valuations led us to consider how uncertainty in the perception of value might be related to decision rules for buying and selling. In doing so, we were influenced by work in human perception and psychophysics, most notably the groundbreaking contribution of David Marr. Marr argued that perception needs to be understood through what he termed “computational theories”, or “functional descriptions of what information processing systems, including brains, are designed to do” (Marr, 1982). The aim of a computational theory is to explain not only what the system does, but why it makes sense for it so to do.

The present paper develops a computational theory of simple exchange. The distinction between a computational theory and a merely descriptive one, has similarities with the distinction between normative and positive economics, and with adaptive and non-adaptive problems in evolutionary science. We prefer to describe our contribution as a computational theory, however, because we wish to remain neutral as to whether it might be regarded as prescriptive, and because our model does not involve any evolutionary processes. Nevertheless, the theory proposes a rationale for the observed behaviour. Our aim is to show how the endowment effect may result from an adaptive response to an uncertain economic environment, rather than from a seemingly irrational psychological quirk.

Blending perceptual theory and economic theory, we show that when the inherent limitations of human perception are combined with a desire to maximise gains from trade, an endowment effect is the likely result. Our model links psychophysical assumptions about human perception of value with standard economic assumptions about the desire to optimise gains from trade. The central claim is that agents take advantage of the likelihood that perceptual limitations are shared by market participants. They therefore use their own uncertainty about value as a signal regarding variation in the valuations of others. We provide a formal derivation of optimum WTA and WTP under such circumstances. The outcome is an endowment effect, which is increasing in the degree of uncertainty. We also show that agents may receive feedback from repeated trades that has heuristic value in setting optimum WTA and WTP.

Section 2 provides a schematic account of the endowment effect and an empirical justification for the associated assumptions. Section 3 presents the formal model. Section 4 relates the model to the empirical literature on exchange. Section 5 concludes with a discussion of the possible implications and limitations of our theory.

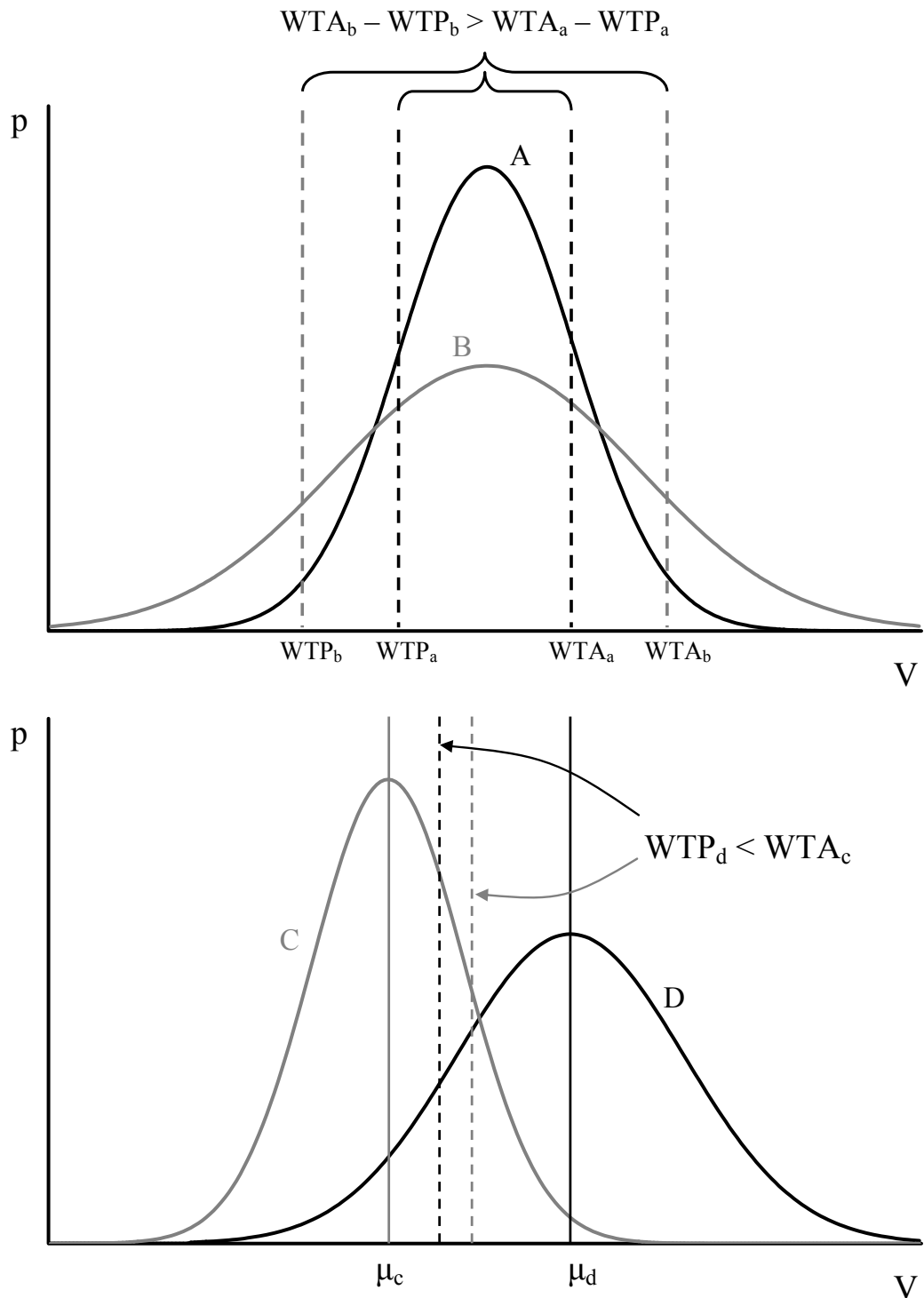
2. The perception of value

The endowment effect and perceptual uncertainty

The endowment effect is typically reported in one of two forms: first, a gap between stated WTA and WTP for the same good, which is larger for some goods than others; second, an unwillingness to exchange an owned item for another item that would be preferred in a binary choice where neither was initially owned. Figure 1 provides a schematic account of what may be behind these results. We assume that the perception of value is such that agents represent the value of each good as a continuous probability density function over a range of possible values. The agent perceives considerable uncertainty, such that variabilities are relatively large with respect to expected values. For now, we also assume that the perceived distributions are symmetrical. We offer an empirical justification for these psychophysical assumptions below.

We assume throughout that WTA and WTP are quantities of money, the values of which are represented without error. In the top chart of Figure 1, the agent sets WTA and WTP for two goods A and B, which are perceived to be of the same expected value, but differ in ease of valuation, such that B results in a flatter distribution. The essence of our account is that the setting of WTA and WTP is sensitive to the different variability of the perceptions, with two consequences. First, WTA and WTP are set substantially above and below the expected value. Second, the gap is increasing in the variability of the distribution, such that good B is assigned a higher WTA and a lower WTP than good A. That is, we conjecture that uncertainty in the perception of value both increases WTA and decreases WTP, increasing the measured endowment effect. Note that while any risk-averse agent would be expected to set $WTP_b < WTP_a$, such an agent would not also set $WTA_b > WTA_a$.

Figure 1: A schematic account of the endowment effect. The agent sets WTA and WTP to account for uncertainty in their perception of value. If good A is perceived to be of the same value as B, but the agent is less certain of the value of B, the $(WTA - WTP)$ disparity is greater for B (top). If C is valued less than D, the agent may nevertheless be unwilling to trade C for D (bottom).



The bottom chart of Figure 1 depicts the second standard result. Given the influence of uncertainty on WTA and WTP, plus the additional assumption that where WTA for one good is greater than WTP for another the agent will not make a direct exchange, the agent might decline a trade of good C, which they own, for good D, which they do not, but which they would be likely to prefer in a binary choice between C and D, on the basis of higher expected value. Thus, if uncertainty in the perception of value is sufficiently large and has sufficient impact on WTA and WTP, the two standard endowment effect findings will be observed.

Of course, this analysis begs the question: why would agents set WTA and WTP this way? We will shortly consider two reasons why this behaviour might be an adaptive response to uncertainty in the perception of value, one of which drives our model. First, however, we provide an empirical justification for this basic account, employing both economic and psychophysical evidence.

Evidence for the role of perceptual uncertainty

With respect to economic evidence, the account above matches a systematic pattern across a large body of work. Horowitz and McConnell's (2002) review covers 45 studies of WTA-WTP gaps and the endowment effect. Their main finding is that, despite variation in methodologies across studies, the ratio of WTA to WTP is systematically related to the type of good. Mean WTA-to-WTP ratios are: ten for public goods, non-market goods and resources related to health and safety; almost three for ordinary consumption goods; just over two for lotteries; and just less than two for time. The review characterises the pattern as such that the further away the good is from quantifiable money and the less likely it is to be routinely exchanged, the greater the disparity. This pattern of evidence motivates our explanation based on variability in valuations.

From a psychophysical perspective, our explanation requires both that perceptions of value are fairly noisy and that humans make judgements that take into account the variability of their own perceptions. Psychophysical evidence on perceptual abilities is consistent with both propositions and, given its centrality to our theory, we briefly review some findings.

The precision of human perception is measured empirically via discrimination tasks. Subjects make repeated forced-choice comparisons between different test stimuli and a reference stimulus. The most common estimate of discrimination is the Weber fraction, $\Delta S/S$, where S is the length, loudness, weight etc. of the standard stimulus and ΔS is the “threshold” or “just noticeable difference” that can be detected reliably (i.e. the subject can perceive that $S - \Delta S < S < S + \Delta S$). The threshold, ΔS , is frequently defined as the standard deviation of the cumulative normal distribution that best fits a “psychometric function” relating a range of test stimuli to the probability of correctly judging whether they are longer, louder, heavier etc. than the reference stimulus. For many perceptual tasks, a cumulative normal provides a good fit to empirical data and the resulting Weber fraction is approximately constant over a wide range of S (the Weber-Fechner Law). In vision, basic spatial dimensions such as size or length typically have Weber fractions of 3 – 8% (e.g. Burbeck, 1987; Morgan, Watamaniuk and McKee, 2000), while for contrast they tend to be higher, at 10 – 20% (Legge, 1981). For the weight of an object held in the hand, Weber fractions are typically around 10% (e.g. Brodie and Ross, 1984). These levels of performance are obtained by trained observers after undertaking practice specific to the perceptual task, which greatly improves on initial performance (Fiorentini and Berardi, 1980). Individual differences within such perceptual discrimination tasks are small relative to differences across tasks. In summary, even the perception of basic visual and haptic dimensions, under controlled conditions and following learning, is subject to substantial and systematic error.

The apparently simple task of valuing a coffee mug requires an individual not only to judge perceptual basics like size and weight, but also complex perceptual properties like attractiveness and durability, before even taking account of dynamic social factors that may affect value, such as fashionability. Little is known about how accurately people can discriminate on these more complex dimensions, but given the magnitude of error surrounding basic perceptual dimensions, as described in the previous paragraph, it is likely that perceptions of the value of everyday consumer goods are very approximate.

There is additional evidence that people incorporate differences in the variability of their perceptions into judgements. For instance, when the shape of an object is

assessed by both vision and touch simultaneously, the observer must combine information from both senses to reach a judgement. In performing such tasks, people take account of the different degree of error associated with the two perceptual systems. Subjects combine the two variabilities such that their judgements resemble the outcome of a theoretical maximum likelihood estimation (Ernst and Banks, 2002).

The account of the endowment effect depicted in Figure 1 is hence consistent with some key economic and psychophysical findings: the variation in the endowment effect for different types of good, the scale of perceptual errors, and the ability to take account of perceptual errors when making judgements. We compare our model with some key empirical studies of exchange in Section 4, once we have presented a formal model.

Adaptive setting of WTA and WTP

A computational theory needs to explain not only what the system does, but why it does it (Marr, 1982). One potential logic for increasing WTA and decreasing WTP as variability in the perception of value increases is based on the danger of making a series of losses. If the agent has a limited budget, then sustaining losses may result in the budget being reduced below a critical level. If the agent trades off the probability of sustaining critical losses against the expected surplus, then it may make sense to set $WTP_b < WTP_a$ and $WTA_b > WTA_a$ (in Figure 1). Constructing a model along these lines is relatively straightforward, following similar stochastic models of survival, such as foraging models in animal behaviour and firm survival models in industrial economics. The agent trades-off the risk of starvation, insolvency or (effectively) zero budget against expected surplus.

We do not favour this explanation because we think there are more plausible alternatives for exchanges in which values are small relative to wealth, so that incurring losses carries no genuine survival threat. Our judgement is that humans are likely to have adapted specific strategies for such trades, because the returns to doing so would be high and the downside negligible across many transactions. Admittedly, this position is challengeable, given empirical evidence of the disinclination to accept small gambles and of systems of mental accounting (Thaler, 1999), which suggest that

people might want to maintain budgets that are small relative to wealth. A full review of this and countervailing evidence is beyond the scope of this paper. For now, our contention is that any model that does not require additional assumptions about critical budget levels but is instead based on the more straightforward assumption that agents maximise surplus, merits consideration.

Our theory recognises that more than one perception informs the setting of WTA and WTP. Exchange is a process involving interaction with other agents. The agent's WTA and WTP determine not only their potential surplus, but also the likelihood that they will be able to trade. Thus, an adaptive setting of WTA and WTP is very likely to reflect perceptions of likely bids or offers respectively from potential trading partners. Although there may be variation in expertise within any given market, commonalities of perceptual abilities mean that the agent's degree of uncertainty contains useful information about the likely variability in the valuations of others. The key assumption of our model is, therefore, as follows: agents use the variability in their own perception of the value of a good as a signal regarding the likely variability of bids and offers. Sellers then set WTA by trading off increases in the price they ultimately receive against reductions in the probability of making a sale. Similarly, buyers set WTP by trading off how much they ultimately pay against the likelihood of obtaining the good at that price or less. We now formalise this theory.

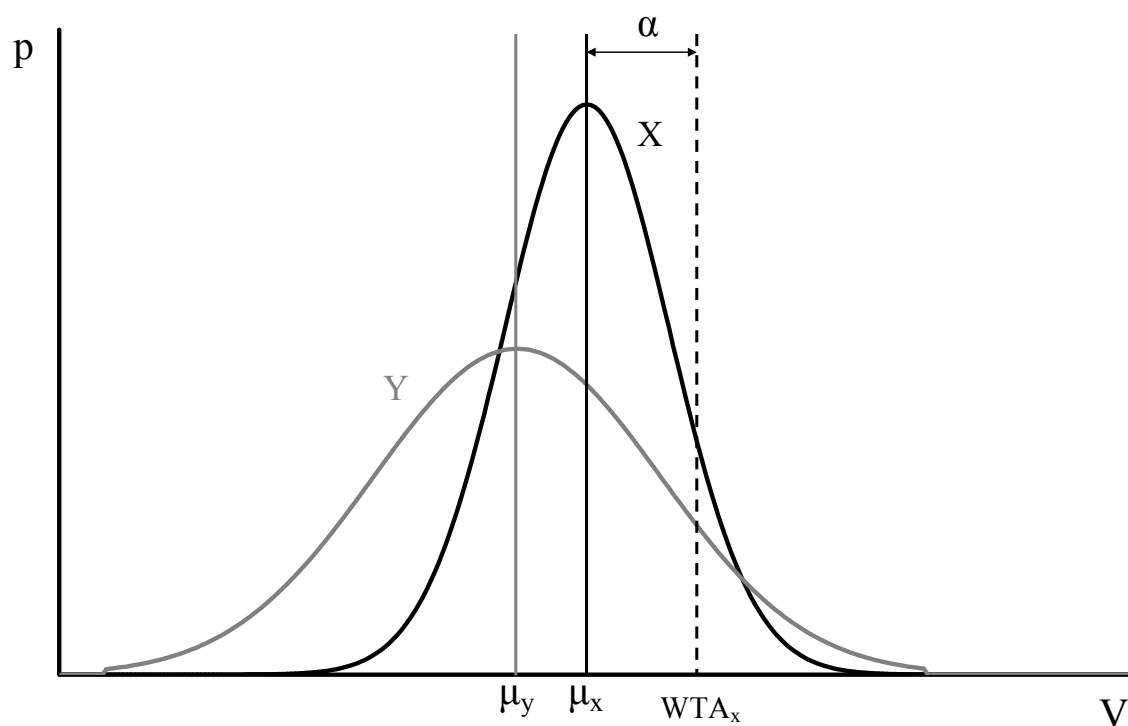
3. Model

The basic set-up for the model is depicted in Figure 2, where we consider WTA. The derivation of the optimal WTA applies to the analogous case of the optimal WTP by similar argument. The agent is endowed with a good, which they perceive to be of value $X \sim N(\mu_x, \sigma_x^2)$. The agent must also perceive the distribution of bids they can obtain for the good. We make the simplifying assumptions, first, that bids take the form of quantities of money and, second, that people perceive the value of money with perfect accuracy. Thus, we can directly compare the perceived value of the good, X , with the perceived value of likely bids, $Y \sim N(\mu_y, \sigma_y^2)$. Note that while the assumptions of normality represent a special case which is useful for illustration, the results we derive hold for all continuous distributions (see below and Appendix).

Furthermore, in Figure 2, $\mu_y > \mu_x$ and $\sigma_y > \sigma_x$, but these are not necessary for our results.

Given these perceptions, the agent sets their minimum acceptable price for selling the good, $WTA = \mu_x + \alpha$. We assume that the agent aims to maximise the expected surplus from the sale.

Figure 2: Agent owns good of perceived value X , perceives likely bids Y , and aims to set WTA to maximise surplus.



Given commonalities of perceptual limitations, the difficulty the agent has in valuing the good will be positively correlated with the difficulty others have in valuing the same good. Our main conjecture is that the agent will take this correlation into account in their representation of the distribution of bids they are likely to receive. The strength of the correlation can be considered a measure of the agent's level of expertise in dealing with the good, but we do not include variation in expertise in the model. The variability in the agent's perception of likely bids will also be determined by their perception of variation in preferences and tastes. Thus, our formulation is that

$\sigma_y^2 = f(\sigma_x^2, \tau_x^2)$ where τ_x^2 is the perceived variability in the valuations of others due to preferences and tastes, with $f_{\sigma_x^2} > 0$ and $f_{\tau_x^2} > 0$.³ The relationship between μ_x and μ_y will depend on whether the perceived value of the good to the agent is more or less than the value they perceive it to have for others, and on the degree of surplus they expect bidders to build in to bids. It is not necessary to constrain either to obtain our results; nor is it desirable, since we are seeking a highly generalised result.

The optimal selling rule given these two perceptions depends on the market institution. For generality and simplicity, we assume that the agent expects to receive bids in sequence $\{Y_1, Y_2, \dots, Y_i, \dots\}$ and sets WTA in advance of receiving bids.⁴ Our model can be adapted easily to one in which the agent posts a selling price, but because empirical studies of the endowment effect usually elicit values for WTA and/or WTP, we think the assumption of setting WTA in order to determine rejection or acceptance of a subsequent sequence of bids is reasonable. Whether subjects in exchange experiments view the request for a statement of WTA like this is an important issue to which we return in the next section.

A vital assumption in our model is that receiving a bid is not costless. We assign a (small) cost, c , to receiving each bid, which we call the “encounter cost”. One way to conceive of the encounter cost is that the number of encounters in which bids are received determines the length of (costly) time it takes to make the sale, although other conceptions of the encounter cost are possible, including equating it to a search cost. A transaction cost, t , is also included and is incurred if and when the sale is made. We assume, for the present model, that both the encounter cost and the transaction cost are known and perceived accurately.

Given these assumptions, we can formulate the expected surplus from the transaction for any given WTA. Assuming a sale is made, the agent expects to receive a price equal to the expected bid given that the bid is greater than WTA,

³ A precise definition of τ_x^2 is not essential for our results. The term merely captures the variability in the perception of bids and offers that is not due to uncertainty in the perception of value.

⁴ Clearly, it is possible for the agent to update their perception of the distribution of bids in light of the ongoing sequence of bids they receive, but for the present we do not incorporate updating in the model.

$$E(\text{price}) = E(Y | Y > \mu_x + \alpha) \quad (1).$$

In addition to giving up the good and incurring the transaction cost, the agent incurs encounter costs as a result of rejecting bids. In setting WTA, they therefore determine a fixed probability of accepting a bid. Thus, the expected number of encounters required to make a sale conforms to a geometric distribution, with parameter $\Pr(Y > \mu_x + \alpha)$, and the expected total cost of encounters up to and including making the sale is therefore given by the encounter cost multiplied by the reciprocal of the probability of making a sale

$$E(\text{total encounter cost}) = \frac{c}{\Pr(Y > \mu_x + \alpha)} \quad (2).$$

Thus, the agent can be considered to face an optimisation problem, in which the aim is to maximise the expected surplus, $E(S)$, from selling the good. Combining equations (1) and (2), the agent chooses α to maximise

$$E(S) = E(Y | Y > \mu_x + \alpha) - \mu_x - t - \frac{c}{\Pr(Y > \mu_x + \alpha)} \quad (3).$$

This optimisation problem can be characterised as a trade-off between increasing the surplus by demanding a higher price and decreasing it by reducing the probability of encountering someone willing to pay the price, thereby incurring encounter costs.

Looking at (3), the structure of our model shares some key features with some models of consumer search, perhaps most notably that of Reinganum (1979), in that it involves a trade-off between expected price and incremental costs, where total cost conforms to a geometric distribution. The parallels are instructive, but there are also major differences. Most importantly, our model of exchange is much more general. It applies to selling as well as buying. The encounter cost need not be a search cost. Moreover, while consumer search models are concerned with deriving an equilibrium between the consumer's optimum search strategy and the firm's optimum pricing strategy, we are concerned with deriving adaptive buying and selling strategies for exchange, involving generalised distributions of perceived value, bids and offers, whether there are firms involved or not. Contrary to most consumer search models,

we do not assume that buyers (or sellers) have perfect information regarding the distribution of offers (bids). Indeed, we consider this assumption unrealistic and instead conjecture that agents use their own uncertainty as a signal of the likely variability of bids and offers.

The solution to the optimisation problem is derived for any continuous distribution in the Appendix. The existence of a positive α^* that satisfies (3) depends on

$$c < \int_{\mu_x}^{\infty} (1 - F(y)) dy \quad (4)$$

where $F(y)$ is the cumulative distribution function of Y . This condition makes sense: if the encounter cost is too high then there is no price at which a surplus is likely to be made. WTA is determined by α^* which satisfies

$$c = \int_{\mu_x + \alpha^*}^{\infty} (1 - F(y)) dy \quad (5).$$

We can further derive the maximum expected surplus from setting WTA according to (5) so as to maximise (3), which turns out to have an interesting solution

$$\max E(S) = \alpha^* - t = WTA - \mu_x - t \quad (6).$$

This shows that a further condition on making the trade is clearly that $\alpha^* > t$. More tellingly, in order for (6) to hold, it must also be the case that the gap between the expected price and WTA matches the expected total encounter cost

$$E(\text{total encounter cost}) = E(\text{price}) - (\mu_x + \alpha^*) \quad (7).$$

From a mental accounting perspective, this solution regarding the expected surplus given an optimal setting of WTA is potentially interesting for at least two reasons. First, and most straightforwardly, it gives a ready indication of the expected surplus, which may have obvious use to an agent involved in repeated trading activity. Second, it is possible that the relationship between the expected price and the expected cost of bids has some heuristic value in helping to set WTA through experience. Equation (3) represents a complex optimisation problem but, in repeated

buying and selling, agents will get feedback that is suggestive of setting WTA too high or too low. If a seller repeatedly incurs higher encounter costs than the additional price they ultimately obtain, over and above WTA, then WTA is being set too high, and vice-versa.

This result is intuitively appealing. When selling, there are times when it takes so long (or so much effort) to make the sale that agents regret holding out for the higher price. Yet there are also times when a quick sale close to the minimum acceptable price may lead a agents to wonder whether they shouldn't have held out for more. On average, given (7), if agents balance the time and effort against the additional price obtained above WTA, they are optimising surplus.

Having solved (3) for the general case of a continuous distribution, we now consider the application to the normal distribution, which offers greater insight into the properties of the solution. For $Y \sim N(\mu_y, \sigma_y^2)$, the solution to the optimisation problem is such that

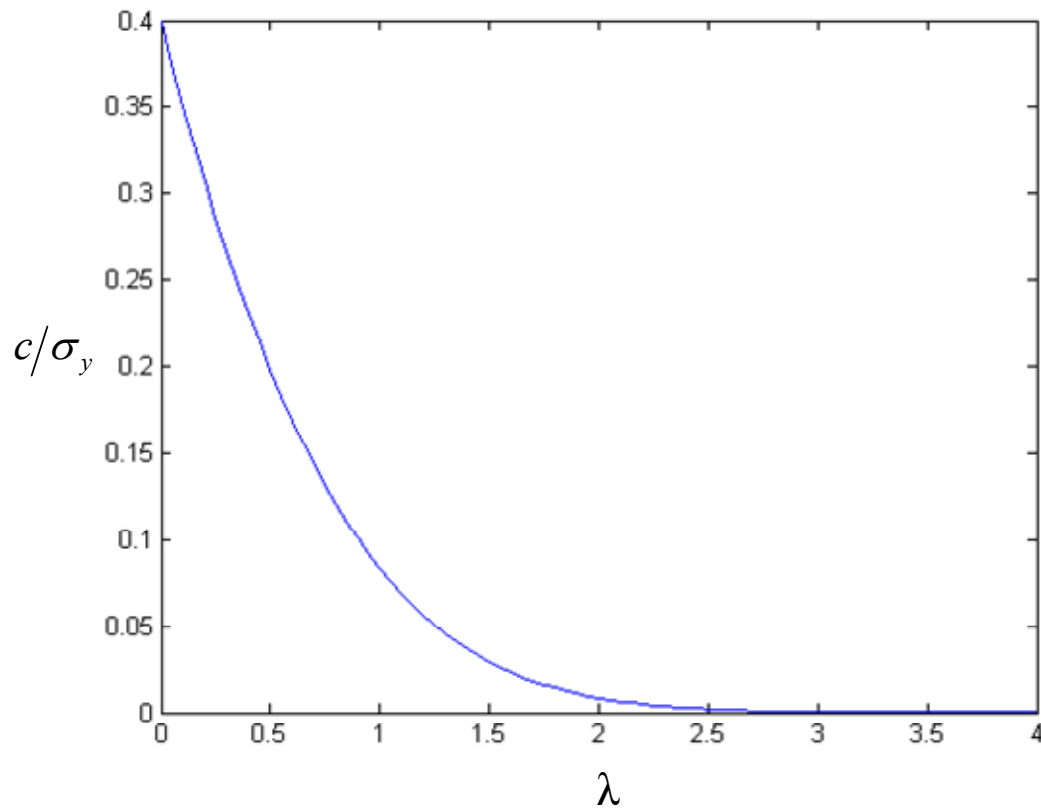
$$\frac{c}{\sigma_y} = \frac{1}{\sqrt{2\pi}} e^{-\frac{\lambda^2}{2}} - \lambda(1 - \Phi(\lambda)) \quad (8)$$

(see Appendix for derivation) where $\Phi \sim N(0,1)$ and

$$\lambda = \frac{\mu_x - \mu_y + \alpha^*}{\sigma_y} \quad (9).$$

Figure 3 shows the relationship between λ and c/σ_y , which is not intuitively obvious from (8) and (9). λ is increasing in σ_y and decreasing in c . Since $\sigma_y^2 = f(\sigma_x^2, \tau_x^2)$ and $f_{\sigma_x^2} > 0$, for any perceived X, Y and t, the greater the degree of uncertainty in the perception of value, the greater WTA, while the higher the cost of encounters, the lower WTA.

Figure 3: For the optimising seller, λ (and thereby WTA, see equations 8 and 9) is an increasing function of the perceived variability in bids (and hence perceived variability of value), σ_y , and a decreasing function of the encounter cost, c .



Lastly, we consider the case of WTP. This time, the agent must set WTP for a good of perceived value $X \sim N(\mu_x, \sigma_x^2)$. We assume a distribution of likely offers $Z \sim N(\mu_z, \sigma_z^2)$ and that the agent receives a sequence of offers $\{Z_1, Z_2, \dots, Z_i, \dots\}$, each at an encounter cost, c . The agent's optimisation problem is to choose β to maximise

$$E(S) = \mu_x - t - E(Z | Z < \mu_x - \beta) - \frac{c}{\Pr(Z < \mu_x - \beta)} \quad (10).$$

Similarly to the case of WTA we obtain the solution

$$\frac{c}{\sigma_z} = \lambda \Phi(\lambda) + \frac{e^{-\frac{\lambda^2}{2}}}{\sqrt{2\pi}} \quad (11)$$

where

$$\lambda = \frac{\mu_x - \mu_z - \beta^*}{\sigma_z} \quad (12).$$

And the expected surplus, given β^* , is given by

$$E(S) = \beta^* - t \quad (13).$$

For any perceived X , Z and t , the greater the degree of uncertainty in the perception of value, the lower WTP, while the higher the cost of encounters, the higher WTP.

Before relating the model to other findings and theories, it is important to note how few constraints it involves. Our result, that the optimal WTA (WTP) is increasing (decreasing) with uncertainty in perceived value holds for all continuous distributions of perceptions and requires only that the encounter cost is small relative to the variability of perceptions. If so, an endowment effect will be a characteristic of an optimising seller (buyer).

4. Relationship to empirical findings

Our computational theory of exchange combines perceptual and economic theory to show that where there is uncertainty in the perception of the value of goods and, therefore, perceived variability also in likely bids and offers, an agent who intends to optimise their transaction surplus will set WTA higher than WTP. The agent will thus display an endowment effect and, furthermore, that endowment effect will be increasing in the degree of uncertainty. This section compares the model with empirical findings on exchange.

Most obviously, the two standard findings that experimental subjects generally state higher WTA than WTP for goods (Kahneman et al., 1990, and others) and that they may be unwilling to trade an endowed good for a good they would prefer in binary choice (Knetsch, 1989, and others), are directly implied by our computational theory. Moreover, our model provides an explanation for the relationship between the type of good and the strength of the endowment effect (Horowitz and McConnell, 2002), assuming that the uncertainty surrounding perceived value is greater for non-market or public goods than it is for consumer goods, and lesser for time and money.

Our theory implies a specific understanding of the endowment effect in laboratory experiments. If subjects instinctively set WTA and WTP as they would outside the laboratory, they will display an endowment effect, which appears to be irrational in the laboratory context. Yet such decisions may represent an adaptive approach to selling and buying goods of uncertain value. The apparent irrationality arises because of the one-shot nature of the experiment. In the real world, buying and selling is rarely a one-shot game, in which the final outcome depends on whether a single announced price falls above or below a threshold and where immediate failure to trade implies a permanently lost opportunity. A strategy for setting WTA and WTP that makes perfect sense outside the laboratory may look nonsensical inside it.

We think there is evidence to support of this account of the standard laboratory findings. We suspect that some manipulations of experimental procedures, which show that the endowment effect can be reduced or eliminated, are likely to be the result of breaking the link between instinctive exchange behaviour outside the laboratory and behaviour in the laboratory. Franciosi et al. (1996) repeated the original Kahneman et al. (1990) experiment with all references to “buying”, “selling” and “price” in the experimental instructions replaced by references to “choosing”. This procedural change reduced the endowment effect. Plott and Zeiler (2005) show that the endowment effect is removed by giving subjects “extensive instruction” on the value elicitation mechanism, in which “specific examples are used to illustrate why announcing valuations that are not actual valuations is a dominated strategy” (p.537). They conclude from this that the endowment effect is caused by a complex range of subject misconceptions in experiments. Our interpretation is more straightforward: if experimenters point out at length and with examples that people’s instinctive setting of WTA and WTP will backfire in one-shot trading rounds, it is very likely to cause them to change behaviour. We think a similar explanation is likely to apply to the experimental manipulations in Plott and Zeiler (2007), whereby the endowment effect was removed for direct exchange of an endowed item for another item. In the “full set of controls” condition, the usual practice of inviting subjects to trade the item they owned for another item, was replaced by a decision form asking them to circle the item they wished to take home. Our theory of exchange will only apply if experimental procedures lead subjects to behave as if they are engaging in ongoing trade, either because that is their instinctive response to the

procedure, or because that is what they believe they are being asked to do. If subjects believe instead that they are being invited to make a once-off choice, we predict no endowment effect. We thus agree with Plott and Zeiler's conclusion that the endowment effect does not result from changes in preferences caused by ownership, but we disagree regarding what does cause it.

Our computational theory of exchange departs from previous accounts of the endowment effect because it depends on not only how agents value goods, but also on how they perceive likely bids and offers. Consistent with this, the endowment effect rapidly disappears when valuations of goods are elicited through repeated second-price auctions, such that bids and offers are made irrelevant to the likelihood of exchange (Shogren et al., 1994). Similarly, our theory implies that experimental manipulations that affect perceptions of likely bids and offers will alter the endowment effect. Indeed, feedback about the distribution of bids and offers appears to alter the setting of WTA and WTP. Franciosi et al. (1996) employed a uniform price double-auction, in which sellers and buyers received updates on the latest high bid and low offer. The endowment effect was reduced. Lastly, McConnell and Horowitz (2002) noted that WTA-WTP gaps tend to be larger when an incentive compatible value elicitation technique is used, the most common being the BDM mechanism (Becker, Degroot and Marschak, 1964). We suspect that by presenting subjects with a list of prices, usually uniformly distributed between generous upper and lower bounds, the mechanism generates a signal that the experimenters expect large variability in people's valuations. If subjects respond to this signal then they will exhibit a larger WTA-WTP disparity, according to our model. Hence our theory concurs with Plott and Zeiler (2007) that any signals contained in experimental procedures that are suggestive of the experimenters' valuations are likely to have an impact on the endowment effect.

We find the results of List's (2003, 2004) field experiments harder to explain with our computational theory. Experienced dealers may well have less variability in their perceptions of value than inexperienced dealers. But in our model, perceived value, σ_x , ultimately has an impact via its correlation with the perception of likely bids and offers, σ_y . It is not immediately obvious whether this correlation is likely to be stronger or weaker for experienced dealers. An alternative factor potentially

associated with experience is the encounter cost. List defined experience by the number of trades a dealer routinely made. Dealers planning to make more deals at a fair could be reasonably assumed to have higher encounter costs, thereby reducing the endowment effect, according to our model. Arguably List's most striking result was that experienced dealers in sports card markets did not display *any* endowment effect in a standard experiment involving mugs and candy bars conducted at a trading fair (List, 2004). It is possible that this result for experienced dealers reflects several factors potentially associated with experience: more accurate perceptions of value, higher encounter costs, and a greater likelihood of realising that the scenario is a one-shot trading game and thus overriding adaptive selling and buying habits. While possible, this explanation is unsatisfactory, because it sets arbitrary limits on the context in which our theory applies. This is unlike the empirical studies discussed previously, where controlled experimental manipulations can be linked to clearer signals to subjects, allowing the results to be compared with what our model predicts.

5. Discussion

Our theory of exchange meets the aim of combining perceptual theory and economic theory to produce a model of exchange behaviour that, first, accounts for how an endowment effect might arise and, second, suggests why such behaviour could be an adaptive response to an uncertain economic environment. In this sense, it fits the criteria of a computational theory of human information processing (Marr, 1982), offering an explanation not only of how the system functions but also why it functions that way.

Much of the literature on WTA-WTP disparities and the endowment effect centres on whether Prospect Theory or neoclassical theory offers the best account of exchange behaviour (e.g. Tversky and Kahneman, 1991; Shogren et al., 1994; Bateman et al., 1997; List, 2003, 2004; Plott and Zeiler, 2005, 2007). These two theories differ regarding the shape of preference functions, but are similar in other respects. Both assume that people's willingness to trade is determined by which outcome offers the greater utility, given the shape of people's preferences. Our computational theory of exchange departs from this debate, because it focuses not on preferences for outcomes following exchange but on the *process* of exchange itself. We suspect that exchange is

not merely a matter of deciding one's preferences and acting accordingly, but requires individuals to combine perceptions of the value of goods with perceptions of how others are likely to value the same goods. In our view, the endowment effect reflects the fact that variability in these perceptions is a key factor in people's willingness to exchange, whatever their preferences.

In Section 4, we compared our theory with empirical findings. The model can account for the standard findings and the association of the endowment effect with different types of good. Its validity as an explanation rests, however, on the conjecture that people behave in one-shot laboratory games in a manner that is well adapted to life outside the laboratory, but is not optimal in the laboratory. Thus, rather than considering the endowment effect to be a laboratory finding that may not occur in the real economy, we consider it more likely that the endowment effect is a real world phenomenon that may sometimes be absent inside the laboratory.

One possible objection to this view is the suggestion that there is not enough variability in people's valuations of goods, or in likely bids and offers, for our account to be plausible. It might be argued, for instance, that markets tightly constrain much variability in prices and that relatively accurate perceptions of "market price" can therefore be quickly formed. These are empirical matters. We reviewed the psychophysical evidence for high variability in the perception of value in Section 2. Regarding perceptions of bids and offers, there is extensive empirical evidence that price dispersion is considerable in extent and persistence, even for everyday goods in modern, competitive markets, where price comparison might be thought to be near costless (Baye et al., forthcoming). The perceptual difficulty of successful exchange is not to be underestimated.

Whether or not our computational theory proves to be a good account of exchange behaviour, there is therefore a larger point to be made. In looking for a general microeconomic theory of exchange, neoclassical theory and Prospect Theory largely ignore the dimension of skill involved in exchange activity. To do so is to do more than assume that individual differences in trading ability are of secondary importance. Given the uncertainties and complexity involved, the ability of humans to exchange

goods successfully and thus continually to reap the benefits of gains from trade requires explanation in its own right.

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Appendix

Choose α to maximise

$$E(S) = E(Y | Y > \mu_x + \alpha) - \mu_x - t - \frac{c}{\Pr(Y > \mu_x + \alpha)}.$$

Suppose that Y has density function $f(y)$ and cumulative distribution function $F(y)$. Then

$$\begin{aligned} E(Y | Y > \mu_x + \alpha) &= \left(\int_{\mu_x + \alpha}^{\infty} y f(y) dy \right) / (1 - F(\mu_x + \alpha)) \\ &= \left([-y(1 - F(y))]_{\mu_x + \alpha}^{\infty} + \int_{\mu_x + \alpha}^{\infty} (1 - F(y)) dy \right) / (1 - F(\mu_x + \alpha)) \\ &= \mu_x + \alpha + \left(\int_{\mu_x + \alpha}^{\infty} (1 - F(y)) dy \right) / (1 - F(\mu_x + \alpha)). \end{aligned}$$

Hence

$$E(S) = \alpha - t + \left(\int_{\mu_x + \alpha}^{\infty} (1 - F(y)) dy - c \right) / (1 - F(\mu_x + \alpha)).$$

Differentiate to find α^*

$$1 - (1 - F(\mu_x + \alpha)) / (1 - F(\mu_x + \alpha)) + f(\mu_x + \alpha) \left(\int_{\mu_x + \alpha}^{\infty} (1 - F(y)) dy - c \right) / (1 - F(\mu_x + \alpha))^2 = 0.$$

So α^* satisfies

$$c = \int_{\mu_x + \alpha^*}^{\infty} (1 - F(y)) dy.$$

Considering the expression for $E(S)$ we can see that

$$\max E(S) = \alpha^* - t$$

provided that

$$c < \int_{\mu_x}^{\infty} (1 - F(y)) dy.$$

Note we are assuming that $F(y)$ is continuous and strictly increasing on the range (a, b) of permitted values for Y and that $y(1 - F(y)) \rightarrow 0$ as $y \rightarrow \infty$.

Application to normal distribution:

Willingness to Accept (WTA)

Solve for α^* if

$$\frac{c}{\sigma_y} < \int_{\frac{\mu_x - \mu_y}{\sigma_y}}^{\infty} (1 - \Phi(z)) dz$$

(using transformation to standard normal $\Phi \sim N(0,1)$ knowing that $Y \sim N(\mu_y, \sigma_y^2)$).

Then to find α^* we use

$$\frac{c}{\sigma_y} = \frac{1}{\sqrt{2\pi}} e^{-\frac{\lambda^2}{2}} - \lambda(1 - \Phi(\lambda)) \quad , \quad \text{where } \lambda = \frac{\mu_x - \mu_y + \alpha^*}{\sigma_y} .$$

When this is solved then the expected surplus is

$$E(S) = \alpha^* - t .$$

Willingness to Pay (WTP)

Suppose amount to pay is $X \sim N(\mu_x, \sigma_x^2)$, and that offers are distributed as $Z \sim N(\mu_z, \sigma_z^2)$. Suppose WTP is $\mu_x - \beta^*$, which satisfies a similar equation, that is β^* maximises expected surplus

$$E(S) = \mu_x - t - E(Z | Z < \mu_x - \beta) - \frac{c}{\Pr(Z < \mu_x - \beta)}.$$

With similar computations to WTA case we determine β^* according to

$$c = \int_{-\infty}^{\mu_x - \beta^*} F(z) dz = \sigma_z \int_{-\infty}^{\frac{\mu_x - \mu_z - \beta^*}{\sigma_z}} \Phi(z) dz,$$

giving $E(S) = \beta^* - t$.

For the normal distribution we get

$$\frac{c}{\sigma_z} = \lambda \Phi(\lambda) + \frac{e^{-\frac{1}{2}\lambda^2}}{\sqrt{2\pi}}, \text{ where } \lambda = \frac{\mu_x - \mu_z - \beta^*}{\sigma_z}.$$

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