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Comments

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Laboratory Experiments of Land Assembly without Eminent Domain [1]

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Abstract: We use laboratory experiments to test two self-assessment tax mechanisms for facilitating land assembly. One mechanism is incentive compatible with a complex tax function, while the other uses a flat tax rate to mitigate implementation concerns. Sellers publicly declare a price for their land. Overstating its true value is penalized by using the declared price to assess a property tax; understating its value is penalized by allowing developers to buy the property at the declared price. We find that both mechanisms increase the rate of land assembly and gains from trade relative to a control in which sellers' price declarations have no effect on their taxes. However, these effects are statistically insignificant or transitory. The assembly rates in our self-assessment treatments are markedly higher than those of prior experimental studies in which the buyer faces bargaining frictions, such as costly delay or capital constraints.

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1. Introduction

The allocation of property rights in real estate places society on the horns of a dilemma. Private ownership allows landholders to demand prices in excess of their subjective valuations, exposing government agencies and private developers to strategic holdout. Thus, valuable infrastructure and public goods such as highways, parks and airports may be underprovided (Becher, 2014; Heller, 1998; Kerekes, 2011; Whitman, 2006). Yet, public ownership discourages tenants from improving land through costly investment (Grossman and Hart, 1986), inhibits them from finding its most valuable use through the price discovery process (Hayek, 1945) and encourages them to overexploit its produce lest their neighbors exploit it first (Lloyd, 1833; Hardin, 1968).

Market democracies try to skirt this dilemma by enforcing private property rights in general, but selectively rescinding them through eminent domain when holdout threatens a valuable development (Posner, 2014; Shavell, 2004, 2010). The justification of such a legal regime is that it captures most of the social benefits of private property, while securing the government the necessary powers to break up holdout problems and provide public goods.

Eminent domain, however, is not without its costs. Developers seek to maximize their own profits, not social welfare, and those who are well connected to the condemnor may acquire properties at below-market prices, leading to excessive assembly (Munch, 1976; Somin, 2004; Benson, 2005; Miceli and Segerson, 2007; Chang, 2010). Furthermore, landowners will often go to court to fight the expropriation of their property or at least increase the price they are paid. This can lead to long delays in assembly and impose significant transaction costs in the form of legal expenses (White, 1980; O'Flaherty, 1994). Moreover, eminent domain is not a panacea with respect to the land assembly problem. Both Kitchens (2014) and Portillo (2017) find that holding out may result in a larger price.

To address the imperfections of eminent domain, scholars have proposed several refinements and alternatives. Some propose to navigate eminent domain through introducing seller competition (e.g. Kominers & Weyl, 2011, 2012), while others propose mechanisms to facilitate fair outcomes when invoking eminent domain (e.g. Heller & Hills, 2008; Lehavi & Licht, 2007). In the current paper, we focus on a more radical proposal: altering the nature of property rights in land through a policy of binding self-assessment. Under this regime, landowners must publicly declare a price at which they would be willing to sell their property. Overstating one's subjective value is discouraged by assessing a tax on the declared price. Understating one's subjective value is discouraged by making the declared price a binding offer to prospective land assemblers. That is, the landowner cannot refuse a qualified offer for his property that meets or exceeds his declared price.[2]

In most U.S. jurisdictions the status quo for land assembly consists of bargaining between buyer and seller(s) under the threat of eminent domain, with reassessment of taxable property values upon resale. Using laboratory experiments as a "policy wind tunnel," we test two versions of a self-assessment regime that was proposed by Plassmann and Tideman (2008) against a variant of the status quo that utilizes the status quo's tax mechanism but excludes the ability to negotiate. The first (incentive compatible) version of self-assessment includes a complex tax function based upon the probability of a developer wanting to purchase the land, while the second version

[2] The public may wish to place limits on what constitutes a "qualified offer." At its most conservative, a self-assessment regime might reserve to the government alone the right to force a sale at the declared price. At the other extreme, any individual could make a qualified offer. Intermediate policies are possible as well.

simplifies the tax function by setting it to a flat rate. We exclude bargaining from our experimental design to isolate the effect of taxes in our three treatments. While tax is paid by the holder of the property at the end of the period in the status quo treatment, tax is always paid by the original property owner under self-assessment. We find that self-assessment increases the rate of land assembly from 70.8% to 83.3% compared to the status quo. This difference is not statistically significant, but assembly rates in our self-assessment treatments are substantially higher than those reported in experimental studies of land assembly through negotiation when the buyer faces capital constraints (Collins & Isaac, 2012) or costly delay without contingent contracts (DeSantis, McCarter & Winn, 2019). We also find self-assessment increases gains from trade though this effect is largely transitory in that it is only present in the first of two experimental negotiations (rounds). We test the robustness of findings with synthetic treatments – computer simulations designed to eliminate the role of "chance" in our experimental design and parameter choices.

Our research fills a gap in the self-assessment literature by offering empirical evidence on the efficacy of such mechanisms. The results are encouraging and suggest that self-assessment could be a useful alternative to the status quo of bilateral bargaining and eminent domain. Future experiments may shed light on whether self-assessment would also encourage the efficient use of other types of property besides land, as Posner and Weyl (2017) advocate.

The remainder of the paper is organized as follows. The relevant related literature is discussed in Section 2. In Section 3, we discuss the theoretical properties of Plassman and Tideman's (2008) self-assessment system, which uses a complex tax formula to ensure that truthful assessments are a dominant strategy, as well as a simplified version of this system. In Section 4, we describe the experiments that we devised to test this tax regime. We present the results of the experiments in Section 5. In Section 6 we consider the results of our self-assessment treatments in light of prior experimental studies on land assembly. We offer concluding remarks in Section 7.

2. Related Literature

Our research sits at the junction of two economic literatures, and advances each of them. The first is the literature on land assembly in laboratory experiments. This literature finds that the holdout problem impedes efficient land assembly, but as of yet scholars have not proposed a workable solution to induce sellers to truthfully reveal their reservation prices.[3] In experiments without eminent domain, the frequency of sellers making (non)binding requests for more than the value of their property is high, and sellers earn greater payoffs when they hold out compared to when they do not (see Cadigan et al., 2009, 2011; Swope, et al., 2011; Collins & Isaac, 2012; Parente & Winn, 2012; Shupp et al., 2013; Swope et al., 2014; Zillante et al., 2014; Isaac et al., 2016).[4] Because holding out is not profitable for sellers unless successful land assembly occurs, the negotiations in these experiments often persist for multiple periods, regardless of whether delay is costly. In the studies cited above, there were a total of 3,013 negotiations in which land assembly could fail. Failure occurred in 298 of them for an overall failure rate of 9.9%, though in some experimental treatments the failure rate exceeded 50%.

The observed market failure raises the possibility that eminent domain can improve efficiency. However, two laboratory studies have found that eminent domain does not increase

[3] Introducing some competition among the sellers has proved quite effective at reducing holdout in the laboratory, but this is not a decision variable for most developers or government agencies.

[4] Recent studies using field data find indirect evidence of seller holdout in land assembly (Cunningham, 2013; Brooks and Lutz, 2016; Yuming, McMillen, and Somerville, 2016; Portillo, 2017). These studies find that properties that are redeveloped as part of an assembly sell at a premium over properties that are redeveloped individually. The advantage of laboratory experiments is their ability to isolate seller holdout as the source of inefficiency, rather than regulatory frictions, such as zoning restrictions and construction codes.

social welfare from land assembly. Kitchens and Roomets (2015) and Winn and McCarter (2018) both conduct experiments in which buyers can force sales, and the authors compare them to experiments in which they cannot. Kitchens and Roomets (2015) model the transaction costs of eminent domain as an exogenous, fixed share of the available surplus, while Winn and McCarter (2018) model the transaction costs as an endogenous result of the participants' spending in a court battle over the price at which a condemned property will trade. In both studies the gains from trade were statistically indistinguishable across treatments.[5]

Thus, the present experimental literature has diagnosed the disease, but has yet to find a remedy. The current paper advances the conversation by proposing and testing mechanisms that facilitate high rates of land assembly and gains from trade.

We also contribute to the law and economics literature on self-assessment taxation. Arnold Harberger (1965) proposed binding self-assessment as a means of taxing the capital value of land in Latin America. In Harberger's proposal, a landowner would declare his own assessment of his property's value, which the government would use to assess a property tax. Harberger (1965) suggested that the government could elicit accurate assessments if it forced the landowner to sell his property to anyone who offered to buy it at a 20% premium over the declared assessment. The appeal of this scheme was that it would be self-enforcing, avoid corruption and offer accurate assessments of property values; all of which were a challenge in Latin America. (Harberger did not advocate self-assessment in nations with well-functioning, comparatively honest political and economic institutions.)

[5] Cardella and Kitchens (2017) report related research on bargaining in the shadow of eminent domain. They find that higher variance in the distribution of possible court-determined prices leads sellers to demand more for their property, resulting in fewer out of court settlements. Increasing the skewness of the distribution has a similar effect.

Over the years, other scholars have recommended self-assessment systems for advanced economies and offered their own refinements. Levmore (1982) proposes a system of "competitive assessment" in which private parties may inspect and submit an assessment on a property. Periodically, the government reveals the highest assessment to the landowner and gives him the option to sell his property to the assessor or accept the assessment as the taxable value of the property. Miceli, Segerson and Sirmans (2008) propose a similar system in which a landowner who rejects a developer's offer will have the taxable value of his property reassessed at that offer.[6] Bell and Parchomovsky (2007) propose a revision to the eminent domain process in which the government declares a property it wishes to condemn and the owner is allowed to determine the price at which such a condemnation must take place. The government may proceed with the condemnation or relent. If it relents, the owner's property is reassessed at his declared price and thereafter he may not sell to any private party at a lower price unless he pays the government a penalty equal to the difference between the price he declared and the price at which he subsequently sold. Plassmann and Tideman (2008) propose a tax formula that ensures the marginal tax rate is always equal to the probability that a developer will wish to purchase the property. We reproduce their mathematical analysis in Section 3 below to demonstrate that this is a sufficient condition to make declaring one's true property value a dominant strategy.[7]

[6] DeSantis, McCarter and Winn (2018) test this tax regime with laboratory experiments. They find that reassessing property taxes at the highest rejected offer increases the rate of land assembly by 58.4% relative to a baseline treatment in which property taxes are held constant. However, the increase in land assembly did not translate into a statistically significant increase in gains from trade.
[7] The papers cited here focus exclusively on allocative efficiency. Weyl and Zhang (2016, 2018) point out that self-assessment taxes create a tradeoff between allocative efficiency and investment efficiency. To the extent that the gains in a property's value will be taxed away, making costly improvements to it would be a waste of the owner's money. This is a valuable insight, but in the interests of simplicity we do not include investment in our experimental design. We leave this facet of self-assessment to future research.

Levmore (1982), Miceli, Segerson and Sirmans (2008), Bell and Parchomovsky (2007) and Plassman and Tideman (2008) emphasize the usefulness of self-assessment in the real estate market. Posner and Weyl (2017) make a more radical proposal: implementing self-assessment taxes (on the Harberger model) on *all* property, including real estate, internet domain names, intellectual property and even personal property. As they acknowledge, such a system would abolish private property as we know it, replacing it with a system of revocable leases. The merits and demerits of such a system are beyond the scope of this paper, but prudence dictates that self-assessment be tested on a small scale before it can be recommended for all property in general.

Indeed, to our knowledge none of the self-assessment mechanisms – from Harberger on – have been tested empirically. Taiwan used a self-assessment regime for land from 1954 – 1977. Chang (2012) shows convincing evidence that landowners substantially understated the value of their property because the taxes were relatively high, and the government rarely compelled a sale. (Private citizens could not force one another to sell.) Yet, Chang (2012) does not provide data on the efficiency of land allocation in this time period or in the years prior to or following it. Thus, while we know that self-assessments were not accurate, we do not know if the system as a whole operated with greater, lesser or equal efficiency than the alternative. Indeed, in our experiments most self-assessments are not "truthful," but the self-assessment mechanisms still facilitate high rates of assembly.

3. Self-Assessment Mechanisms

3.1 Incentive Compatible Self-Assessment

In situations where owners face a nonzero probability of a developer seeking to acquire their property, Plassmann and Tideman (2008) – hereafter PT – propose a mechanism which we refer to as incentive compatible self-assessment (ICSA). Every landowner must declare to the government a price at which he will voluntarily sell his property. That is, if a developer offers the owner this price he is obligated to sell. PT assume that the probability that a developer will wish to buy an owner's land falls as the declared price increases. They also implicitly assume that the declared prices of one's neighbors do not affect this probability. Each owner is assessed a property tax which is an increasing function of his declared price. The tax is paid by the owner even if his property is purchased by the developer. PT motivate this mechanism as a type of insurance under which each landowner pays a premium equal to his expected loss (his private value minus the price he is forced to accept) multiplied by the tax rate. Just as a fire insurance premium is paid whether or not there is a fire, the self-assessment tax is paid whether or not the home is purchased. Thus, as noted by PT, this mechanism "…provides the owner…with assurance that he will receive compensation for this *true* loss, rather than an amount that someone else considers 'reasonable'."[8]

To increase his payoff conditional on selling the owner may report a value above his true value. However, the owner would then face a higher tax bill. Conversely, suppose the owner reports a value less than his true value to reduce his tax burden. This would make his property more appealing to a developer, increasing the probability that the developer will make an offer on the property – an offer that the owner cannot refuse.

PT show that reporting one's true value maximizes one's expected utility under certain assumptions. Let x be the owner's declared price and r be his true reservation value. Let $p(x)$ be the probability a developer purchases the owner's property. As noted above, we assume $p(x)$ is decreasing in x, i.e. $dp(x)/dx < 0$. Let V denote the developer's value and $T(x)$ denote the

[8] Note that the ICSA mechanism is distinct from a Vickrey-Clarke-Groves mechanism. See Plassmann and Tideman (2008) for an application of a Vickrey-Clarke-Groves mechanism (or Clarke tax) to the land assembly problem.

owner's tax assessment. Finally, assume the owner is non-risk seeking, with an increasing utility function $U(\pi)$, where π represents the owner's profit, given by:

$$\pi = \begin{cases} x - T(x), & \text{if the owner sells} \\ r - T(x), & \text{otherwise} \end{cases} .$$

The owner's expected utility is therefore

$$E[U(\pi)] = p(x)U\big(x - T(x)\big) + \big(1 - p(x)\big)U\big(r - T(x)\big). \qquad (1)$$

This function is maximized at $x = r$ provided the government sets the marginal tax rate, $dT(x)/dx$, equal to the probability that a developer will buy the property, $p(x)$. To see that this is the case, note that the first order condition implied by (1) is:

$$\begin{aligned} dE[U(\pi)]/dx = {} & (dp(x)/dx)\big[U\big(x - T(x)\big) - U\big(r - T(x)\big)\big] \\ & - U'\big(r - T(x)\big)(dT(x)/dx)\big(1 - p(x)\big) \\ & + U'\big(x - T(x)\big)(1 - dT(x)/dx)p(x) = 0. \end{aligned} \qquad (2)$$

Setting $dT(x)/dx = p(x)$ simplifies the first order condition (2) into:

$$\begin{aligned} dE[U(\pi)]/dx = {} & (dp(x)/dx)\big[U\big(x - T(x)\big) - U\big(r - T(x)\big)\big] \\ & + [p(x) - p(x)^2]\big[U'\big(x - T(x)\big) - U'\big(r - T(x)\big)\big] = 0 \end{aligned} \qquad (3)$$

Notice that if the owner declares a price $x > r$ then $dE[U(\pi)]/dx < 0$ and if he declares a price $x < r$ then $dE[U(\pi)]/dx > 0$. Therefore, a seller can only maximize his expected utility by declaring his true reservation value. Thus, ICSA mitigates the holdout problem by discouraging sellers from strategically requesting more for their property than their true value. Moreover, the properties will only be acquired if a developer's value for the entire project, V, is greater than the sum of the owners' declared prices. Assuming the owners maximize their utilities by declaring their true values only efficient projects will proceed. The general form of the tax function is found by solving the following ordinary differential equation:

$$\int_0^x dT(z)/dz = \int_0^x p(z)dz \tag{4}$$

yielding

$$T(x) = \int_0^x p(z)dz \tag{5}$$

where we assume $T(0) = 0$, implying an owner pays nothing if he declares his property to have zero value.

Unfortunately, ICSA faces two challenges as an implementable policy. First, a key assumption of the mechanism is that the government is able to accurately gauge (or at least convince the owners that it can accurately gauge) the probability that a developer will seek to acquire an owner's property. Without this information the government cannot set the property tax formula appropriately to ensure incentive compatibility. Further, estimating the probability functions for every parcel of land within a jurisdiction would be a costly (if not intractable) undertaking.

Second, ICSA may encourage proximate landowners to hold out collusively even though they have no incentive to hold out individually. In a practical setting with multiple owners, it is probably not realistic to assume that each owner's probability of selling depends only upon his declared price. Rather, it is likely that one owner's probability is dependent on both his declared price and the declared prices of nearby landowners as well. A straightforward extension of the ICSA mechanism is possible provided that each owner's probability of selling and tax burden is dependent upon the declared prices of all owners. Extending the model in this way does not alter the central result that the owners' dominant strategy is to truthfully declare their reservation values. However, the interdependence of the owners' tax assessments may lead to situations in which cooperative strategies emerge.

Suppose there are two owners, i and j, with reservation values r_i and r_j. Further, suppose a developer desires these properties and her value for the assembled parcels, V, is drawn from a uniform distribution over the interval $[A, B]$, similar to our experimental design (see Section 4.1). Then the probability that the sum of the owners' declared prices, x_i and x_j, is less than V is given by $(B - x_i - x_j)/(B - A)$.[9] Owner i's tax burden is therefore given by

$$T(x_i; x_j) = \int_0^{x_i} p(z; x_j) dz$$

$$= \int_0^{x_i} \frac{B - z - x_j}{B - A} dz = \frac{1}{B - A}\left[\left(B - x_j\right) x_i - \frac{{x_i}^2}{2}\right] \quad (6)$$

where owner j's declared price is treated as a constant.[10] Note that if owner j increases his declared price, x_j, then not only does owner i's probability of sale decrease but his tax burden decreases as well. Similarly, if owner i increases his declared price then owner j's probability of sale and tax burden will both decrease. Thus, cooperative strategies may exist and will depend on the distribution from which the developer's value is drawn.

3.2 Simplified Self-Assessment

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[9] For simplicity, we assume $A \leq x_i + x_j \leq B$ for this example.

[10] The tax burden for owner j is similarly derived by integrating the probability function with respect to x_j instead of x_i.

The two shortcomings of ICSA lead us to consider a simplified self-assessment (SSA) tax mechanism that was proposed by Levmore (1982). SSA is similar to ICSA but with one significant distinction: the assessed property tax is a fixed percentage of the declared value. This eliminates the need for the government to estimate the probability functions for each parcel of land. It also eliminates the collusive holdout strategies because an increase in a neighbor's declared value does not decrease the owner's tax obligation.

Under the SSA tax mechanism[11] an owner would maximize the same expected utility as given by equation (1) but with $T(x)$ set equal to a constant tx where t is the tax rate:

$$E[U(\pi)] = p(x)U(x - tx) + \big(1 - p(x)\big)U(r - tx). \quad (5)$$

The first order condition implied by Equation (5) is

$$dE[U(\pi)]/dx = (dp(x)/dx)[U(x - tx) - U(r - tx)] + U'(x - tx)(1 - t)p(x)$$

$$-U'(r - tx)t\big(1 - p(x)\big) = 0 \quad (6)$$

which, for a risk-neutral seller implies

$$x - r = -(p(x) - t)/(dp(x)/dx).$$

Thus, an owner would truthfully reveal his value only if he believed the tax rate was equal to the probability of an assembler purchasing his property. If an owner believes the flat tax rate is lower (higher) than the probability of an assembler purchasing his property, then he would be inclined to declare a value greater than (less than) his reservation value. Thus, while the SSA tax

[11] We use the same notation as in Section 3.1.

mechanism addresses the two drawbacks to the ICSA tax mechanism, it is not generally incentive compatible.

4. Experiment Design

The ICSA and SSA mechanisms entail two changes to the status quo. First, they eliminate the need for haggling between the developer and landowners. To aggregate a set of properties the developer need only visit the tax office and confirm that her maximum willingness-to-pay exceeds the sum of the self-assessments. Second, it alters the tax code. Under the status quo a landowner's tax assessment is unaffected by his decisions in the negotiation; the land is reassessed only upon sale to the developer. This introduces a tax wedge between the parties that may inhibit assembly. ICSA and SSA eliminate the tax wedge and impose a cost on the landowners for overstating their true reservation values.

For this study, we focus our analysis on the second point – alteration of the tax. (We consider the advantage of allowing assembly without negotiation in Section 6.) To isolate the tax effect, we conducted experiments for three treatments. Our *Ultimatum* treatment represents an intermediate regime between the status quo and self-assessment (ICSA/SSA). In this treatment property taxes were collected from the holder of the property (at the end of the negotiation), and the property value was reassessed upon sale. Each landowner submitted an ultimatum price that the developer could accept or reject, as in a self-assessment regime. The *ICSA* treatment corresponds to PT's self-assessment mechanism, and the *SSA* treatment represents a simplified (and more easily implemented) version of PT's mechanism. Comparing *Ultimatum* to *ICSA* (*SSA*) allows us to measure the effect of altering the tax code.

Our treatment design is shown in Table 1. For each treatment we ran three sessions of experiments with 10 negotiations per session, giving us 30 negotiations per treatment. Below we describe the design elements that were common to all three treatments. In subsequent subsections we describe the design elements that were unique to each treatment.

4.1 Common design elements

In every experiment the participants were partitioned into groups with one developer (called the buyer) and four landowners (called the sellers). The sellers were assigned values for their property denominated in Economic Currency Units (ECU), with an exchange rate of 15,500 ECU to one US dollar. The buyer was assigned a value strictly for the combination of all four properties (not for any individual property). In each treatment the sellers simply declared a price for their property and the buyer bought the properties if it was profitable to do so given the declared prices. Since there was no role for strategic decision-making in the buyer's role, a computer (robot) served as the buyer.

The sellers' reservation values were drawn independently with replacement from a discrete uniform distribution with support [100,000, 150,000] and rounded to the nearest thousand. The buyer's value was a number drawn at random from the discrete uniform distribution [300,000, 1,250,000] and rounded to the nearest thousand. Both the buyer's and sellers' values were private information, but the distributions from which they were drawn were common knowledge.[12]

The properties all began with an assessed value of 100,000 ECU, the lower bound of the sellers' value distribution. This simulates a land market in which the equilibrium price is 100,000

[12] The lower bound of the buyer's value distribution was less than four times the upper bound of the sellers' value distribution, so that there was a nonzero probability that assembling the land would be inefficient. This design element was necessary to ensure that $dP(x_i)/x_i < 0$ for x_i within the range of the sellers' value distribution.

ECU. All sellers' values were greater than or equal to this equilibrium price because a seller with a property worth less to him than the equilibrium price would have already sold it. The assessed value was the basis for calculating property taxes, which varied in each treatment.

The sellers' earnings depended on whether they sold their property and the tax regime. A seller who sold his property to the buyer earned the price at which he sold (minus tax in the *ICSA* and *SSA* treatments). A seller who did not sell his property earned his value for the property (minus tax in all treatments). We conducted three sessions of experiments for each treatment. In every session we recruited enough participants for five groups to negotiate simultaneously. After the first negotiation we partitioned the participants into new groups. No participants who had been grouped together in the first negotiation were grouped together in the second. We followed this re-grouping procedure to prevent participants from engaging in repeated game strategies. This design gives us observations from 30 independent negotiations in each treatment.

Before conducting any experiments, we randomly generated buyer and seller values for 30 negotiations. To make comparisons across treatments as accurate as possible we used the same value draws for every treatment. These value draws are displayed in Table 2. Of the 30 negotiations, assembly was efficient in 24 (80%). We refer to these as the "positive-sum" negotiations. In the remaining six (20%) negotiations the properties were more valuable in the hands of the sellers. The available gains from trade in the positive-sum negotiations ranged between 5,000 and 765,000 ECU, with an average of 379,000 ECU.

The experiments were facilitated by a graphical software interface which displayed a grid of four properties, each numbered 1 – 4 with a house icon. On each seller's screen one of the grid numbers was highlighted yellow to indicate which property belonged to him. All participants' screens also displayed their values, the distributions from which the buyer's and sellers' values were drawn and their private exchange rate. Sellers could communicate with each other via a text chat function. Allowing the participants to communicate was an important part of the experimental design because it gave sellers in the *ICSA* treatment the best chance of following cooperative strategies to lower their tax burdens and raise their expected earnings.

4.2 Design Elements of the *Ultimatum* Treatment

In the *Ultimatum* treatment, we informed the sellers that a value had been selected for the buyer in their group and that the computer software would compare their total price plus 10% property tax to that value to determine whether they would sell their properties. Given the flat tax rate, there was no dominant strategy in the *Ultimatum* treatment. Assuming there are N risk neutral sellers and the buyer's value is drawn from a uniform distribution with support $[A, B]$ (as above), seller i should maximize the following expected utility function

$$E[U(\pi_i)] = \frac{B - x_i - X_{-i}}{B - A}(x_i) + \left(1 - \frac{B - x_i - X_{-i}}{B - A}\right)(r_i - tx_i). \tag{7}$$

This yields the following first order condition:

$$x_i = \frac{1}{2(1+t)}[B + At + r_i - (1+t)X_{-i}]$$

which represents seller i's best response to the sum of his neighbors' declarations, X_{-i}. If seller i believes his neighbors are maximizing the same expected utility function, then his equilibrium declaration is given by

$$x_i^* = \frac{B + At + Nr_i - R_{-i}}{(N+1)(1+t)}$$

where R_{-i} represents the reservation values of seller i's neighbors.[13,14] Note that this best response function leads sellers to overstate their valuations in our experiments.

Suppose, for example, seller i has a value equal to his expected value of $125,000 and he assumes his three neighbors' values are the same as his. Then his optimal declaration would be $255,455, more than double his true value. If the other three sellers adhered to the same strategy, then their optimal declarations would be the same as those of seller i.

The sellers' screens in the *Ultimatum* treatment allowed sellers to submit a price declaration to the buyer via a "Send Price Declaration" Button. They also were equipped with a graphing tool to allow the sellers to visualize their expected earnings as a function of their price declaration. A seller could enter the prices he expected the other three members of his group to declare in text boxes, then click a button marked "Generate." The tool generated a line graph with the expected earnings on the y-axis and the declaration range on the x-axis. The participants could select regions of the graph to zoom in on. They could also mouse over a point on the curve to see the exact expected earnings that would occur from a specific declaration.

Negotiations lasted for a single round. For the first 20 minutes of the round the sellers could communicate with each other through free-form text. The contents of the communication were saved to a chat log. During this time, they could also explore the expected earnings function using the graphing tool. After the 20 minutes had elapsed they were prompted to submit a price declaration. Once all sellers had submitted their price declarations every seller's declaration was publicly displayed below his house. If the buyer's value exceeded the sum of declared prices plus

[13] Refer to Appendix A for details of these derivations.
[14] Note that the equilibrium declaration depends on the other sellers' values, whereas the best response function depends upon their declarations.

tax, then every house icon turned green as well. If the buyer purchased the land the sellers were paid their declared prices, otherwise they were paid their values minus 10,000 ECU in property taxes.

4.3 Design Elements of the *ICSA* Treatment

The *ICSA* treatment was identical to *Ultimatum* except for the assessment of property taxes. Following PT, in the *ICSA* treatment we set a seller's tax function equal to the integral of the probability function that the buyer would choose to purchase his property, based on his declaration and the declarations of his neighbors. The probability that the robot buyer would purchase a seller's property was equal to the probability that its value draw exceeded the sum of the four sellers' declarations. Using the same notation as in Section 4.2, the probability that seller *i*'s property will sell given his neighbors' declarations, X_{-i}, is:

$$p_i(x_i; X_{-i}) = \begin{cases} 1 & \text{if } x_i + X_{-i} < A \\ \dfrac{B - x_i - X_{-i}}{B - A} & \text{if } A \le x_i + X_{-i} \le B \\ 0 & \text{if } B < x_i + X_{-i} \end{cases} \quad (7)$$

Taking the integral of (7) and setting the constant term to zero we have the tax function:

$$T_i(x_i; X_{-i}) = \int_0^{x_i} p_i(z; X_{-i}) dz$$

$$= \begin{cases} x_i & \text{if } x_i + X_{-i} < A \\ \dfrac{-1}{B - A}\left[\dfrac{1}{2}x_i^2 - (B + X_{-i})x_i\right] & \text{if } A \le x_i + X_{-i} \le B \\ 0 & \text{if } B < x_i + X_{-i} \end{cases} \quad (8)$$

Tax function (8) is not wholly satisfactory because if a seller offers a declaration greater than $B - X_{-i}$ he can unilaterally reduce his tax burden to zero. This is because the probability of sale is non-decreasing in x_i once the sum of all declarations exceeds the upper bound of the buyer's value distribution. We addressed this by defining a maximum declaration that was dependent on the declarations of the other sellers: $x_i^* = B - X_{-i}$. If seller *i* submitted a declaration $x_i > x_i^*$, then we used x_i^* to calculate his tax (though x_i was still used for the total price presented to the robot buyer).

Also note that if $x_i + X_{-i} < A$ then the probability that the buyer would purchase the properties is equal to 1, and the integral of this region of the probability function would imply a tax equal to x_i. In this case the tax would exactly equal the price the seller was paid for his property, leaving him with a payoff of zero. Thus, the sellers would have no incentive to collusively understate their values. To simplify the description of the tax function for our participants, we used the following tax function:

$$T_i(x_i; X_{-i}) = \begin{cases} \frac{-1}{B-A}\left[\frac{1}{2}x_i^2 + (B - X_{-i})x_i\right] & \text{if } x_i < B - X_{-i} \\ \frac{-1}{B-A}\left[\frac{1}{2}x_i^{*2} + (B - X_{-i})x_i^*\right] & \text{if } x_i \geq B - X_{-i} \end{cases}. \quad (9)$$

Figure 1 illustrates the theoretical tax function (8) as well as the implemented tax function (9). The graph assumes that the buyer's value range is [300,000, 1,250,000] – as in our experiments – and seller *i*'s neighbors' declarations are equal to zero. Notice that within the buyer's value range the functions are identical. Above the upper bound of the buyer's value range the theoretical tax falls to zero, while the implemented tax function is constant, ensuring that participants could not unilaterally eliminate their own taxes. Below the lower bound of the buyer's value range the implemented tax function assesses a higher tax than the theoretical one. Thus, under both tax functions sellers have no incentive to collusively set the total price below the lower bound of the buyer's value distribution. Because of the complexity of the property tax formula we added the ability to graph the tax formula to the sellers' graphing tool. A drop-down menu allowed them to choose whether to graph the expected earnings or property taxes. Figure 2 provides close-up images of the graphing tool in the *ICSA* treatment.

The sellers received their price declarations if the buyer purchased the properties and received their values otherwise. In either case they paid the assessment tax. As a result, there was no tax wedge between the total price declared by the sellers and the price paid by the robot buyer. In our experiments each seller's declaration could have a large impact on the probability of assembly, so the equilibrium assessment taxes were very high. For instance, in a group where all four sellers' values were 125,000 ECU and they truthfully declared these values, the assessment tax would be roughly 106,700 ECU per seller, so that each would earn approximately 18,300 ECU.

Notice, however, that tax function (9) is decreasing in X_{-i}, which created room for tax avoidance through collusive holdout. In the extreme, if $X_{-i} \geq B$ then seller i would pay no tax, because the probability of assembly would be zero regardless of his declaration. Thus, if each of the four sellers agreed to declare a price greater than or equal to one third of the upper bound of the buyer's value distribution then the sellers would all keep their property and pay no tax, capturing the full consumption value of their land: 125,000 ECU. This would be almost 600% higher than their earnings from truthfully declaring their values. The high potential earnings from collusion make these experiments a formidable stress test of the ICSA mechanism.[15] Allowing the sellers to communicate gave them the best chance of coordinating on such a strategy.

4.4 Design Elements of the *SSA* Treatment

[15] In our experiments the cooperation of only four sellers was necessary for successful collusion. It is possible that collusion would be more difficult to achieve for a large number of sellers. Thus, our design stress tests ICSA not only in the incentives to collude but in the ease of doing so.

The basic features of the *SSA* experiments were the same as those of the *ICSA* experiments. The only distinction is that the assessment tax was 10% of the seller's price declaration, as in *Ultimatum*. Consequently, there was no dominant strategy in the *SSA* treatment. Assuming there are N risk neutral sellers and the buyer's value is drawn from a uniform distribution with support $[A, B]$ (as above), seller i should maximize the expected utility function:

$$E[U(\pi_i)] = \frac{B - x_i - X_{-i}}{B - A}(x_i - tx_i) + \left(1 - \frac{B - x_i - X_{-i}}{B - A}\right)(r_i - tx_i). \qquad (7)$$

This yields the following first order condition:

$$x_i = \frac{B - t(B - A) + r_i - X_{-i}}{2}$$

which represents seller i's best response to the sum of his neighbors' declarations, X_{-i}. If seller i believes his neighbors are maximizing the same expected utility function, then his equilibrium declaration is given by

$$x_i^* = \frac{B - t(B - A) + Nr_i - R_{-i}}{N + 1}$$

where R_{-i} represents the reservation values of seller i's neighbors.[16,17] Note that this best response function leads sellers to overstate their valuations in our experiments.

Suppose, for example, seller i has a value equal to his expected value of $125,000 and he assumes his three neighbors' values are the same as his. Then his optimal declaration would be

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[16] Refer to Appendix A for details of these derivations.
[17] Similar to the *Ultimatum* treatment, note that the equilibrium declaration depends on the other sellers' values, whereas the best response function depends upon their declarations.

$256,000, more than double his true value. If the other three sellers adhered to the same strategy, then their optimal declarations would be the same as those of seller i.

To allow the participants to earn the same amount in the *ICSA and SSA* treatments as in the *Ultimatum* treatment while keeping their exchange rates the same, we made the taxes revenue neutral by redistributing all self-assessed taxes back to the sellers in the form of a bonus. Specifically, the taxes from one group were divided evenly and paid to the sellers of another group. Communication across groups was not allowed, so the bonus payments were exogenous from the recipient's perspective.

4.5 Expected Earnings in the Three Treatments

As noted in the Sections 4.2 – 4.4, declaring a price equal to one's reservation value was the Nash Equilibrium in the *ICSA* treatment, while declaring a price above value was the Nash Equilibrium in the *Ultimatum* and *SSA* treatments. In Table 3 we illustrate the effect on expected earnings with a numerical example. For each treatment we assume that all sellers' values are 125,000 ECU and that the seller's counterparts declare prices equal to the Nash Equilibrium given the treatment. We calculated the seller's expected earnings from declaring prices equal to value and 25,000 ECU above and below value, displayed in the top three rows. We also calculated the seller's expected earnings from declaring the Nash Equilibrium price, shown in the fourth row.

Notice that declaring a price below value is strictly dominated in all treatments. In *ICSA*, declaring a price 25,000 ECU above value is also dominated, reducing the seller's payoff by 329 ECU. In *Ultimatum* and *SSA* overstating the value by 25,000 would increase the seller's payoff by 6,829 ECU and 6,242 ECU respectively. Declaring the Nash Equilibrium price in *Ultimatum* and *SSA* would increase the seller's payoff by 19,705 ECU and 18,087 ECU relative to truthful declarations.

4.6 Procedures

All experiments were conducted at a university in the American Southwest. We randomly recruited a total of 180 participants (60 for each treatment) from an online database of approximately 1,500 volunteers. All participants were undergraduate or graduate students, and none participated in more than one session.

Before the experiment, participants were ushered into a computer laboratory and seated at stations separated by privacy dividers. One of the experimenters read the instructions aloud from a script, pausing at pre-determined points to answer questions. Screenshots of the user interface were projected on the screen at the front of the room.[18] After completing the instructions, one-page summary sheets of the instructions were distributed to the participants. Copies of the instructions, screenshots and summary sheets may be found in online appendices A, B, and C.

After the first negotiation an experimenter entered the lab to remind the participants that in the second negotiation they would be put in new groups that did not have any of their counterparts from the first negotiation. After the second negotiation the participants were paid in cash one by one. They received $7 for attending the experiment in addition to payment based on their decisions. The average participant earnings were $21.72 including the attendance bonus. The typical session lasted 90 minutes.

5. Results

[18] The instructions included a discussion of expected value so that the participants would understand the purpose of the graphing tool. We also showed the participants two short video clips on how to use the graphing tool.

To assess the impact of the different tax mechanisms on the land assembly problem, we consider three measures: seller premiums, assembly rates, and social welfare. Previewing the results, we find that seller premiums are significantly lower in ICSA than in SSA or Ultimatum. We do not find any significant differences between the treatments with respect to rates of assembly. And, finally, while more surplus is captured by the self-assessment mechanisms than the status quo, the difference between ICSA and SSA is not significant.

5.1 Seller Premiums

We begin by examining the amount sellers demanded in excess of their induced values. We refer to this amount as the *seller premium*. The seller premium gives us a measure of the frictions to assembly that buyers faced that can be compared across treatments. We measure the seller premiums by subtracting the sellers' values from their price declarations. Given ICSA's incentive compatibility the theoretical seller premium for this treatment is zero. In the *Ultimatum* treatment the buyer paid a 10% property tax assessed on the prices they had paid the sellers for their property. This put a tax wedge between the prices paid by the buyers and the prices received by the sellers. Thus, in *Ultimatum* the seller premiums must be tax-adjusted by adding the property tax a buyer would have to pay upon successful assembly.

Figure 3 displays the average seller premium for each treatment with gray columns and standard error bars. In the *ICSA* treatment there was a single group that collusively overstated their values to eliminate their tax burden. Three of the sellers in this group self-assessed at 1 million ECU, the fourth self-assessed at 1.25 million ECU. In Figure 3 we display two average premiums for the *ICSA* treatment: one including this group and one trimming it from the dataset as an outlier. When the outlier group is included, the average seller premium is more than 69,000 ECU, the highest of any treatment. Excluding this group reduces the average premium to less than

38,000 ECU – the lowest of any treatment – and reduces the standard error by almost 80%. We believe that the trimmed average better reflects the frictions to assembly that a developer would expect to face. Notice, however, that in either case the average is well above zero.

The average (tax-adjusted) seller premiums in the *Ultimatum* and *SSA* treatments are quite similar to each other, approximately 58,000 ECU and 52,000 ECU. However, both are at least 14,000 ECU (37%) greater than the average trimmed *ICSA* seller premium, and their standard error bars do not overlap with trimmed *ICSA* error bars.

To test for treatment effects, we fit the data to a regression model with the (tax-adjusted) seller premium as the dependent variable. The independent variables were dummy variables indicating whether the seller was in the *ICSA* or *SSA* treatment, the negotiation number and the seller's value. We also included random effects for each seller. We fit the model once to the full data sample and a second time omitting the four sellers who had submitted assessments of 1 million ECU or more. Sellers within a group likely influenced one another's decisions, so we clustered the standard errors by group. The estimates are displayed in Table 4.

Fitting our model to the full data sample we find no treatment effects. The estimated effect of the *ICSA* mechanism is an 11,129 ECU *increase* in seller premiums relative to *Ultimatum*, but the estimate is not statistically significant ($p = 0.498$). The *SSA* mechanism is estimated to reduce the seller premium by 5,693 ECU, but this estimate is also statistically insignificant ($p = 0.499$). A Wald test cannot reject the null hypothesis that the estimated coefficients for *ICSA* and *SSA* are equal ($p = 0.289$).

When we trim the outlier group, however, significant differences appear between *ICSA* and the other two mechanisms. The estimated tax-adjusted seller premium for *Ultimatum* – reflected in the constant term – is \$111,428 ($p < 0.001$). The estimated effect of the *ICSA* mechanism is a reduction in the seller premium of 19,178 ECU, or 17.2%. This estimate is statistically significant ($p = 0.011$). The estimated coefficient for the *SSA* treatment is negative but statistically insignificant ($p = 0.497$). However, a Wald test rejects the equality of the coefficients for the *ICSA* and *SSA* treatments ($p = 0.031$), so we may conclude that seller premiums were significantly lower in *ICSA* than in *SSA*. Notice also that the model estimates a negative and statistically significant coefficient on the sellers' values ($p = 0.019$), indicating that sellers with higher values demanded smaller premiums.

Why did sellers' assessments exceed their true values in the *ICSA* treatment? Collusive holdout could increase their profits because it allowed them to mutually reduce their tax burdens. However, a review of the chat logs in the *ICSA* sessions indicates that very few of them fully understood this. Participants discussed the tax benefits of collusion in only three of the 30 groups, and only one of these realized that they could pay zero taxes by holding out for more than the buyer's maximum value. Instead, most sellers seemed to take it for granted that the purpose of holding out was to sell at a price above their values, and they sought to avoid declaring prices so high that the buyer would reject their offers. The most common strategy that sellers discussed in the *ICSA* treatment was to coordinate a total price that was less than the buyer's expected value, so that the chances of success exceeded 50%.

5.2 Assembly

Figure 4 displays the rate of assembly by treatment in the positive-sum negotiations. In the *Ultimatum* treatment the buyers were able to acquire all four properties in 70.8% (17 of 24) of these negotiations. The assembly rate was 83.3% (20 of 24) in both the *ICSA* and *SSA* treatments. We tested for statistical significance with a logistic regression. The independent variable was a dummy indicating assembly (1 = success, 0 = failure). The independent variables were dummy variables for the *ICSA* and *SSA* treatments, the negotiation number and the amount of available surplus (scaled in 10,000 ECU). We limited the dataset to those observations where the available surplus was positive. The results are displayed in Table 5.

The estimated coefficients for both treatment dummies are positive but statistically insignificant ($p = 0.203$ in both cases). We cannot be confident that self-assessment taxation improved the assembly rate in our experiments. The model does indicate that assembly was more likely in negotiations in which more surplus was available. The estimated coefficient for the available surplus is positive and highly statistically significant ($p < 0.001$). This finding is encouraging because it indicates that holdout is less of a barrier when the development in question is of high value (provided the value is sufficiently uncertain from the sellers' perspective). The marginal effect is substantial for the *Ultimatum* treatment, but moderate for the *ICSA* and *SSA* treatments. If we set the available surplus to the observed mean (379,000 ECU) and assume that the participants are in their first negotiation, then an increase in available surplus of 10,000 ECU increases the probability of assembly by 1.6 percentage points in *Ultimatum* and 0.6 percentage points in *ICSA* and *SSA*.

5.3 Social Welfare

The customary measure of social welfare in laboratory experiments is efficiency, the earnings that the participants received divided by the maximum earnings they could have received. However, this measure has two shortcomings for our experiments. First, the participants were guaranteed to earn a certain amount regardless of their decisions, which inflates the measure. Second, the negotiations varied in the gains from trade that were available. Capturing 80% of 1,000,000 ECU generates more social welfare than capturing 100% of 10,000 ECU but dividing the achieved earnings by the maximum earnings treats the latter as a better outcome. Thus, we measure the social welfare as the gains from trade, or surplus, captured in the negotiation.

To calculate the surplus, we subtracted the earnings that the participants would have received if the buyer had never made an offer from their earnings at the end of the negotiation. We include the robot buyer's earnings in the calculated surplus. Across the 24 positive-sum negotiations there was a maximum available surplus of 9,096,000 ECU, with an average of 379,000 per negotiation. Figure 5 shows the average surplus per positive-sum negotiation achieved in each treatment, with standard error bars. (No negative-sum assemblies occurred in our experiments.)

In *Ultimatum* the participants gained approximately 310,000 ECU per negotiation, 82% of the available surplus. Gains from trade were higher under self-assessed taxation. Participants in *ICSA* improved their earnings by almost 350,000 ECU per negotiation, or 92% of the available surplus. *SSA* saw the highest average surplus, nearly 371,000 per negotiation. That is, in the *SSA* treatment the participants captured nearly 98% of the available surplus.

We tested the statistical significance of these results with an OLS regression. The variance of available surplus was large across negotiations. The minimum available surplus was 5,000 ECU, the maximum was 765,000 ECU. To remove this noise from the data, for each negotiation in the *ICSA* and *SSA* treatments we normalized the observed surplus by subtracting out the surplus captured in the equivalent negotiation in the *Ultimatum* treatment. Let S_{tn} represent the surplus captured in negotiation *n* of treatment $t \in \{ICSA, SSA\}$ and S_{un} represent the surplus captured in negotiation *n* of the *Ultimatum* treatment. Then normalized surplus equals $S_{tn} - S_{un}$.[19] After

[19] We also analyzed the surplus captured by buyers vs. sellers in each treatment. The results of this analysis are in Appendix B.

calculating these differences for all negotiations we test whether they are statistically different from zero with a regression model using normalized surplus as the dependent variable and including treatment dummies and the negotiation number as the independent variables. We held the regression constant fixed at zero to avoid perfect collinearity with the treatment dummies and to simplify their interpretation. Table 6 contains the estimates.

The results of the model indicate that participants captured more surplus under self-assessed taxation than in the *Ultimatum* treatment in their first negotiation, but not in their second. The estimated coefficients for *ICSA* and *SSA* are both positive and statistically significant (p = 0.036 and p = 0.020 respectively). The estimated effect of the negotiation number is negative, marginally statistically significant (p = 0.072) and roughly half the magnitude of the treatment dummies. If we set the negotiation number equal to one, the model estimates that participants generated 85,875 ECU more per negotiation in *ICSA* than in *Ultimatum*. An F-test of the hypothesis that the sum of the *ICSA* and negotiation number coefficients sum to zero falls just short of statistical significance at the 5% level (p = 0.051). Keeping the negotiation number equal to one, the model estimates that in the *SSA* treatment the participants generated 106,875 more per negotiation than in *Ultimatum*. This estimate is significant at the 5% level (F-test, p = 0.016). However, if we set the negotiation number equal to two then the estimated differences between the *Ultimatum* treatment and self-assessment treatments are -5,458 (*ICSA*) and 15,542 (*SSA*). Neither of these estimates is statistically significant (F-tests, $p > 0.7$ in both cases). Additionally, an F-test of the self-assessment treatment dummies cannot reject equality (p = 0.673), indicating that ICSA and SSA were equally effective at increasing gains from trade.

The gain in surplus relative to *Ultimatum* is due in part to the fact that there were more assemblies in the *ICSA* and *SSA* treatments. But in addition to that, many of the extra assemblies occurred in negotiations with substantial available surplus. Table 7 displays the available gains from assembly for each negotiation and indicates whether assembly occurred in each treatment. The negotiations are rank-ordered from highest available gains from assembly to lowest. There were 17 successful assemblies in *Ultimatum*, generating a total surplus of 7,430,000 ECU. If we look at the 17 highest-surplus assemblies in the *ICSA* treatment they generated total gains from trade of 7,926,000 ECU. In the *SSA* treatment the top 17 assemblies generated 8,032,000 ECU of surplus.

5.4 Robustness Checks Using Synthetic Treatments

Our experimental results on assembly rates and gains from trade are due in part to the "luck of the draw." When the sellers in our experiments submitted their price declarations they did not know what value had been drawn for the buyer. There were cases in which a group of sellers asked for barely more or less than the buyer's value. For instance, one group in the *Ultimatum* treatment set a total (tax-adjusted) price of 990,000 ECU when the buyer's value was 960,000 ECU. A group in the *ICSA* treatment set a total price of 819,000 ECU when the buyer's value was 832,000 ECU. There were also cases in which total prices with a high *ex ante* probability of being below the buyer's value draw turned out to be above it, and vice versa. One group in the *ICSA* treatment asked for a total of 568,000 ECU, which had a 72% probability of being less than the buyer's value. The value turned out to be 507,000. A group in the *SSA* treatment asked for a total of 900,000 ECU, which had only a 37% probability of being less than the buyer's value. In a stroke of good luck, the actual value draw was 1,172,000 ECU.

Given the role chance played in our results, we test the robustness of our findings by considering what the results would have been with different sets of value draws for the robot buyers. We conducted a series of 10,000 simulated sessions for each treatment. In a given simulation, we drew 30 new values for the robot buyer independently from the uniform distribution [300,000, 1,250,0000], rounding to the nearest thousand. We then compared the sellers' total (tax-adjusted) prices to the new values, recording whether or not an assembly would have occurred, the gains from trade (if any), and the amount of surplus captured by the buyer and sellers. To keep the results as comparable as possible across treatments, we compared the total prices from a given negotiation in each treatment to the same value draw. Because the simulations combined real human decisions with simulated value draws, we refer to them as *synthetic treatments*. The synthetic treatments allow us to observe the results that would occur from the sellers' decisions if the role of chance were averaged out through very large sample sizes.

For the synthetic treatments the unit of observation is not at the level of the negotiation, but rather at the level of the simulation, i.e. all 30 negotiations with new buyer value draws. There are three primary metrics of interest for each synthetic treatment. These are the percent of positive-sum negotiations that resulted in assembly (i.e., the "efficient assembly rate"), the percent of negative-sum negotiations that resulted in assembly (i.e., the "inefficient assembly rate"), and the total surplus per simulation.[20] We compared treatments on their performance on these metrics using pair-wise Mann-Whitney U tests. The z-statistics for each comparison are presented in Table 8. Note that there are only two comparisons for which the null hypotheses cannot be rejected with 95% confidence: the inefficient assembly rate of the *Ultimatum* and *ICSA* treatments ($p = 0.780$) and the total surplus of the *ICSA* and *SSA* treatments ($p = 0.893$). For all other comparisons the null is rejected with greater than 99.9% confidence ($p < 0.001$ in all cases).

[20] Two additional metrics, buyer surplus per simulation and seller surplus per simulation, are considered in Appendix B.

The sizes of the observed effects are also of interest, particularly since the effects are almost all statistically significant. We measured effect sizes with Cohen's *d*, dividing the difference between two synthetic treatments' means by their pooled standard deviation. We use the effect size cutoffs suggested by Cohen (1988) and Sawilowsky (2009). That is, $d \geq 1.2$ implies a very large effect size, $d \geq 0.8$ a large effect size, $d \geq 0.5$ medium and $d \geq 0.2$ small. A $d < 0.2$ implies a very small effect size. Table 9 displays the Cohen's *d* values for every pair-wise comparison of our three metrics. We will refer to the values in Table 9 in our discussion below.

Figure 6 displays the average efficient assembly rates for the three synthetic treatments. The performance in all the synthetic treatments is lower than in the experiments: 68.8% in *Ultimatum*, 76.3% in *ICSA* and 72.0% in *SSA*. Notice also that the difference in efficient assembly is smaller in the synthetic treatments than it was in the experiments. Still, each treatment is statistically significantly different from the other two. The effect size between *Ultimatum* and *ICSA* is large ($d = 0.84$), while the effect size between *Ultimatum* and *SSA* is small ($d = 0.34$).

Figure 7 displays the average inefficient assembly rates for the synthetic treatments. There were no inefficient assemblies in our experiments, but with a sufficient number of simulations there were a small number of such assemblies in the synthetic *Ultimatum* and *ICSA* treatments. In each of these the inefficient assembly rate was 0.6%, and these are statistically indistinguishable. There were no inefficient assemblies in the synthesized *SSA*, which is statistically significantly lower than the other synthetic treatments. The effect size is small between *Ultimatum* and *SSA* ($d = 0.27$) and between *ICSA* and *SSA* ($d = 0.26$).

The average gains from trade in the synthetic treatments are displayed in Figure 8. Note that the gains from trade were almost identical in the *ICSA* and *SSA* treatments (8.04 million ECU vs. 8.05 million ECU). Even though the efficient assembly rate was higher in the synthetic *ICSA* treatment than in synthetic *SSA*, the inefficient assembly rate was lower in synthetic *SSA*. These two effects counterbalanced each other, leading to parity in gains from trade. Both synthetic self-assessment treatments captured more gains from trade than the synthetic *Ultimatum* treatment, but the difference is not large. The effect size between the synthetic *Ultimatum* and *ICSA* treatments is very small (d = 0.16), as is the effect size between the synthetic *Ultimatum* and *SSA* treatments (d = 0.17). If we compare the realized gains from trade to the maximum gains available, the synthetic *Ultimatum* earned 87% of the available gains on average, while the synthetic *ICSA* and *SSA* both earned 90%.

6. Our Results in the Context of the Experimental Land Assembly Literature

The results of our experiments and simulations do not show a large improvement in assembly and social welfare from self-assessment mechanisms relative to ultimatum bargaining. However, developers are more likely to pursue land assembly through an iterative negotiation process with landowners. Thus, it is worth comparing the results reported here to those of other studies in the experimental land assembly literature that use negotiation rather than ultimatum offers. We will focus on two studies: DeSantis, McCarter & Winn (2019) and Collins & Isaac (2012).

The study by DeSantis, McCarter & Winn (2019) is most directly comparable to the present study because both use the same experimental environment: a single buyer, four sellers and values drawn from the same distributions. In fact, we used precisely the same value draws in both studies and gave them to the participants in the same order. The only difference is in the bargaining institution. We will focus in particular on the *Baseline* treatment discussed in DeSantis, McCarter & Winn (2019).

In the *Baseline* the role of buyer was played by a human participant, not a robot. The buyer and sellers negotiated for up to five periods. Each period began with the sellers submitting nonbinding price requests to the buyer. The buyer then either aborted the negotiation or sent binding offers to the sellers, which they could accept or reject. If at least one seller rejected his offer negotiations continued to the next round. (Before submitting their price requests and before accepting or rejecting the buyer's offers the sellers were allowed to communicate with each other via text chat. Communication between buyers and sellers was restricted to the price requests and offers.) If a seller accepted the buyer's offer the sale occurred even if other sellers had rejected their offers. That is, contracts were non-contingent.

The tax framework was the same as in *Ultimatum*. Sellers owed 10,000 ECU in tax if they kept their property, but owed no tax if they sold. Buyers owed 10% of the prices they paid if they assembled all four properties. If the negotiations ended and the buyer had assembled fewer than four properties, she sold them back to the experimenter for 100,000 ECU each, and paid no tax.

The buyer started each negotiation with 350,000 in cash that served as an opportunity cost to negotiation. Delay was costly to the buyer, but not the sellers. The buyer had an earnings multiplier that started at 100%. The multiplier was reduced to 95% if the buyer failed to assemble all properties by the end of period one, 90% if she failed to assemble them by the end of period two, etc. This multiplier was applied to the buyer's cash on hand and – if assembly was achieved – her induced value for assembly.

Efficient assembly was just 50% in the *Baseline* treatment, considerably less than in any of the treatments we conducted for the present study. Because the economic environment was the same in both studies, we can compare our treatments to the *Baseline* with a logistic regression, controlling for negotiation number and available surplus, as in Section 5.2 above. The omitted treatment dummy is *Baseline*.

The results are displayed in Table 10. Both *ICSA* and *SSA* have positive, statistically significant coefficients (p = 0.006 in both cases), indicating that self-assessment is effective in increasing land assembly relative to bilateral bargaining with non-contingent contracts and costly delay. The estimated coefficient for *Ultimatum* is positive but it is only marginally statistically significant (p = 0.075) and is not statistically significantly different than the *ICSA* or *SSA* coefficients (Wald test, p = 0.198 in both cases). Thus, the efficient assembly rate appears to be intermediate under ultimatum offers, relative to negotiation and self-assessment.

The use of a human buyer by DeSantis, McCarter & Winn (2019) constitutes an uncontrolled variable when comparing the outcomes in the *Baseline* to the treatments in the present study, so these results should be interpreted with caution. Still, it is worth noting that adopting a self-assessment regime would put developers in a position to move forward with projects that would be profitable given the landowners' assessments. Under such circumstances – particularly where there is robust competition among developers – we would expect human developers to operate on the same principle as our robot buyers, assembling any group of properties that offers a positive economic profit.

We now turn to Collins & Isaac (2012). Like DeSantis, McCarter & Winn (2019), their experiments also consisted of a single buyer negotiating with four sellers. The sellers' values were drawn independently in cents from a uniform distribution with support [100, 300]. The buyer's value was equal to the sum of the sellers' values plus a random number of cents drawn at random from a uniform distribution with support [300, 1,100]. Offers were made by the buyer to the sellers, who chose to accept or reject. However, the buyer could communicate with the sellers via text chat. The sellers could also communicate with each other via text chat. The participants had 12 minutes to negotiate. Unlike DeSantis, McCarter & Winn (2019), Collins & Isaac (2012) imposed no delay cost on the buyer, but did not allow her to sell properties back to the experimenter if she assembled fewer than four.

Collins & Isaac (2012) studied two treatment variables. The first was whether the buyer was operating under a capital constraint. In the capital constraint treatment, the buyer had 740 cents in working capital that limited the prices she could offer the sellers. Specifically, the buyer could spend no more than 740 cents on acquiring the first three properties. Once the third property was acquired, the capital constraint was removed and she could offer the remaining seller a price up to her assembly value minus the prices she had already paid. In the contingent contracts treatment the buyer did not actually pay any of the sellers unless and until all four of them had accepted her offers. The buyer still started with 740 cents in cash, but it did not limit her offers. The second treatment variable was whether the buyer's value for assembly, working capital and the number of completed contracts was known only to the buyer or was public information available to all participants. This treatment variable had no impact on the assembly rate, so we pool the results, focusing only on whether or not there was a capital constraint.

Collins & Isaac (2012) report that in their capital constrained negotiations, the buyer was successful in approximately 46% of negotiations, while buyers who had access to contingent contracts were successful in almost 94% of negotiations. Recall that the efficient assembly rate in our self-assessment treatments was 83.3%. This is an improvement of 81% relative to their capital constrained negotiations, and only 11% below their contingent contracts negotiation.

A pessimistic read of the evidence may lead one to question the utility of self-assessment, as it has a lower assembly rate than contingent contracts in laboratory experiments. However, it is important to note that self-assessment does not preclude negotiation between developers and landowners. Rather, it establishes a maximum price that developers may pay if they choose to forego negotiation, or if negotiation fails. A developer who faces neither a capital constraint nor significant delay costs may treat the self-assessed prices as the landowners' opening offer and try to bargain them down to a lower price. (The fact that most of our sellers' self-assessments exceeded their value suggests that this approach would be profitable.) On the other hand, a developer who faces high costs from delay could pay the self-assessed prices and avoid negotiation. Similarly, capital constraints would be of little practical importance if the developer could calculate the total price of assembly *ex ante* and take this figure to a bank or credit markets. Thus, self-assessment would reduce the transaction costs of delay and capital constraints in precisely those circumstances where they are barriers to assembly.

7. Conclusion

We tested the ability of two self-assessment mechanisms to facilitate land assembly by comparing them to a variant of the status quo (eminent domain). In particular, we designed our experiments to focus on the effect of each mechanism's tax function. Although our baseline, Ultimatum, did not allow for bilateral negotiation, it did utilize the status quo's tax mechanism, thus enabling our analyses. Self-assessment increased assembly by 12.5 percentage points and gains from trade by 10 – 16 percentage points relative to ultimatum bargaining. However, the first effect is statistically insignificant and the second is transitory. On the other hand, prior studies by Collins & Isaac (2012) and DeSantis, McCarter & Winn (2019) have found that when buyers face negotiating frictions – such as capital constraints or costly delay – the rate of assembly is 50% or less. In our self-assessment treatments the efficient assembly rate was 83.3%, a substantial improvement.

Implementing ICSA in the field would require substantial effort and resources to estimate the sale probability functions for every piece of land in a jurisdiction. Moreover, if landowners in that jurisdiction did not trust that the government had accurately estimated the probability functions then the mechanism may not be as effective in the field as in our laboratory. In contrast, SSA would be straightforward to implement, and – in our experimental environment – delivers a similar rate of assembly and level of gains from trade.

Certain aspects of self-assessment may raise popular objections that could make its implementation politically difficult. Landowners may be reluctant to accept a tax regime in which they may owe tax on a property for some period even after selling it. Still, this would affect a relatively small number of owners in a given year, and it may be mitigated by selling property on or near the date that a new declaration is due or incorporating the leftover tax payment into the sale price of the property. Another objection may be the risk that any private citizen may exercise a purchase option on another's property at any time. This may be addressed by restricting the right to purchase to the municipal, state and federal governments. Whatever the political viability of self-assessment may be, it is our hope that the performance of these mechanisms in the laboratory will spur more research into alternatives to eminent domain. There may be other mechanisms yet untested that satisfy the dual constraints of economic efficiency and political palatability.

Beyond the discussion of eminent domain, our findings contribute to the conversation about the tragedy of the anti-commons, of which the land assembly problem is a special case. In an anti-commons dilemma, multiple agents own separate inputs to a valuable output (Heller, 1998). The veto power of multiple agents can hinder economic efficiency. Anti-commons scholars submit that structural solutions – those that often require a superordinate authority to coordinate – provide a necessary means for navigating such land social dilemmas (e.g., Heller, 2008). Our results demonstrate that there are (at least) two structural solutions to the tragedy of the anti-commons in land assembly. Posner and Weyl (2017) have argued that such structural solutions should be applied to all goods and services generally, and the findings we present may be taken as evidence in their support. A fruitful direction for future research would be to test self-assessment in other markets, such as electromagnetic spectrum and personal property. This would allow scholars to identify the limits (if any) of self-assessment as a means of improving social welfare.

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Table 1. Treatment Design

Treatment	**Sessions**	**Negotiations per Session**	**Total Negotiations**
Ultimatum	3	10	30
Incentive Compatible Self-Assessment (ICSA)	3	10	30
Simplified Self-Assessment (ICSA)	3	10	30
Total:	**9**		**90**

Table 2. Buyer and Seller Values in ECU

Session	Negotiation	Group	Buyer Value	Seller 1 Value	Seller 2 Value	Seller 3 Value	Seller 4 Value	Total Seller Value	Gains from Assembly
1	1	1	815,000	109,000	147,000	102,000	110,000	468,000	347,000
1	1	2	312,000	135,000	126,000	145,000	106,000	512,000	(200,000)
1	1	3	1,201,000	125,000	128,000	132,000	101,000	486,000	715,000
1	1	4	363,000	107,000	147,000	132,000	124,000	510,000	(147,000)
1	1	5	832,000	146,000	136,000	104,000	109,000	495,000	337,000
1	2	1	1,224,000	102,000	119,000	122,000	116,000	459,000	765,000
1	2	2	950,000	114,000	123,000	127,000	147,000	511,000	439,000
1	2	3	816,000	124,000	119,000	108,000	128,000	479,000	337,000
1	2	4	391,000	135,000	100,000	118,000	121,000	474,000	(83,000)
1	2	5	663,000	145,000	104,000	144,000	138,000	531,000	132,000
2	1	1	768,000	121,000	102,000	117,000	143,000	483,000	285,000
2	1	2	507,000	142,000	113,000	105,000	142,000	502,000	5,000
2	1	3	828,000	142,000	106,000	123,000	116,000	487,000	341,000
2	1	4	555,000	142,000	136,000	109,000	116,000	503,000	52,000
2	1	5	1,051,000	121,000	120,000	102,000	138,000	481,000	570,000
2	2	1	499,000	140,000	129,000	147,000	117,000	533,000	(34,000)
2	2	2	524,000	120,000	148,000	124,000	124,000	516,000	8,000
2	2	3	870,000	132,000	147,000	132,000	111,000	522,000	348,000
2	2	4	902,000	103,000	106,000	122,000	126,000	457,000	445,000
2	2	5	1,172,000	131,000	112,000	134,000	114,000	491,000	681,000
3	1	1	686,000	100,000	100,000	113,000	128,000	441,000	245,000
3	1	2	870,000	139,000	135,000	145,000	109,000	528,000	342,000
3	1	3	960,000	128,000	125,000	130,000	139,000	522,000	438,000
3	1	4	444,000	106,000	123,000	141,000	122,000	492,000	(48,000)
3	1	5	953,000	135,000	125,000	147,000	105,000	512,000	441,000
3	2	1	884,000	144,000	116,000	113,000	109,000	482,000	402,000
3	2	2	417,000	142,000	113,000	150,000	125,000	530,000	(113,000)
3	2	3	1,144,000	147,000	120,000	135,000	122,000	524,000	620,000
3	2	4	871,000	102,000	148,000	135,000	128,000	513,000	358,000
3	2	5	902,000	139,000	115,000	102,000	103,000	459,000	443,000

Table 3. Expected earnings from various price declarations. All participants are assumed to have a reservation value of 125,000 ECU and the seller's counterparts are assumed to play the Nash Equilibrium. Nash Equilibrium bids are 255,455 ECU (*Ultimatum*), 125,000 ECU (*ICSA*) and 256,000 ECU (*SSA*).

Seller's Declaration	**Expected Earnings**		
	Ultimatum	ICSA	SSA
100,000	108,943	17,763	104,749
125,000	117,219	18,092	112,306
150,000	124,048	17,763	118,548
Nash Equilibrium	136,924	18,092	130,393

Table 4. Estimates from random effects regression on seller premiums. (Premiums are tax-adjusted in the *Ultimatum* treatment.)

Variable	Full Sample Coefficient (Std. Err.)	Trimmed Sample Coefficient (Std. Err.)
Constant	126,976*	111,428***
	(51,968)	(23,111)
ICSA Treatment	11,129	-19,178*
	(16,427)	(7,549)
SSA Treatment	-5,693	-5,693
	(8,422)	(8,387)
Negotiation Number	20,050†	-522
	(11,065)	(4,012)
Seller's Value	-0.798†	-0.425*
	(0.450)	(0.181)
Observations	360	356
Overall R^2	0.025	0.041
Wald χ^2	7.03	16.58

†Significant at 10%, * Significant at 5%, ** Significant at 1%, *** Significant at 0.1%

Table 5. Estimates from logistic regression on successful assembly of properties in negotiations with positive available gains from trade.

Variable	Coefficient (Std. Err.)
Constant	-2.65†
	(1.45)
ICSA Treatment	1.18
	(0.73)
SSA Treatment	1.18
	(0.86)
Negotiation Number	0.22
	(0.76)
Available Surplus	0.10***
(in 10,000s)	(0.02)
Observations	72
Pseudo R^2	0.361
Likelihood Ratio χ^2	26.59

†Significant at 10%,* Significant at 5%, ** Significant at 1%, *** Significant at 0.1%

Table 6. Estimates from OLS regression on normalized surplus.

Variable	Coefficient (Std. Err.)
ICSA Treatment	177,208* (82,091)
SSA Treatment	198,208* (82,091)
Negotiation Number	-91,333† (49,503)
Observations	48
Adjusted R^2	0.091
F-Statistic	2.59

†Significant at 10%, * Significant at 5%, ** Significant at 1%, *** Significant at 0.1%

Table 7. Successful assembly in each negotiation by treatment. Negotiations are listed in rank order of the available gains from assembly in ECU.

		Successful Assembly In		
Rank	Available Gains from Assembly	*Ultimatum* Treatment	*ICSA* Treatment	*SSA* Treatment
1	765,000	X	X	X
2	715,000	X	X	X
3	681,000	X	X	X
4	620,000	X	X	X
5	570,000		X	X
6	445,000	X	X	X
7	443,000	X		X
8	441,000	X	X	X
9	439,000	X	X	X
10	438,000		X	X
11	402,000	X	X	X
12	358,000	X	X	X
13	348,000		X	X
14	347,000	X	X	X
15	342,000	X	X	X
16	341,000	X	X	X
17	337,000	X	X	X
18	337,000	X	X	X
19	285,000	X	X	X
20	245,000			X
21	132,000	X	X	
22	52,000		X	
23	8,000			
24	5,000			
25	(34,000)			
26	(48,000)			
27	(83,000)			
28	(113,000)			
29	(147,000)			
30	(200,000)			

Table 8. Pairwise z-statistics from Mann-Whitney U tests comparing outcomes between synthetic treatments.

	Efficient Assembly Rate	Inefficient Assembly Rate	Total Surplus
Ultimatum vs. *ICSA*	54.50***	-0.28	11.34***
Ultimatum vs. *SSA*	22.94***	-17.78***	11.25***
ICSA vs. *SSA*	33.02***	17.55***	-0.13

†Significant at 10%, * Significant at 5%, ** Significant at 1%, *** Significant at 0.1%

Table 9. Pairwise Cohen's d statistics of effect sizes between synthetic treatments.

	Efficient Assembly Rate	Inefficient Assembly Rate	Total Surplus
Ultimatum vs. *ICSA*	0.84	0.01	0.16
Ultimatum vs. *SSA*	0.34	0.27	0.17
ICSA vs. *SSA*	0.49	0.26	0.01

Effect size cutoffs: $d \geq 1.2$ (Very Large); $d \geq 0.8$ (Large); $d \geq 0.5$ (Medium); $d \geq 0.2$ (Small); $d < 0.2$ (Very Small)

Table 10. Estimates from logistic regression comparing assembly in the present study to assembly in the Baseline treatment of DeSantis, McCarter and Winn (2019).

Variable	Coefficient (Std. Err.)
Constant	-3.07^{*}
	(1.23)
Ultimatum Treatment	$1.38^{\dagger}$
	(0.77)
ICSA Treatment	2.57^{**}
	(0.93)
SSA Treatment	2.57^{**}
	(0.93)
Negotiation Number	-0.49
	(0.62)
Available Surplus	0.10^{***}
(in 10,000s)	(0.02)
Observations	96
Pseudo R^2	0.385
Likelihood Ratio χ^2	43.96

†Significant at 10%, * Significant at 5%, ** Significant at 1%, *** Significant at 0.1%

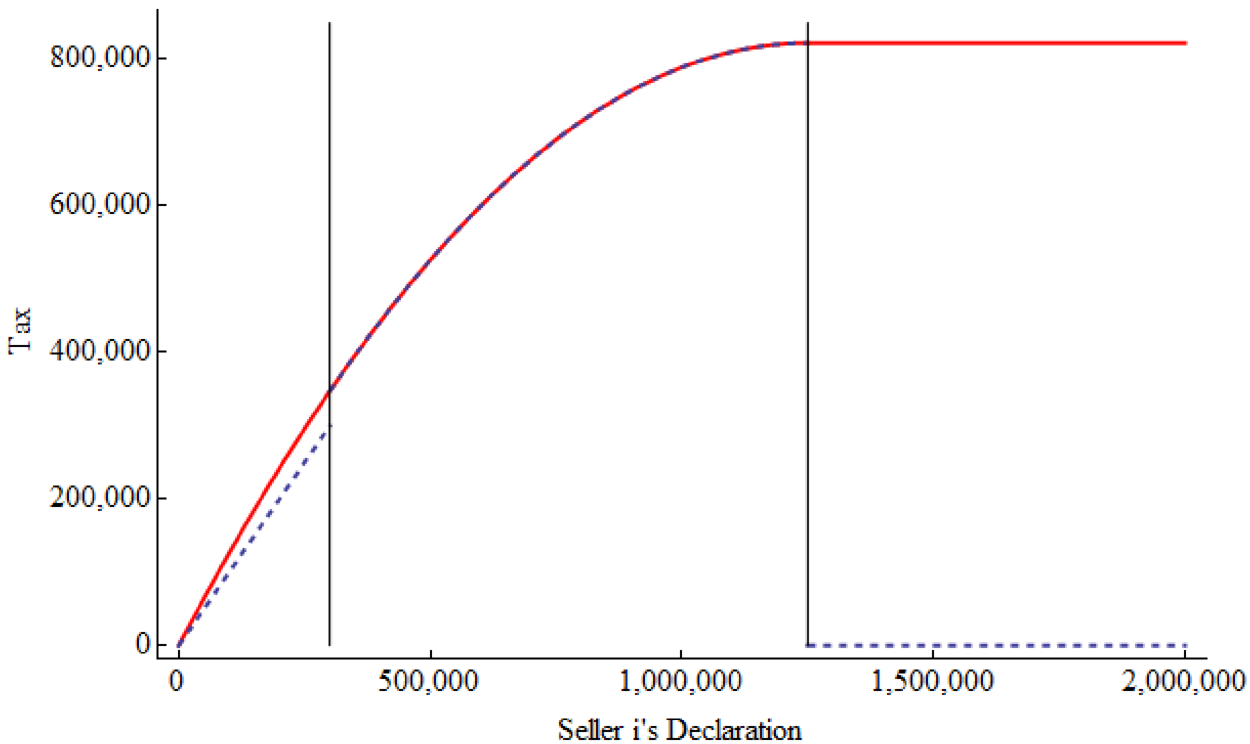

Figure 1. The theoretical tax function is represented by the blue, dashed curve. The implemented tax function is represented by the red, solid curve. For simplicity, we assume the sum of the neighbors' declarations is equal to zero. The solid vertical lines represent the bounds of the buyer's value range: [300,000, 1,250,000].

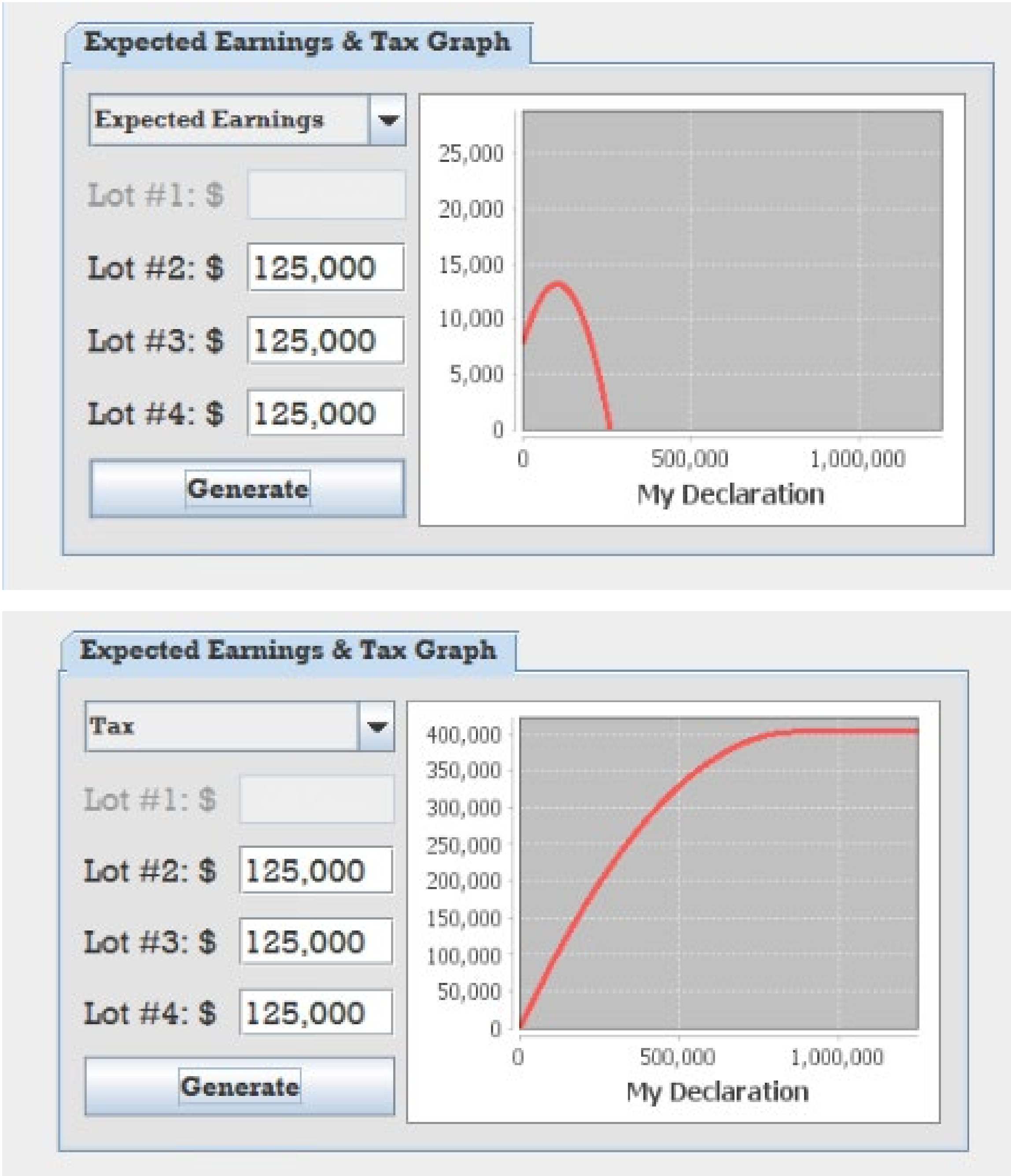

Figure 2. Close-up of the graphing tool on participants' user interfaces, which allowed them to visualize their tax formula and expected earnings based on the expected declarations of their counterparts.

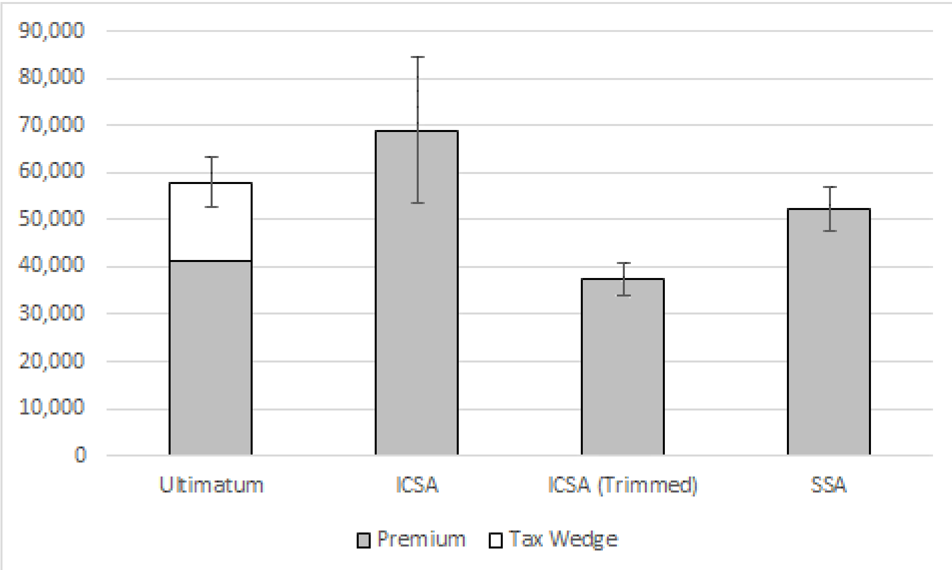

Figure 3. Average premium (in ECU) sellers charged above their induced values in each treatment. Error bars indicate the standard errors.

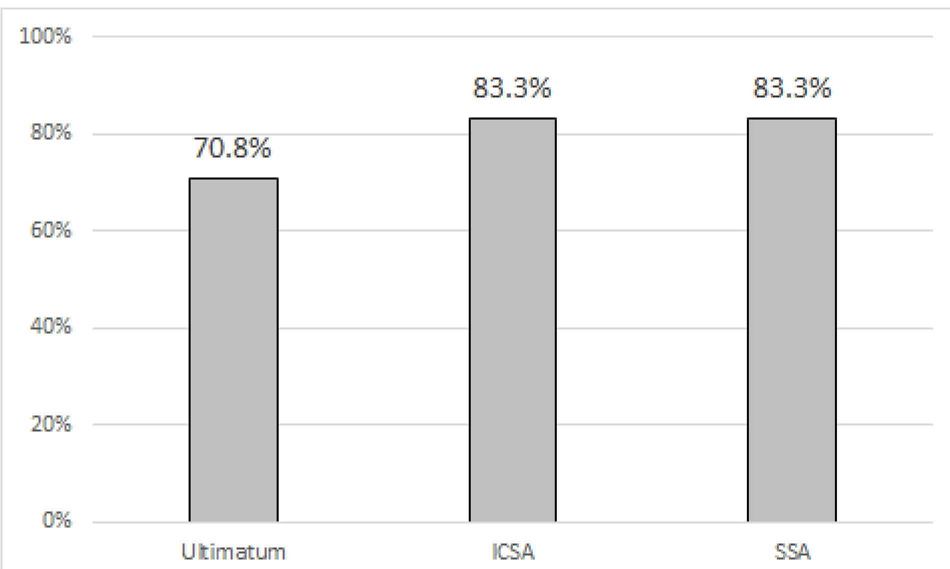

Figure 4. Rate of successful assembly in negotiations with the potential for positive gains from trade.

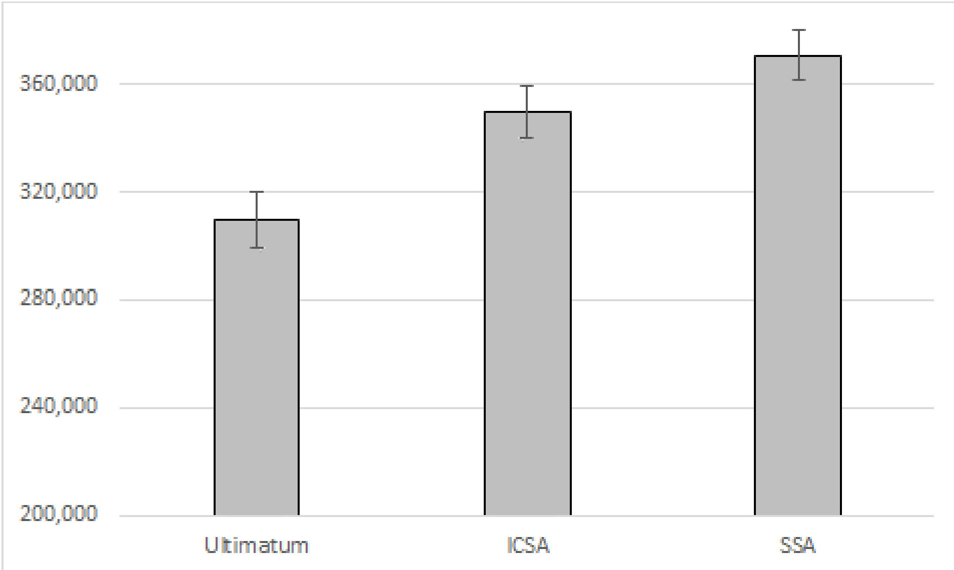

Figure 5. Average gains from trade (in ECU) in each treatment. (*Note:* The maximum available gains from trade were 379,000 ECU per positive-sum negotiation.)

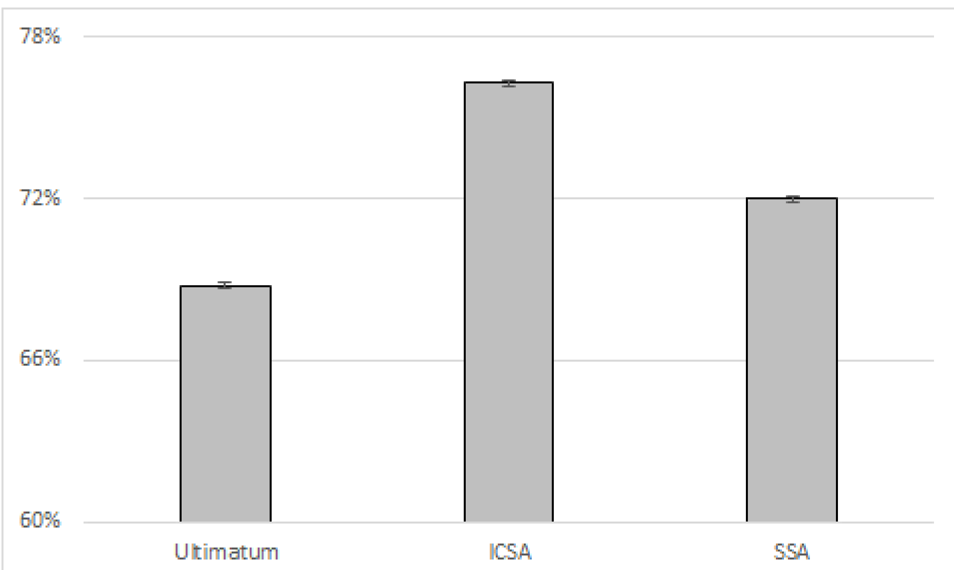

Figure 6. Average percent of positive-sum negotiations in which assembly occurred in the synthetic treatments.

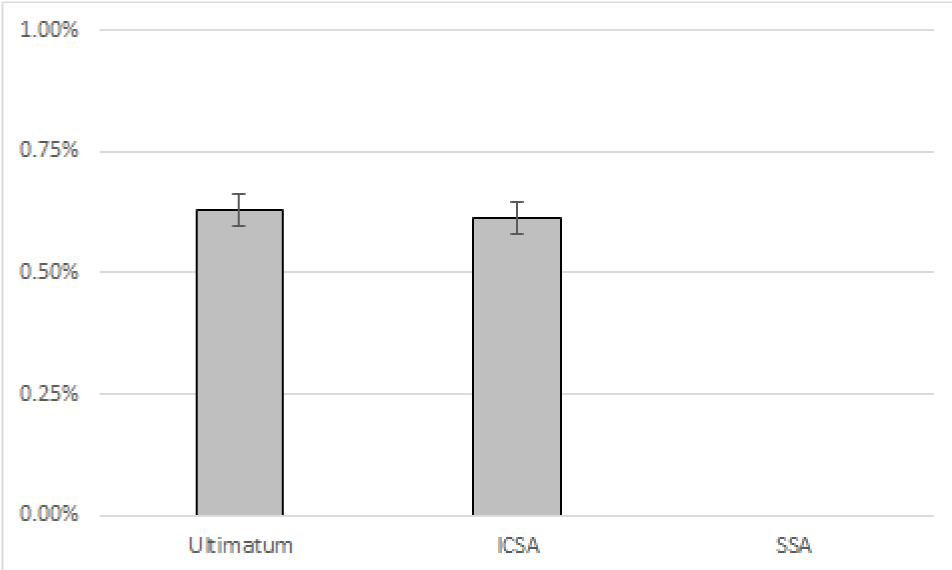

Figure 7. Average percent of negative-sum negotiations in which assembly occurred in the synthetic treatments.

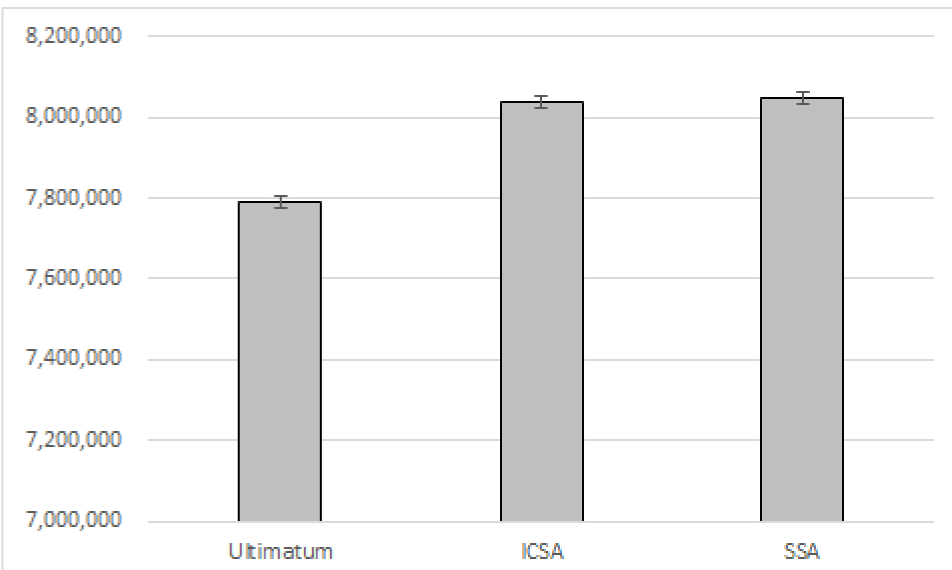

Figure 8. Average gains from trade per simulated session in the synthetic treatments.

Appendix A. Detailed derivations of the Ultimatum and SSA equilibrium declarations

We first consider the case of the Ultimatum mechanism. Suppose there are N sellers with declarations x_i and reservation values r_i, $i = 1, \ldots, N$. Further, suppose each seller has the following expected utility function:

$$E[U(\pi_i)] = p_i(x_i)U(x_i) + \big(1 - p_i(x_i)\big)U(r_i - tx_i) \quad \text{(A1)}$$

$$= \tfrac{B-x_i-X_{-i}}{B-A}(x_i) + \left(1 - \tfrac{B-x_i-X_{-i}}{B-A}\right)(r_i - tx_i). \quad \text{(A2)}$$

Differentiating with respect to x_i, setting the derivative to zero, and solving for x_i leads to the following system of first order conditions

$$x_i = \tfrac{1}{2(1+t)}[B + At + r_i - (1+t)X_{-i}],\ i = 1, \ldots N \quad \text{(A3)}$$

where each equation represents a seller's best response to the sum of his neighbors' declarations, $X_{-i} = \sum_{\substack{k=1 \\ k\neq i}}^{N} x_k$. If seller i assumes his neighbors are also maximizing the same expected utility function, then his equilibrium declaration is given by

$$x_i^* = \tfrac{B+At+Nr_i-R_{-i}}{(N+1)(1+t)} \quad ,\ i = 1, \ldots N \quad \text{(A4)}$$

where R_{-i} corresponds to the sum of the reservation values of seller i's neighbors. This is determined by iteratively substituting the best response bid x_j, $j = 1, \ldots, N$, $j \neq i$ into equation (A3) for seller i. Suppose $N = 4$ as in our experiments and consider seller 1. Substituting

$$x_2 = \frac{1}{2(1+t)}[B + At + r_i - (1+t)X_{-2}]$$

into equation (A3) yields

$$x_1 = \frac{1}{3(1+t)}[B + At + 2r_1 - (1+t)(x_3 + x_4) - r_2].$$

Repeating this process for the best responses of sellers 3 and 4 (i.e., substitution of equation (A3) for x_3 and x_4) leads to

$$x_1^* = \frac{B + At + 4r_1 - R_{-1}}{5(1+t)}.$$

Generalizing to N sellers gives (A4).

We next consider the SSA mechanism. Again, suppose there are N sellers with declarations x_i and reservation values r_i, $i = 1, \dots, N$. Further, suppose each seller has the same expected utility function given in Section 4.4:

$$E[U(\pi_i)] = p_i(x_i)U(x_i - tx_i) + \left(1 - p_i(x_i)\right)U(r_i - tx_i) \qquad \text{(A5)}$$

$$= \tfrac{B - x_i - X_{-i}}{B - A}(x_i - tx_i) + \left(1 - \tfrac{B - x_i - X_{-i}}{B - A}\right)(r_i - tx_i). \qquad \text{(A6)}$$

Differentiating with respect to x_i, setting the derivative to zero, and solving for x_i leads to the following system of first order conditions

$$x_i = \tfrac{1}{2}[B - t(B - A) + r_i - X_{-i}],\ i = 1, \dots N \qquad \text{(A7)}$$

where each equation represents a seller's best response to the sum of his neighbors' declarations, $X_{-i} = \sum_{\substack{k=1 \\ k \neq i}}^{N} x_k$. If seller i assumes his neighbors are also maximizing the same expected utility function, then his equilibrium declaration is given by

$$x_i^* = \tfrac{B - t(B-A) + Nr_i - R_{-i}}{N+1} \qquad ,\ i = 1, \dots N \qquad \text{(A8)}$$

where R_{-i} corresponds to the sum of the reservation values of seller i's neighbors. This is determined by iteratively substituting the best response bid x_j, $j = 1, \dots, N$, $j \neq i$ into equation (A7) for seller i. Suppose $N = 4$ as in our experiments and consider seller 1. Substituting

$$x_2 = \frac{1}{2}[B - t(B - A) + r_i - X_{-2}]$$

into equation (A7) yields

$$x_1 = \frac{1}{3}[B - t(B - A) + 2r_1 - x_3 - x_4 - r_2].$$

Repeating this process for the best responses of sellers 3 and 4 (i.e., substitution of equation (A7) for x_3 and x_4) leads to

$$x_1^* = \frac{B - t(B - A) + 4r_1 - R_{-1}}{5}.$$

Generalizing to N sellers gives (A8).

Appendix B. Division of surplus between buyers and sellers.

In addition to total gains from trade policymakers and stakeholders may be interested in how much surplus was captured by each side of the market. In this appendix we present the results from both the experiments as well as the synthetic treatments.

B.1 Results from Experiments

Figure B1 displays the average buyer surplus and seller surplus in each treatment. On average, in Ultimatum the buyers captured about 171,000 ECU and the sellers captured about 139,000 ECU. In ICSA the buyers earned approximately 232,000 ECU, an increase of 36% relative to Ultimatum. However, sellers in ICSA earned an average of approximately 117,000 ECU, a decrease of almost 16%. In contrast, both buyers and sellers earned more in SSA relative to Ultimatum. The average surplus captured by buyers was about 214,000 in SSA, and the average surplus captured by the sellers was about 157,000. These are increases of approximately 25% and 13% relative to Ultimatum.

Regression analyses indicate that the surplus gains to the buyers were statistically significant in the self-assessment treatments, while the changes to seller surplus were not. We normalized the buyer and seller surplus data as we had the total surplus data, by subtracting the buyer or seller surplus that had been achieved in the equivalent negotiation in the Ultimatum treatment. We then fit these data to OLS models with treatment dummies and the negotiation number as the independent variables. The models' estimates are displayed in Table B1.

The model of buyer surplus estimates that buyers captured more surplus in the first round of ICSA and SSA than in Ultimatum, but not in the second round. The estimated coefficient for

ICSA is positive and statistically significant (p = 0.040), and the estimated coefficient for SSA is positive and marginally significant (p = 0.068). The estimated coefficient of the negotiation number is negative but not statistically significant (p = 0.164). Summing the ICSA and negotiation number coefficients results in an estimate that the buyer captured 93,579 ECU more in the ICSA treatment than in Ultimatum, and this is statistically significant (F-test, p = 0.020). Using the same analysis for SSA, the model estimates that the buyer captured 74,979 ECU more in the first round of SSA than Ultimatum. This effect is marginally significant (F-test, p = 0.059). However, if we set the negotiation number equal to two, the estimated treatment effects become statistically insignificant (F-tests, p > 0.4 in both cases).

The seller surplus model finds no significant treatment effects or effect due to experience. The estimated coefficients for ICSA, SSA and negotiation number are all statistically insignificant (p > 0.4 in all cases). Thus, in our experiments the buyer gained a temporary increase in surplus due to self-assessment, while sellers were unaffected.

B.2 Results from Synthetic Treatments

An analysis of buyer and seller surplus in the synthetic treatments shows that the largest effect of self-assessment is not on the gains in overall performance, but the division of those gains. Figure B1 shows the average buyer and seller surplus for each synthetic treatment. Average buyer surplus was highest in the synthetic *ICSA* treatment (5.6 million ECU), followed by *SSA* (4.9 million ECU) and *Ultimatum* (4.6 million ECU). Comparing treatments via pair-wise Mann-Whitney U tests yields significant results. Z-statistics for each comparison are presented in Table B2. In addition, the effect size between *Ultimatum* and *ICSA* is large (*d* = 0.99), while the difference between *Ultimatum* and *SSA* is of small size (*d* = 0.30) (see Table B3). In contrast, average seller surplus was lowest in synthetic *ICSA* (2.4 million ECU), followed by *Ultimatum* and *SSA* (3.2 million

ECU each). The effect size of the difference between *Ultimatum* and *ICSA* is very large ($d = 1.30$), and the effect size is very small between *Ultimatum* and *SSA* ($d = 0.07$).

The synthetic results on buyer and seller surplus suggest that *ICSA* would be quite unpopular relative to *Ultimatum*. Synthetic *ICSA* had a large positive impact on buyer welfare at the expense of a large negative impact on seller welfare. Due to the large number of landowners relative to developers, we would expect *ICSA* to face steep political opposition. Synthetic *SSA*, on the other hand, gave buyers a small welfare improvement with no loss to sellers. This could produce a motivated interest group unopposed by an indifferent public, making *SSA* a politically feasible tax regime.

Table B1. Estimates from OLS regressions on normalized surplus captured by the buyers and sellers.

Variable	Buyers Coefficient (Std. Err.)	Sellers Coefficient (Std. Err.)
ICSA Treatment	156,708*	25,500
	(73,962)	(75,548)
SSA Treatment	138,108†	60,100
	(73,962)	(75,548)
Negotiation Number	-63,129	-28,204
	(44,600)	(45,557)
Observations	48	48
Adjusted R^2	0.090	-0.040
F-Statistic	2.59	0.38

†Significant at 10%, * Significant at 5%, ** Significant at 1%, *** Significant at 0.1%

Table B2. Pairwise z-statistics from Mann-Whitney U tests comparing outcomes between synthetic treatments.

	Buyer's Surplus	Sellers' Surplus
Ultimatum vs. *ICSA*	62.53***	-77.68***
Ultimatum vs. *SSA*	20.23***	-4.15***
ICSA vs. *SSA*	45.31***	-76.66***

†Significant at 10%, * Significant at 5%, ** Significant at 1%, *** Significant at 0.1%

Table B3. Pairwise Cohen's d statistics of effect sizes between synthetic treatments.

	Buyer's Surplus	Sellers' Surplus
Ultimatum vs. *ICSA*	0.99	1.30
Ultimatum vs. *SSA*	0.30	0.07
ICSA vs. *SSA*	0.69	1.28

Effect size cutoffs: $d \geq 1.2$ (Very Large); $d \geq 0.8$ (Large); $d \geq 0.5$ (Medium); $d \geq 0.2$ (Small); $d < 0.2$ (Very Small)

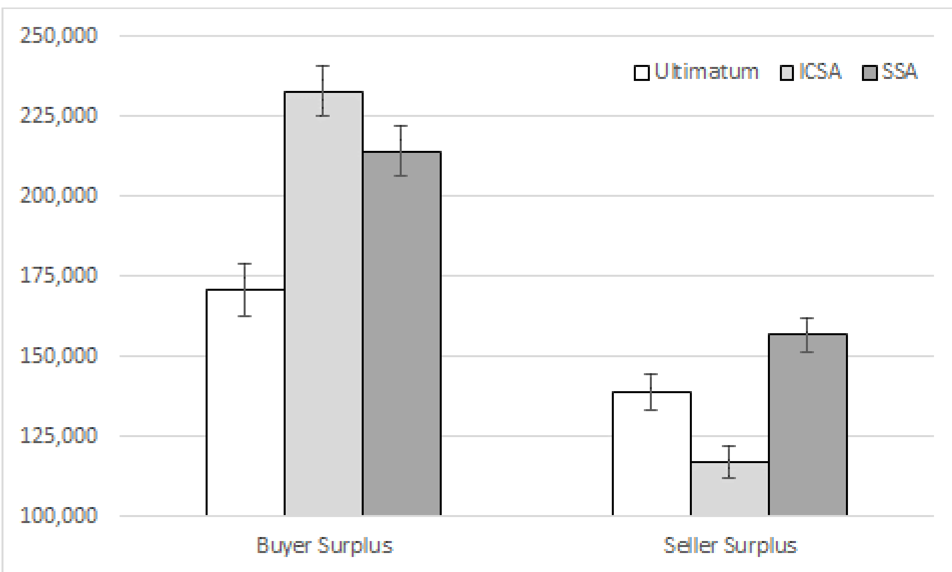

Figure B1. Average gains from trade (in ECU) captured by the buyers and sellers in each treatment.