An Agent-based Model of Tax Ceilings: Leviathan Extraction and Tax Payment Uncertainty

Andreas D Pape[a,1,*], Todd Guilfoos[b], Nathan Anderson[c], Jeffery Schmidt[d]

[a]*Economics Department, Binghamton University, PO Box 6000, Binghamton NY, 13902*
[b]*Environmental and Natural Resource Economics, University of Rhode Island, Kingston, RI, 02881-2020*
[c]*Northwestern Law School, Chicago, IL, 60611, J.D. candidate*
[d]*Systems Science Department, Binghamton University, Binghamton NY, 13902, Ph.D. candidate*

Abstract

In 1978, California voters passed Proposition 13, which imposed binding ceilings on the property taxes of California local governments. Since 1978, at least 31 states have passed similar laws. Most studies posit that voters seek to constrain rent-seeking Leviathan governments. Research has shown that voters may also support tax ceilings to reduce uncertainty over future tax payments. In this paper, we present a new agent-based model that incorporates unique administrative data on property taxes to provide, for the first time, a detailed explanation of how tax payment uncertainty determines the extraction choice set of a Leviathan government.

Our agent-based model is unique because it allows voters to forecast the future effects of alternative policies by simulating rational expectations. For a given referendum, we use the model to generate a joint distribution for all random variables as a function of the proposed policy. Voters then choose whether to support the referendum by calculating their expected utility with this distribution as a prior.

Our model incorporates administrative data on tax-payment uncertainty from two American cities with different property tax assessment regimes and thus different profiles of tax-payment uncertainty across their populations. Our model suggests that voters in a city with a high-uncertainty assessment regimes would support a tax ceiling on their Leviathan government that is five times as restrictive as voters in a city with a low-uncertainty assessment regime. This provides new insight into how differences in assessment policy can explain variation in support for property tax ceilings.

Since attitudes about uncertainty are critical to the model, we model both risk aversion and loss aversion. We find that under loss averse voters are more tolerant of Leviathan extraction for low to moderate levels of idiosyncratic risk; for high levels of idiosyncratic risk, loss averse and risk averse voters approximately converge in tolerance.

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*Corresponding author
Email addresses: apape@binghamton.edu (Andreas D Pape), guilfoos@mail.uri.edu (Todd Guilfoos), n-anderson2014@nlaw.northwestern.edu (Nathan Anderson), jschmid1@binghamton.edu (Jeffery Schmidt)
[1]Phone: 607-777-2660 Fax: 607-777-2681

The *certainty* of what each individual ought to pay is, in taxation, a matter of great importance.

> Adam Smith
> *The Wealth of Nations (Book V)*
> (Italics added)

1. Introduction

Laws to constrain property taxes have been an American phenomenon since at least California's Proposition 13 in 1978. Over the next twenty-five years, 31 states passed similar laws.[2] There is ample economic evidence that these laws effectively restrict local government.[3]

Why do voters support laws to constrain local government? Economic models provide one explanation, Leviathan governments: governments with both the desire and the power to raise taxes beyond the median ideal level.[4] We extend a model introduced in Anderson and Pape (2013) which offers a second reason: voter uncertainty over tax payments. The agent-based model we use here allows us to incorporate empirical data to estimate how important both tax payment uncertainty and Leviathan extraction are to providing popular support for tax ceilings.[5] We use empirical data from two American cities: Minneapolis, MN and Binghamton, NY. Minneapolis and Binghamton have different property assessment regimes, which in turn generate different profiles of tax price variance across their populations. According to our model, the different property assessment regimes imply that Binghamton residents would be as much as five times as tolerant of Leviathan extraction as the residents of Minneapolis. We can find restrictive ballot initiatives which would pass with nearly one hundred percent support in Minneapolis that would not pass in Binghamton. This suggests that property tax assessment regimes, and the resulting tax payment uncertainty, could be a key factor determining voter support for these laws.

The methodological contribution of this paper is to introduce a new kind of sophisticated voter to agent-based policy modeling. The voters in this model forecast the impact of alternative policies before they vote using the agent-based model that they are themselves embedded in. Full rational expectations (Muth, 1961; Lucas, 1973) require that agents use the correct distributions of all random variables to make their forecasts; here, the true distributions can only be computationally approximated. We simulate rational expectations by computationally sampling the space of exogenous random variables, and for each policy, calculating the associated endogenous random variables. The resulting joint distribution over all variables as a function of policy is then endowed to all agents as a common prior. Finally, all agents choose their favorite ex-ante policy by choosing the policy which maximizes expected utility with regard to this common prior.[6]

Investigating impacts of voter sophistication has a long tradition. As mentioned above, sophistication is a central tenet of rational expectations and the accompanying Lucas critique. One

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[2]Anderson (2006) provides a history until 2006. Since then, New York State passed a Property Tax Cap in 2011.

[3]See Bradbury et al. (2001), Dye and McGuire (1997), Figlio (1997), O'Sullivan et al. (1995), Poterba and Rueben (1995), and Brooks and Phillips (2010).

[4]'Median ideal level' (Downs, 1957) is considered by the literature as the level which is consistent with a government that is completely responsive to the public will. See Section 3 for details.

[5]Anderson and Pape (2013) are able to solve their model analytically by making some population symmetry assumptions which fail in the empirical data we use here. Where no closed-form solution is available, agent-based simulation provides an alternative.

[6]In this model, there is no private information, but it could be incorporated after the common prior is estimated. We intend to include private information in a future extension.

vein of literature investigates the impact of economic variables on voting outcomes[7] or the sophistication of voters' conceptual models.[8] Farquharson (1969) and related works[9] investigate strategic voting, which they call 'sophisticated voting,' contrasted with 'sincere voting' like in the Downsian model (Downs, 1957). Voters in our model, like in Downs, vote sincerely, so are not sophisticated in the Farquharsonian sense. The sophistication of the agents in our models is in their understanding of economic policy models. This paper is more akin to Gomez and Wilson (2001), in which voters learn to attribute causality to variables in the economy. There are some also agent-based models that investigate agent sophistication, typically with adaptive learning in an abstract political landscape.[10] Our contribution to that literature is the specificity of our policy question and the incorporation of relevant data into the agent-based model to answer the question.

While the policy considered here is a property tax ceiling, this method of simulating rational expectations to calculate policy support could be paired with other agent-based models to predict support in other economic policy settings. Agent-based models of economic policy design could be attached to a simulated rational expectations voting model like ours, to predict voter preferences over these policies.[11] Or, attaching simulated rational expectations voters to agent-based market models[12] could be used to forecast support of a variety of market-related policies, such as taxes, price restrictions, redistribution, social insurance, or a minimum wage. Or, simulated rational expectations could be attached to a number of environmental economic agent-based models,[13] to predict support for resource rationing, user fees, or land-use policy.

The economic policy contribution of this paper is to show that, all else equal, assessment policy can significantly change the freedom that a local government has to raise revenues on a scale that we estimate could plausibly explain which cities support, and which don't support, a given tax ceiling. In particular, we estimate that the city of Binghamton can raise property taxes nearly five times as far above median ideal level as can Minneapolis, before facing a tax ceiling, and that difference is largely attributable to differences in tax assessment policy which generate different levels of tax price volatility. We also find that this result is robust to modeling the utility of agents using risk aversion or loss aversion, both calibrated to functional forms found in the literature.

The economic policy contribution is noteworthy contribution because existing models in the literature, with the exceptions of Vigdor (2004) and Anderson and Pape (2013), offer Leviathan extraction as the only explanation of support.[14,15] We are the first to model how *uncertainty in tax*

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[7]E.g., Chappell (1983) Backus and Driffill (1985), and Peltzman (1990).

[8]E.g., Suzuki (1991), Suzuki (1994), Duch et al. (2000).

[9]E.g. McKelvey and Niemi (1978).

[10]Marchi (2003) and Jackson (2003) investigate the informational diversity of voters with adaptive learning. Kollman et al. (1992) show that political parties with adaptive learning in a multidimensional environment of voter preferences tend to converge to a central region of the policy space, just like under the unidimensional median voter theorem (Downs, 1957). For an overview of agent-based models in political economy, we recommend the 'Handbook of Computational Economics' chapter "Computational Methods and Models of Politics"(Kollman and Page, 2006) and the paper "Computational Public Economics" in a dedicated issue of the Journal of Public Economic Theory (Judd and Page, 2004).

[11]As examples, attaching simulated rational expectations voters to Neugart (2008) could be used in this way to predict voter support for labor market policies; attaching it to Chen and Chie (2008) could predict voter support for lottery programs; attaching it to Wilhite and Allen (2008) could predict voter support for various policies on crime.

[12]This literature is too large to cite here. It includes seminal papers such as Gode and Sunder (1993) and many papers in the special issues of *Computational Economics* and *The Journal of Economic Dynamics and Control* starting with Tesfatsion (2001a) and Tesfatsion (2001b).

[13]E.g. Brown et al. (2005), Happe et al. (2008), or Guilfoos et al. (2013).

[14]See e.g. Brennan and Buchanan (1980), Romer and Rosenthal (1979). Brooks et al. (2012) assumes uncertainty in the 'type' of politician in terms of their spending desires; it provides a "Leviathan" motivation in that voters try to protect against a politician whose choices deviate from majority will.

[15]Vigdor (2004) investigates whether voters support these laws to restrict other local governments (not their own)

payments effects support for tax ceilings and to use data in that pursuit. Moreover, the data we use is new: the empirical literature on tax ceilings has never used household-level, panel tax-price data.[16]

We proceed in six sections. In Section 2, we discuss how the basic institutions of property taxation can embed idiosyncratic tax price uncertainty. In Section 3, we describe the three-stage voting game model and its agent-based implementation. In Section 4, we describe the data we have about these two cities and how these data are incorporated into the model. In Section 5, present and discuss our results, including the implications of Binghamton's and Minneapolis's tax assessment regimes. In Section 6, we conclude.

2. Property Tax Background

Understanding the model of property taxes presented here requires understanding some details of property taxation. We consider tax bills first from the perspective of the individual taxpayer and second from the perspective of the jurisdiction. Then we discuss the implications for tax price volatility.

Tax bills from the perspective of an individual taxpayer. Taxpayer i's property tax bill (T_i) is an accounting identity defined as the product of the property tax rate (τ_j) in her jurisdiction j and her property's taxable value (v_i),

$$T_i \equiv \tau_j \times v_i. \tag{1}$$

In the United States, most states define taxable value, v, to be something different than the current market value of the property. These differences arise from infrequent revaluations, exemptions, exclusions from the property's taxable value, and both intentional and unintentional assessment errors.

Tax bills from the perspective of the jurisdiction. A jurisdiction's property tax base is defined as the sum of the taxable values of all properties located within the jurisdiction. Unlike the income or sales tax, the property tax base (B_j) is known ex-ante to policy makers. As a result of this ex-ante knowledge, most local governments select their level of desired revenue R_j. (R_j is also known as 'the property tax levy.') the ratio of the ex-ante tax base and desired revenue produces the statutory property tax rate,

$$\tau_j \equiv \frac{R_j}{B_j}. \tag{2}$$

In practice, a jurisdiction's statutory tax rate often changes annually as both tax base and desired revenue changes.[17] We use the definition of the tax rate to express an individual's tax bill as a function of revenue and the tax price p at time t

$$T_{it} \equiv \frac{v_{it}}{B_{jt}} \times R_{jt} = p_{it} \times R_{jt}. \tag{3}$$

Individual i's tax share (v_i/B_j) is her tax price (p_i) of an additional dollar of property tax revenue. This is a price in a very real way: it is what the individual i must pay for an additional unit of

[16]There are many noteworthy papers empirically investigating support for tax ceilings. Citrin (1979), Courant et al. (1980), and Ladd and Wilson (1982) use survey data to ascertain factors that affect desire for a tax ceiling. Ladd (1978) and Alm and Skidmore (1999) find evidence that high property tax burdens and growth in local expenditures increase support for tax ceilings. Temple (1996) finds support for tax ceilings among communities with low income voters, higher tax prices, and modest property tax revenue growth.

[17]For instance, Anderson (2012) demonstrates that from one year to the next property tax rates change for over 90% of MN cities for the period 2000 to 2003.

revenue.

This equation captures the basic ways that tax bills can vary over time and across a community. Since the tax price is an increasing function of ones' home value, at any point in time the highest value home also has the highest tax price. Critically, however, this logic does *not* carry over to changes over time.[18] This implies that individuals' tax prices need not be correlated with home value over time. Empirical evidence suggests that there are substantial differences in price appreciation rates across properties even within relatively small geographic areas like counties, cities, and school districts.[19]

3. Model

This model is an agent-based extension of the analytical model introduced in Anderson and Pape (2013). The setting for the model is a local jurisdiction of property-owning citizens, who use the local government to fund a collective good G. The collective good is financed through a property tax, which is levied on the citizens and subject to their approval. The local government may have some agenda-setting power, and may be able and willing to extract revenues beyond what the median citizen desires. Also, the citizens face some uncertainty over their individual tax payments. For both of these reasons, the citizens may desire to restrict future revenue levels. They have a mechanism for doing so, which is a property tax ceiling.

The level of tax revenues R used to fund the collective good is the key policy variable. The most important reference policy is the 'median ideal level' of R. 'Median ideal level' is defined in the Downsian or Median Voter Theorem manner (Downs, 1957). I.e.: consider the population of voters, arranged in order by their ideal level of tax revenue. A revenue level which matches the preferences of the voter who sits at the median of this distribution will always win a majority vote against any other proposed level (assuming single-peaked preferences). That voter is called the *median voter*, and the median voters' level is called the *median ideal level* of revenue.[20] The literature defines a government which implements the median ideal level as one which is completely responsive to the public will. Deviations from this—in particular, levels of taxation which exceed the median ideal level—are Leviathan (Romer and Rosenthal, 1979; Brennan and Buchanan, 1980). We follow these definitions.

There are two goods in this economy: a private good x and the collective good G. The private good is produced with a constant marginal cost of 1 and each individual must pay for the private good out of their own wealth. The collective good G is made with public revenues R (paid for by property taxes, described below). We assume G has a constant marginal cost of 1, like the private good, but that there is an unknown fixed cost d (i.e. $G = R - d$). d is a binary random variable that takes on either a value of 0 or $D > 0$. This random variable is called a *calamity*. For example, in 2006, the City of Binghamton experienced a flood which destroyed a fair number of city streets and bridges, so to achieve the same level of public streets as previous, the City had to spend more money.[21] Calamities are the source of common risk in the model. D is called the *severity* of the

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[18]For example, suppose ones' home value depreciates at a rate less than ones neighbors. Then her tax price will increase. Massachusetts' Proposition $2\frac{1}{2}$ limits annual property tax levy increases to no more than 2.5%, but it does not do the same for individual tax bills. At the 2.5% levy limit, properties that appreciate at a rate 5% higher than the rest of the tax base will see their tax bills increase by 7.5%.

[19]See, for example, Shiller and Weiss (1999) who measure the "substantial geographic variability" of home prices within Suffolk County, MA in describing the basis risk involved with hedging home price movements using real estate price indices.

[20]The median voter is often called the pivotal voter.

[21]Although it is convenient to think of the calamity as a natural disaster, it could be also be a human-caused collective risk which is exogenous to the city, such as a military invasion or the global financial crisis, so long as it can be thought of as destroying a certain fraction of the collective good.

calamity, and $\pi_D \in [0, 1)$ is the *likelihood* of the calamity. We let $\pi_0 = 1 - \pi_D$ be the likelihood of no calamity.

There are two types of agents: a single local government and population of citizens, indexed by $i \in I$, who reside in the jurisdiction of this government. Notation: Suppose y is a variable of interest. $\vec{y}$ is a profile vector, which has one entry for each citizen in the jurisdiction, and $\widehat{y}$ will be used to designate the population median of the vector $\vec{y}$. I.e.:

$$\vec{y} = \{y_i\}_{i \in I}$$
$$\widehat{y} = \text{Median}\left(\vec{y}\right) = \text{Median}_{i \in I}\{y_i\}$$

An *allocation* (or *final allocation*) in this economy is a pair $(\vec{x}, G)$, where $\vec{x}$ is a profile of private good levels and G is the level of the collective good. The government receives no allocation directly and instead has preferences over allocations and, possibly, calamity severities 0, D.

The *citizens* i are expected utility maximizers, and we model them as risk averse or loss averse agents. Risk-averse agents have the following identical von Neumann-Morgenstern utility function over final bundles of goods:

$$U(x, G) = u(x) + \lambda u(G)$$
$$\text{where } u(x) = \frac{x^{1-r}}{1-r}$$

It is additively separable, constant relative-risk aversion utility, where r is the coefficient of relative risk aversion.[22]

For loss-averse agents, we define loss aversion as a transformation of U. In particular, let u be an arbitrary level of utility and let U be a reference level of utility agent i. Then define the loss aversion function as follows:

$$v(u, U) = l(u, U) \left(\frac{|u - U|}{|U|}\right)^{.88} \tag{4}$$

$$\text{where } l(u, U) = \begin{cases} 1, & \text{if } u \geq U \\ -2.25 & \text{otherwise} \end{cases} \tag{5}$$

The function v incorporates the loss aversion elements; in particular the kink at the reference point. That is abstracted into the function l for notational simplicity. The values of l and the exponent are values from the literature: Tversky and Kahneman (1992) and Barberis et al. (2001). We calculate u by the magnitude of utility so that it is on a comparable range.[23] (We discuss calculation of a reference point below.)

Each citizen i has a wealth ω_i to spend on the private good and on the tax payment, since the

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[22]For simplicity, we choose a single value for the coefficient of relative risk aversion for all scenarios, and instead change the level of uncertainty (see below). Meyer and Meyer (2005) provides the most comprehensive analysis we found regarding the appropriate calibration level for this value. We follow their interpretation of Barsky et al. (1997) that this value for consumption falls between 4 and 8; we choose 5 for most of our analysis. Importantly, we choose the same CCR for all citizens in Binghamton and Minneapolis. Choosing a different value—so long as it is the same between the cities—would have little effect on the qualitative results.

[23]An alternative formulation to the one we use here would be to apply loss aversion separately to the additively separable elements of U_i. This undercuts the notion of loss aversion, in the opinion of the authors; because of the negative tradeoff between consumption x and revenue r, agents will experience, simultaneously, a loss and a gain for most bundles of x and r. This runs counter to the spirit of loss aversion, in which particular outcomes are seen monolithically as a loss or a gain.

collective good is paid for by property taxes. The tax payment of an individual is her tax price times the revenue, i.e. $p_i \cdot R$ (see Section 2). Moreover, since there are only two goods, assuming a binding budget constraint implies: $x_i = \omega_i - p_i R$, so private consumption is determined by the size of the tax bill. We assume the tax price is a random variable of the form $p_i = \mu_i + \epsilon_i$, where μ_i is a known constant which can vary across citizens and ϵ_i are independent, normally-distributed, mean-zero random variables with variance σ_i^2, which can also vary across citizens. These epsilons are the source of individual risk in this model.

The *government* is also an expected utility maximizer, and has a von Neumann-Morgenstern utility function U_{gov} over final allocations $(\vec{x}, G)$ and levels of calamity $d = 0$ or D. Here are four examples:

$$\text{The utilitarian:} \quad U_{gov}(\vec{x}, G, d) = \sum_{i \in I} U(x_i, G)$$

$$\text{The benign median ideal implementer:} \quad U_{gov}(\vec{x}, G, d) = \text{Median}_{i \in I} U(x_i, G)$$

$$\text{The Leviathan local revenue maximizer:} \quad U_{gov}(\vec{x}, G, d) = G + d$$

$$\text{Single citizen as dictator:} \quad U_{gov}(\vec{x}, G, d) = U(x_j, G) \text{ for some } j \in I$$

The last three as the most interesting cases. The benign median ideal implementer is the government that perfectly follows the (current) will of the people. The Leviathan local revenue maximizer is the opposite extreme: a government that makes government as large as possible, without regard to the will of the people. The last is a single citizen who, like any other citizen, has a particular ideal level of the collective good and dislikes deviations above or below that level.

We model this situation as a three-stage game. The free parameters of this model are the likelihood and severity of the calamity π_D and D, and the profile of tax price variance $\vec{\sigma}^2$. During the following discussion, assume that these free paramters are fixed at some levels $\bar{\pi}_D > 0$, $\bar{D} > 0$, and $\vec{\bar{\sigma}}^2 \geq \vec{0}$.

In the first stage, citizens vote on whether to implement a tax ceiling $c \in \mathbb{R}_+ \cup \{\infty\}$, where $c = \infty$ can be thought to mean "no ceiling." The value of c represents the maximum level of (future) revenues R allowed by law. Massachusetts' Prop 2½ was named after the the maximum allowable growth rate of local revenues, so if R_0 represents current revenue levels, then Proposition 2½ can be represented by the policy $c = 1.025 \cdot R_0$.[24,25]

We consider the referendum for a given tax ceiling c is imposed. As described above, when they vote in the first stage, citizens have uncertainty about two variables, calamity d and tax price errors $\vec{\epsilon}$. Each citizen i then evaluates the expected utility of her final allocation bundles under the tax ceiling c and the expected utility of no ceiling $c' = \infty$, and votes truthfully for her preferred option.[26]

Now consider all possible referenda. We define $c^\star$ as the *most restrictive property tax ceiling which gains majority support*. If some proposed law restricts revenues to a level below $c^\star$, then that law will not pass. Alternatively, any revenue level greater than $c^\star$ is ruled out by at least one tax ceiling which has majority support in stage one. Formally: let $\theta_i(c)$ be the vote of agent i, so

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[24]The actual proposition includes exceptions to that cap. We ignore those exceptions here.

[25]If this model considered more than one round of future revenues, growth rates versus levels would have a more complicated relationship. For simplicity, we only consider one period.

[26]If she is indifferent, we assume she votes *against* c.

that:

$$\theta_i(c) = \begin{cases} 1, & \text{if } EU_i(c) > EU_i(\infty) \\ 0 & \text{otherwise} \end{cases} \tag{6}$$

Then $c^\star$ can be defined as:

$$c^\star = \min\left\{ c \,\middle|\, \frac{\sum_{j\in I}\theta_j(c)}{\#(I)} > \frac{1}{2} \right\} \tag{7}$$

When the second stage begins, the values of random variables d and $\vec{\epsilon}$ are revealed to all agents. Voters then select an intermediate level of revenue R, again in a median-voter-theorem manner, where each agent submits her expected-utility-maximizing ideal revenue level $r_i^\star$ and the median is selected. The first and second stage submissions may not be equal (i.e. $c_i^\star \neq r_i^\star$) because of the values of d and $\vec{\epsilon}$ revealed. Moreover, they may not even be equal in expectation (i.e. $c_i^\star \neq E(r_i^\star)$) because of risk aversion or loss aversion. Given the notation above, $\widehat{r}^\star$ is value of the median ideal revenue level from the second stage.

Then the third stage begins. The government chooses an extraction level γ, which determines the final level of revenues raised by the jurisdiction in prices. Let R_{final} represent this final, implemented level of revenue. It solves the following equation:

$$R_{\text{final}} = \min\left[(1+\gamma)\cdot\widehat{r}^\star, c^\star\right] \tag{8}$$

From this it can be seen that γ functions as a kind of 'markup' over the median ideal level.

A Leviathan revenue maximizer, who values only local revenues, would choose a γ as large as permissible by law:

$$(1+\gamma)\cdot\widehat{r}^\star = c^\star$$
$$\implies (1+\gamma^\star_{\text{leviathan}}) = \frac{c^\star}{\widehat{r}^\star}$$

(Note that this is not constant, as $\widehat{r}^\star$ is a random variable.)

On the other hand, a benign median-ideal-implementing government would select

$$\gamma^\star_{\text{benign}} = 0 \tag{9}$$

One way of viewing the outcome of this model is to find under simulated rational expectations, in which all agents are at all times correct in their beliefs about other agents' reaction functions and the probability distributions of all future variables, what levels of revenue citizens vote to rule out by choosing the tax ceiling $c^\star$.

As is typical of comparative static exercises, it is of interest to find how $c^\star$ changes, as the amount of idiosyncratic and common risk change.

In a formal paper, Anderson and Pape (2013) analytically show, in a restricted setting, that:

1. $c^\star$ *falls* as the common risk (calamity level D or likelihood π_D) increases
2. $c^\star$ *rises* as the individual risk (variance of $\vec{\epsilon}$) increases

Why? Let $\widehat{i}_t$ designate the index of the median voter stage t.[27] This agent shares common risk with the second stage pivotal agent, but does not share idiosyncratic risk with the second stage

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[27]In stage 1, $\widehat{i}_1$ may be a random variable, if there are multiple equilibrium median agents in ex-ante beliefs. In stage 2, $\widehat{i}_2$ is a random variable, as it depends on the draws of d and $\vec{\epsilon}$.

median ideal agent. Therefore, this agent values *flexibility* in the face of common risk and values *rigidity* in the face of idiosyncratic risk. And, because of risk aversion, rigidity comes in the form of wanting to lower revenues on average.[28] There is also an effect similar to Romer and Rosenthal (1979), in which, if the second-stage revenue is above the median voter's ideal revenue in the first stage, then the median voter would support a ceiling which was more restrictive than her ideal level. But notice that this effect can only serve to magnify existing Leviathan or risk aversion effects mentioned above.

Anderson and Pape solve this in a restricted setting by imposing certain population symmetry assumptions. These assumptions are violated in the empirical data we have collected here. Without these restrictive assumptions, this problem becomes analytically untractable, because because rational expectations or backwards induction requires that agents forecast *the probability distribution of the population distribution* in order to calculate the median ideal revenue level. No closed-form solution to that problem is available in the probability literature. Therefore, to evaluate with realistic distributions of tax prices, property values, and tax price uncertainty, we are best served by an agent-based simulation.

We implement a simulated rational expectations/backwards induction version of this model. Simulated rational expectations is performed computationally by sampling the space of the random variables which describe all sources of uncertainty. That is, random variables d and $\vec{\epsilon}$ are sampled from their distributions, creating a single stage two 'scenario.' This process is then repeated until a distribution of possible stage two scenarios are generated. Then, in the stage one, agents evaluate their expected utility across scenarios, for each possible policy choice. Agents then vote for the stage one policy which maximizes their expected utility over the space of scenarios.

We implement simulated rational expectations by running the agent-based model in reverse chronological order: to simulate the second stage, agents are subjected to draws of $\vec{\epsilon}$ and d and the median ideal R is recorded. That combination (ϵ_i, d, R), is added to a data base. This space is sampled repeatedly (in our runs, 200 times). Then, the first round is run, and each agent considers whether a each tax ceiling c is in their best interest, by evaluating their expected utility under tax ceiling c versus expected utility under no tax ceiling. They submit their vote for the least restrictive, expected-utility-maximizing c.

Simulated rational expectations also play a role in the calculation of the reference level under loss aversion. Given our formulation of the problem, it turns out that agents' optimal ideal level of revenue in the second stage, as a function of the realized random variables, is the same as under risk-aversion. This arises from the fact that we apply loss aversion to total utility and not to the additively separate components of utility.[29] Therefore, in the simulation of the second stage, we find the ideal revenue of each agent under CRRA utility at expected prices and expected damages,

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[28]It can be shown that the agent doesn't prefer a revenue floor, for example, which would lower variability of second-stage revenue, but would increase, not lower, revenue on average.

[29]Define the function $U_i(r)$ be the final utility of some agent i derived from some revenue level r, where p_i is their revealed price, ω_i is wealth, and d is damages. Then by previous:

$$U_i(r) = u(\omega - pr) + \lambda u(r)$$

Now define the function V_i, which is the composition of the loss aversion function v and the function U_i:

$$V_i(r, R) = v\left(U_i(r), U_i(R)\right) \tag{10}$$

Define R as the reference level of revenue. Now suppose that agents were considering their ideal level of revenue $r^\star$. They would calculate it by maximizing the following equation:

$$\max_r V_i(r, R) \tag{11}$$

$$\implies \frac{\partial V_i}{\partial r} = 0 \tag{12}$$

find the population median of that value, and declare that–the population median ideal revenue at expected prices and expected damages–as the reference level of revenue. This then defines, for each agent, a reference level of utility equal to their utility at the reference level of revenue and at expected prices and damages. Choosing these values means we have scaled to the CRRA values, so this becomes as close as we can get to an "all else equal" exercise.

The key question that this simulation answers is: If the government chooses an extraction level γ, what is the probability that it will be blocked by a tax ceiling? We call the probability of being blocked ρ. In order to calculate whether a particular level γ is blocked by a tax ceiling, we must first calculate which tax ceilings have support in the first stage given the amount of idiosyncratic risk and common risk as described above. We supply the agent-based model with the data from the cities of Binghamton and Minneapolis and vary the amount of common and idiosyncratic risk, and for each combination of common and idiosyncratic risk, we calculate whether each agent in the first round supports each possible tax ceiling. The amount of common risk is given by D, the calamity severity. The amount of idiosyncratic risk is constructed by assuming tax price uncertainty is proportional to observed tax price variability and varying that proportion. That proportion is measured by a variable called s, which is called *log tax price scalar*. That is, the base level variance in the data is multiplied by a scalar equal to 10^s to find tax price uncertainty, and we vary s to vary the amount of tax price uncertainty (i.e. idiosyncratic risk.)

We now relax the assumption that idiosyncratic risk s and calamity severity D are fixed, but maintain π_D fixed at .1. All other parameters we assume are defined by the jurisdiction j. Now define $c^\star$ as a function of these parameters: $c^\star(j, s, D)$. Now we can define the key outcome variable ρ, the probability that some extraction level γ will be blocked by voters:

$$\rho_j\big(\gamma|s, D\big) = \text{Prob}\big((1+\gamma)\widehat{r} > c^\star(j, s, D)\big) \tag{16}$$

(Note that $\widehat{r}$ is a random variable.) After describing the empirical data we use in the next section (Section 4), we share our estimates and interpretation of ρ in the results section, Section 5.

4. Data

In this study, we use data from two local jurisdictions: Binghamton, New York, a city in upstate New York, and Minneapolis, MN, a city on the Mississippi river in the southeast corner of Minnesota. Minneapolis shares a greater metropolitan area with St. Paul, which is the state capital. Minneapolis is much larger than Binghamton: Minneapolis has $400,000$ people in the city

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which is the first-order condition. Let us unpack the FOC.

$$\pm \frac{\partial l}{\partial r} .88 \left(\frac{|u - U|}{|U|}\right)^{-.12} u'(r) = 0 \tag{13}$$

The $\pm$ in this case is *positive* if $u \geq U$ and *negative* if $u < U$. Similarly, $\frac{\partial l}{\partial r}$ is positive if $u \geq U$ and negative if $u < U$. Therefore, their signs multiply to *positive*. So we can re-express it as:

$$.88 \left|\frac{\partial l}{\partial r}\right| \left(\frac{|u - U|}{|U|}\right)^{-.12} u'(r) = 0 \tag{14}$$

Since $\left|\frac{\partial l}{\partial r}\right| \neq 0$ and, for all $u \neq U$, $\left(\frac{|u-U|}{|U|}\right)^{-.12} \neq 0$, this implies that, for $r^\star$,

$$u'(r^\star) = 0 \tag{15}$$

But $u'(r) = \frac{\partial U_i}{\partial r}$, which is the FOC of the CRRA maximization. So the $r^\star$ is the same under loss aversion and risk aversion.

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	Mean	Std Dev	Max	Min
Wealth	73,839	35,386	505,000	25,000
Tax Price	0.00015	0.00007	0.001	0.00005
Tax Price Variance * $1M$	0.00014	0.00228	0.12044	0
N	6,821			

Table 1: Binghamton 100% Sample Summary Statistics

	Mean	Std Dev	Max	Min
Wealth	748,617	323,948	3,296,000	415,000
Tax Price	0.00038	0.00016	0.0017	0.00022
Tax Price Variance * $1M$	0.00118	0.00369	0.1	0.00002
N	2,644			

Table 2: Minneapolis 30% Sample Summary Statistics
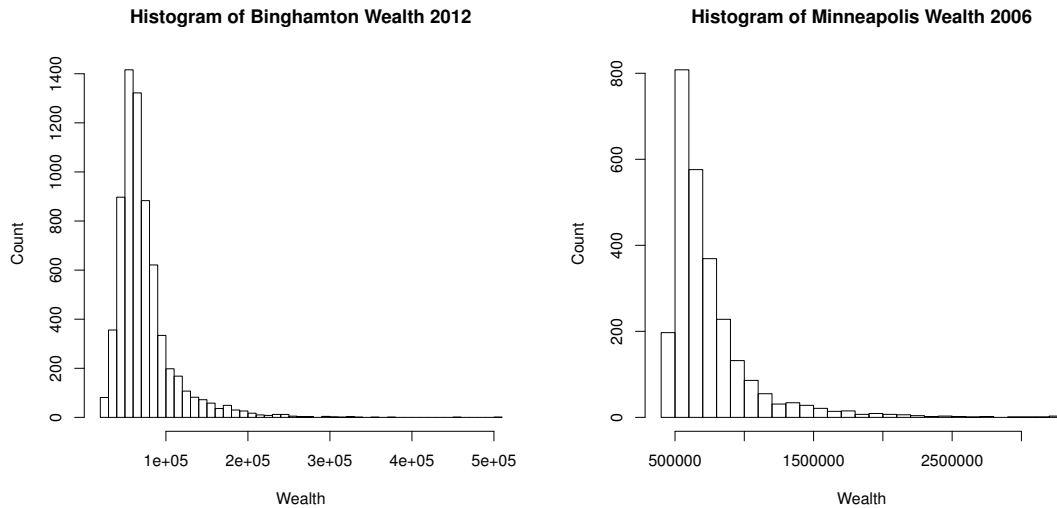
Figure 1: Wealth Distributions

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proper and 3.4 million residents in the greater metropolitan area, while Binghamton has $50,000$ people in the city proper and $250,000$ in the greater metropolitan area.

Binghamton and Minneapolis have also have different local property tax regimes, which generate very different profiles of tax price variance. Binghamton properties are reassessed infrequently: only a minority of properties in Binghamton are reassessed at all over the six-year period we observe $(2007 - 2012)$. Minneapolis properties, on the other hand, are reassessed every year during the ten years we observe $(2000 - 2009)$. This means that variance is both larger and more widespread in Minneapolis than in Binghamton. This gives rise to the fundamental empirical question of this paper: does this difference in actual tax property assessment policy generate differences in available extraction levels to the local government, that are on the scale that could explain differences in support for a tax ceiling like Proposition 13 or Proposition 2½?

For Binghamton, we have the universe of 100% of the properties in the city; for Minneapolis, MN, a 30% sample of properties in the city. For both cities, we have assessed property values over time. For computational reasons, we use a smaller sample in some results shown here: only 10% of Binghamton properties and .3% of Minneapolis properties. Data for the city of Binghamton are constructed from the city's residential properties from 2007 to 2012 provided by Broome County GIS Portal Website (2013). This dataset is then restricted to only residential single family homes that remained in the sample over the 6 years with values between $25,000$ and $550,000$. Data for the city of Minneapolis are provided by the Minnesota Department of Revenue and constructed from parcel level data for every taxable parcel of land within Minneapolis. We calculate the tax price of each parcel but restrict our analysis to a 30% random sample of homes that appear each year from 2000 to 2009 with estimated market values between $50,000$ and $5 million. The tax price variance is calculated for each home, and that data is multiplied by the log tax price scalar to produce tax price uncertainty (see next section for details). In both cities, the tax price is calculated on the share of the total assessed value in each year. The tax price variance is calculated by the variation of the tax price observed over the period for each property. In both cities, one year of assessed property value–in Binghamton, 2012, and Minneapolis, 2005–is used as a proxy for wealth of a household.[30]

In the simulation, due to computational constraints, we chose to limit our analysis to a subset of 200 Binghamton and 200 Minneapolis properties. We chose these subsets randomly, and then verified that the first four moments of our samples match that of the data. A potential criticism is that, since the population of Binghamton is so much smaller than that of Minneapolis, it is not appropriate to use sample that are similar in size. However, we ran simulations with larger and smaller samples and none of the results changes substantively, so, since the results are not driven by the sample size, this is not a concern.

The summary statistics from Tables 1 (Binghamton) and 2 (Minneapolis) indicate that these two cities are very different. Wealth is much greater in the city of Minneapolis than in the city of Binghamton. The tax price variance in Minneapolis is greater than in Binghamton, reflecting the *de facto* policy difference in effect. The distribution of wealth in both cities is skewed and looks roughly exponential, where the mass of wealth resides on the low side, illustrated in Figure 1. The spatial distribution of wealth is available for Binghamton, and, as can be seen in Figure 2, wealthy and poor homes are clustered together.

5. Results

In this section, we present empirical estimates of the probability landscape $\rho_j(\gamma|s, D)$ faced by the government of city $j = bing, mpls$. This probability ρ_j is the probability that extraction

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[30]In the future, we hope to extend this work with richer data about wealth.
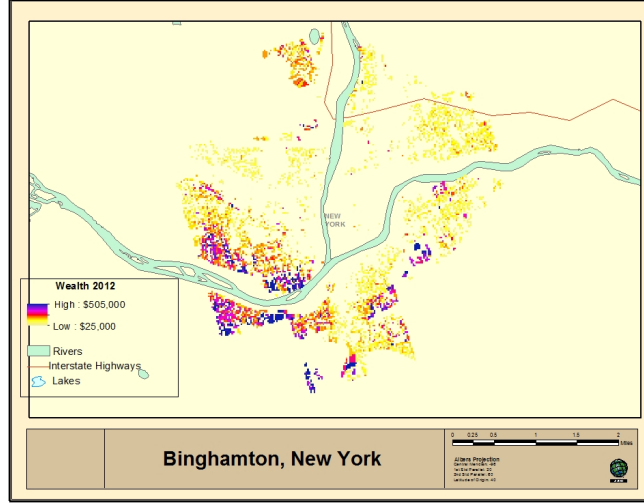
Figure 2: Assessed Values in the City of Binghamton

level γ will be blocked by a tax ceiling, given idiosyncratic uncertainty scalar s and common risk D. After defining more details about ρ, we interpret a representative graph (Section 5.1) and use that interpretation to define a 'Leviathan Extraction Choice Set.' We use this definition to establish our key result: we estimate that if there is any common risk, Binghamton voters will be more tolerant of Leviathan extraction than Minneapolis voters (Section 5.2). Then we establish secondary results: that Leviathan extraction tolerance increases as common risk increases (Section 5.3) and that loss aversion results in increased tolerance, but only for low to moderate levels of idiosyncratic risk 5.4.

The probability ρ that some extraction level γ with be blocked by a tax ceiling varies across jurisdictions because s does not fully capture idiosyncratic uncertainty. We assume that idiosyncratic uncertainty of each voter is *proportional* to the empirical tax price variance experienced by that voter (see previous section). s governs that proportion.[31] So an increase in s does (weakly, as we see below) increase uncertainty for all agents, but there are still differences in base levels of empirical tax price variance. In particular, the empirical tax price variance profiles $\vec{\sigma}^2_{mpls}$ and $\vec{\sigma}^2_{bing}$ vary in both mean tax price variance and the distribution of that tax price variance, and these differences are directly influenced by housing assessment policy. As described in Section 4, because of different tax assessment regimes, Minneapolis has a much larger mean tax price variance, and *all* citizens in Minneapolis have non-zero variance. On the other hand, Binghamton has a much smaller tax price variance, and most citizens have a very low tax price variance, while a small number of others have one that is markedly higher. So the population distribution of tax price variance between Minneapolis and Binghamton are significantly different.

5.1. Interpretation of a representative graph.

Figure 3 is a depiction of $\rho_{\text{bing}}(\gamma|s, D)$, where is set equal to $D = .5\%$ of total housing wealth and agents have only risk aversion, not loss aversion. That is, this figure depicts the probability that the most restrictive tax ceiling that gains majority support binds in the second round of the

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[31]The proportion is 10^s. That is why s is referred to below as log tax price variance scalar.
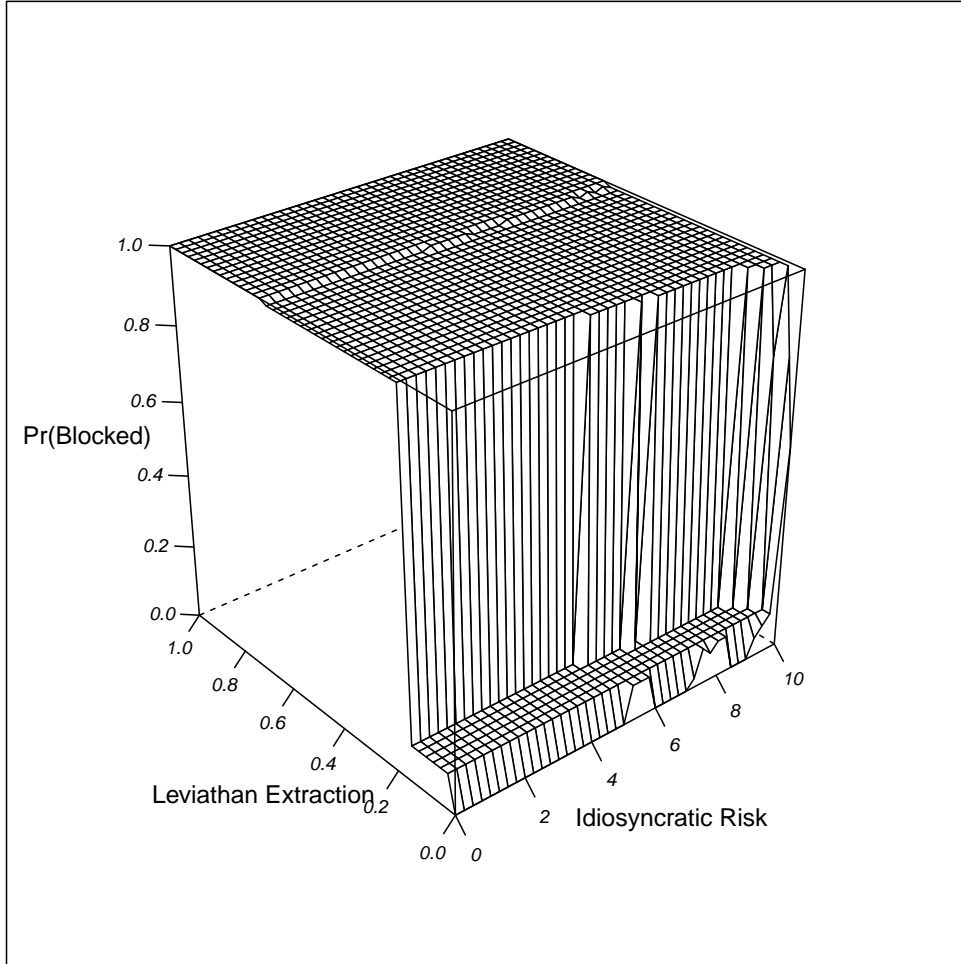
Figure 3: Probability a Choice of Leviathan Extraction will be blocked by Voters

log Tax Price VAR Scalar is the idiosyncratic uncertainty faced by voters as a function of actual tax price variance. (s)
Leviathan Extraction the level of Leviathan extraction chosen by the local government. (γ)
Pr(Blocked) predicted probability that local government will be blocked by a tax ceiling. (ρ)
Calamity Severity D is set equal to 0.5% of Wealth.

voting game. In other words, it depicts the probability that there is a tax ceiling that (a) will pass and (b) matters.

Figure 3 is a typical shape ρ takes on. (A full set of graphs is available the appendix, Section 7.) Log Tax Variance Scalar s, is idiosyncratic uncertainty faced by voters as a function of the actual tax price variance in Binghamton. It is on the x axis. Leviathan Extraction γ is the local government's choice variable, given a value of s and a value of D (which is constant in this graph). It is on the y axis. The outcome variable Pr(Blocked) is ρ. ρ is on the z axis. I.e., given s, when the Binghamton government chooses an extraction level γ, the z axis depicts the probability that this γ level will be blocked by a tax ceiling.

Figure 3 reveals that there are essentially only three values of ρ for any given combination of s and γ: zero probability, which occurs occasionally along the $\gamma = 0$ axis, a probability of .1, which occurs in a contiguous set around the origin, and certainty (a probability of 1), which occurs outside of this set. On this graph, this sharp divide appears as a 'cliff,' where low levels of s and γ do not invite retaliation, while high levels of either do. We think it is useful to think of this as providing a "Leviathan Extraction Choice Set" for the government, where the lower level in the Figure can be thought of the options that the government sees as available Leviathan extraction choice sets.

These three levels of probability of binding–zero, .1, and ≈ 1–correspond to the common risk in the problem. There is a fixed, ten percent chance of calamity of severity D equal to 0.5% of total housing wealth in the town, with a corresponding reduction in the collective good. The (s, γ) which result in a ρ of .1 bind only when calamity happens, but the government is relatively unrestricted when the calamity does not happen. The theory model predicts that any extraction level greater than zero will be constrained in the case of damages, which is what we find here. On the other hand, the (s, γ) which result in a ρ of 1 bind regardless of whether damages occur.

In principle, there could be intermediate levels of ρ other than the three levels consistent with the type of common risk we are facing, but as we see, this rarely happens. Why might this happen? The idiosyncratic risk does imply that, even conditional on damages, there is a distribution of median ideal revenue levels. And at high levels of s, there is a fair amount of variability. But these figures show that voters rarely choose to exclude particular levels of revenue within these distributions, choosing instead to contain either all revenue levels consistent with a certain level of damages, or none of them. This suggests it is reasonable to assume that the ex-post median ideal revenue level, conditional on damages, is essentially deterministic for the purposes of considering extraction levels.[32]

Given that this sharp divide exists between extraction levels which are rarely or never blocked, versus extraction levels which are always blocked, it is useful to think of the "lowlands" of the probability landscape–extraction levels which are rarely blocked–as the Leviathan Extraction Choice Set of the local government. For the remainder of this section, we then present depictions of these Leviathan Extraction Choice Sets, which we view 'from above,' as one views contour lines (i.e. indifference curves or isoquants.)

5.2. Binghamton versus Minneapolis: The Key Result

Figures 4 and 5 depict our key result: the differences in tax price variance brought about by assessment policy differences between Binghamton and Minneapolis result in striking differences between the empirical estimates of the choice sets faced by their local governments. If there is any common risk, the government of Binghamton has much more freedom to extract than does

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[32]This cannot be taken to mean that idiosyncratic tax price variance does not matter. If it did not matter, the line between extraction levels would be parallel to the x axis.
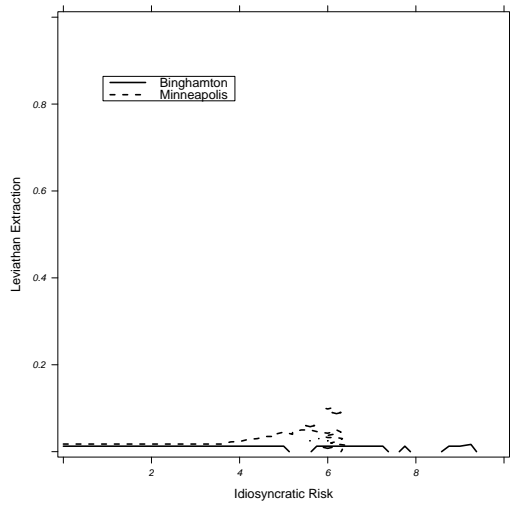
(a) Damage severity of 0%
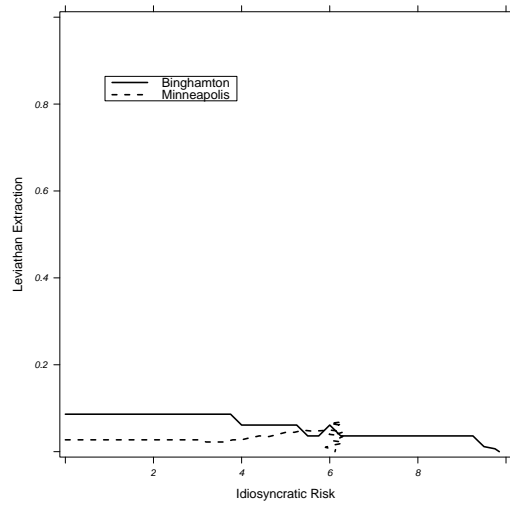
(b) Damage severity of .25%
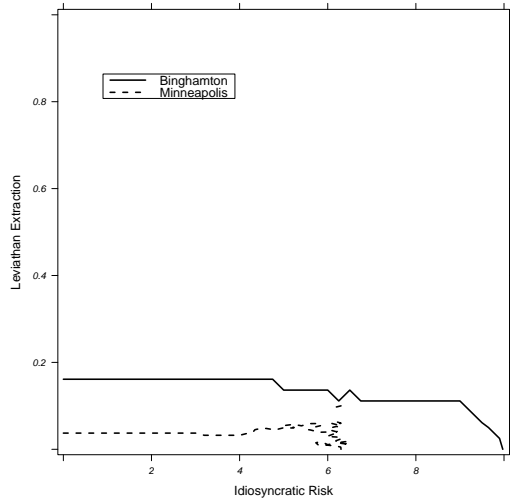
(c) Damage severity of .5%
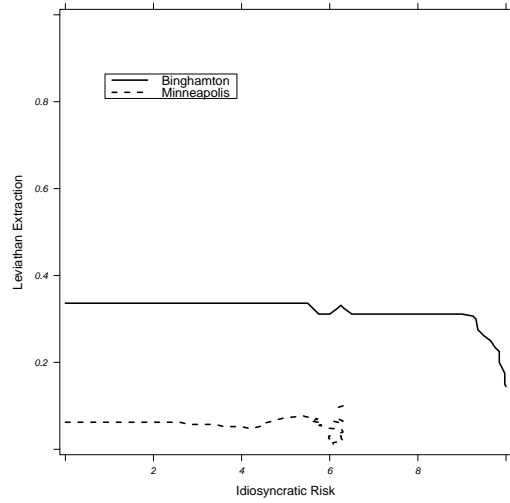
(d) Damage severity of 1%

Figure 4: Relative Size of Leviathan Extraction Choice Sets Under Risk Aversion: Binghamton vs. Minneapolis
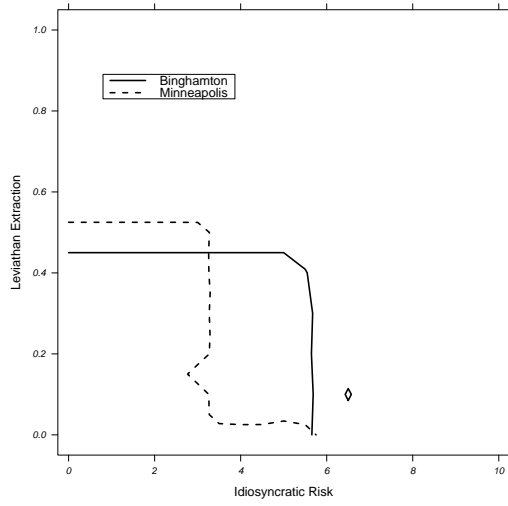
16

(a) Damage severity of 0%
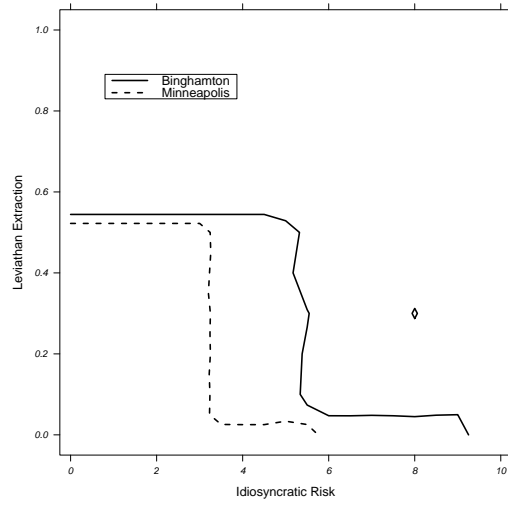
(b) Damage severity of .25%
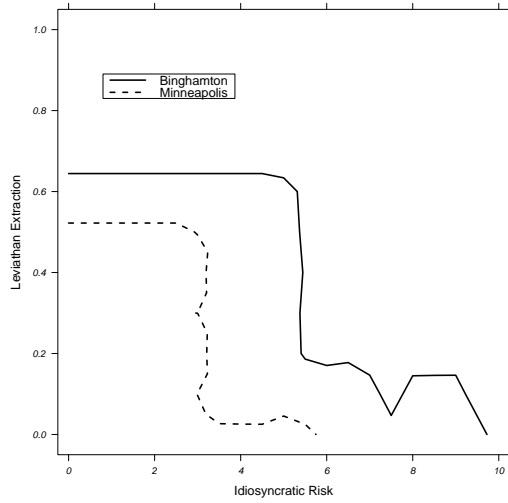
(c) Damage severity of .5%
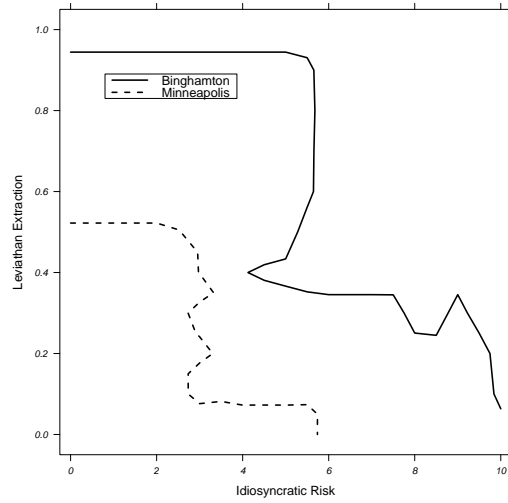
(d) Damage severity of 1%

Figure 5: Relative Size of Leviathan Extraction Choice Sets Under Loss Aversion: Binghamton vs. Minneapolis

Minneapolis at all levels of idiosyncratic risk s. And as common risk increases, the edge that the Binghamton government has over Minneapolis increases.

Moreover, we find this result holds over both risk aversion (Figure 4) and loss aversion (Figure 5).

For the highest level of calamity severity (1% of housing wealth), we find that the Binghamton government can extract as much as five times as many cents on the dollar as can the Minneapolis government can. This result strongly suggests that assessment policy could significantly change voter support for a tax ceiling in a given jurisdiction.

(a) Binghamton   (b) Minneapolis
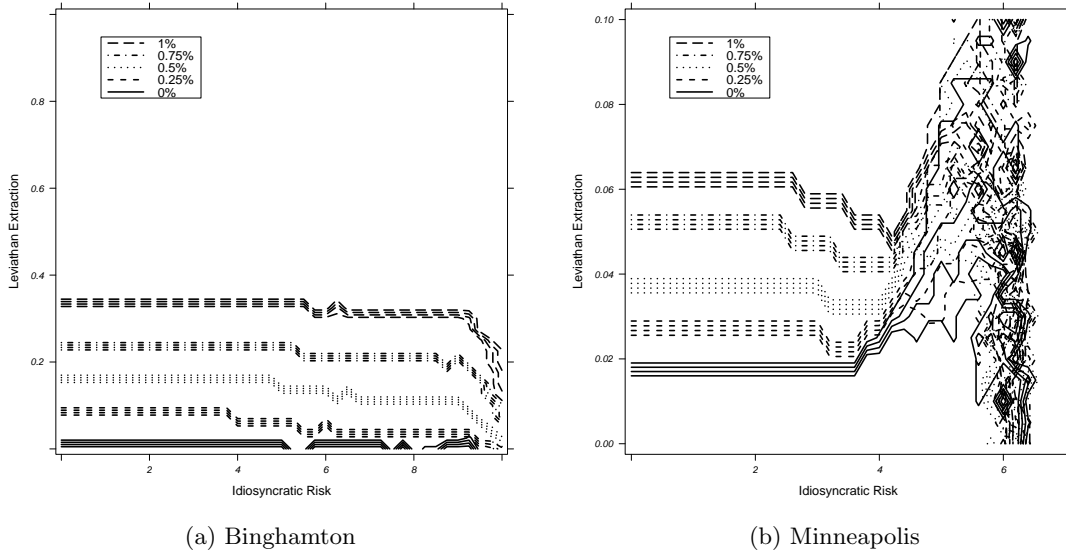
Figure 6: How Leviathan Extraction Choice Sets vary as Calamity Severity D Varies from 0% to 1% of Wealth under Risk Aversion

Note that scales differ between Figures 6a and 6b. See Figure 4 for a direct comparison across cities.

5.3. Within-city comparison of Leviathan Extraction Choice Sets as Common Risk Varies.

Figure 6 depicts how Leviathan Extraction Choice Sets vary as the level of calamity severity D varies. Binghamton is on the left (Figure 6a), and Minneapolis is on the right (Figure 6b). The x-axis in these graphs are idiosyncratic risk s and the y-axis is the level of Leviathan Extraction γ; although it should be noted that the y-axis range depicted for Binghamton is from zero to one and Minneapolis only ranges from zero to .1.

In both figures, it can be seen that, by and large, the choice sets are flat or downward sloping and are nested, one within the next, as calamity severity increases. In Binghamton this effect can be seen quite clearly and cleanly; however, in Minneapolis the ordering collapses after idiosyncratic risk s exceeds 4. More on that below. This overall effect (ignoring, for a moment, the collapse in the pattern in Minneapolis for high levels of s) indicates that, as *common risk* increases, the local governments have more freedom to tax in those times that the calamity *doesn't* occur.

The exception to the downward-slopedness and nestedness occur in Minneapolis for high levels of s (> 4). The reason for this is truncation of tax price at (close to) zero. When a tax price error is applied to average tax price of an individual that brings it near zero, it is truncated at a small,
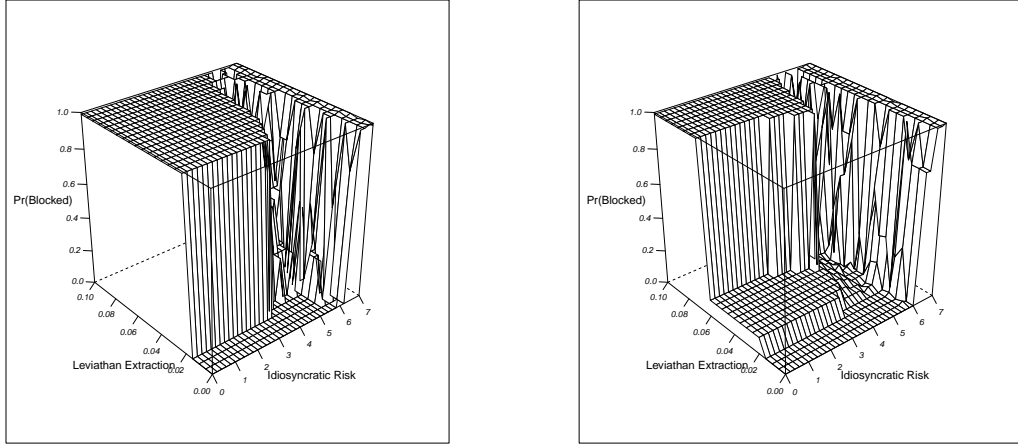
Calamity Severity $D = 0\%$ of Housing Wealth   Calamity Severity $D = 1\%$ of Housing Wealth

Figure 7: Leviathan Extraction Choice Sets for Minneapolis: two representative Calamity Severity Levels

positive value.[33] This means when the empirical level of tax price variance in Minneapolis $\vec{\sigma}^2_{mpls}$ is raised to too large a level, many agents become truncated at this identical, low tax price level at the same time. This truncation makes the idiosyncratic risk into a kind of common risk. Therefore, when calamity severity is low enough, this artificial common risk, which is increasing in s, has some impact on the tax ceilings which are supported. Why doesn't this truncation effect occur in Binghamton? The reason is, as mentioned above in this section, in Binghamton, the majority of properties experience no change in home value so have a tax price variance of zero. So, even at high levels of s, not enough properties are simultaneously truncated to induce a significant amount of this artificial common risk. Figure 7 depicts representative three-dimensional graphs for Minneapolis that show that $s \in [4, 6]$ results in a noisy 'spike' in the choice set.

5.4. Within-city comparison of Leviathan Extraction Choice sets under Risk versus Loss Aversion.

Figure 8 depicts the two Leviathan Extraction Choice Sets in Binghamton under risk aversion and under loss aversion. The pattern here is typical of Minneapolis as well (see Figure 22 in the Appendix for the graphs for Minneapolis). Loss aversion appears to, for lower levels of idiosyncratic risk ($s < 6$), greatly increase the perceived cost of too little revenue being collected because of a tax ceiling; so the voters allow for much more Leviathan Extraction at those levels, even under zero common risk. However, as the level of idiosyncratic risk passes this turning point, idiosyncratic risk now becomes the risk that drives loss aversion, and this effect quickly leaves. This suggests **TODO:Say more here.**

6. Conclusion

Our agent-based model incorporates empirical data to estimate how important both tax payment uncertainty and Leviathan extraction are to providing popular support for tax ceilings. We

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[33]Negative property tax prices are never seen in reality and zero tax prices imply an agent who is indifferent to costs, and therefore has perverse preferences, and we wished to rule out such preferences.
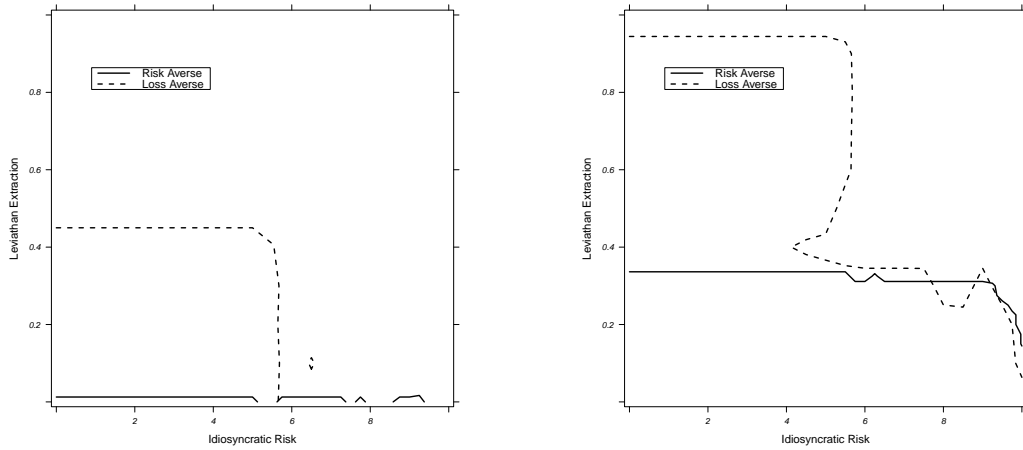
Calamity Severity $D = 0\%$ of Housing Wealth   Calamity Severity $D = 1\%$ of Housing Wealth

Figure 8: Binghamton, Probability That Most Restrictive Passing Limit Binds: Risk v Loss Aversion

use empirical data from two American cities: Minneapolis, MN and Binghamton, NY. These cities have different property assessment regimes, which in turn generate different profiles of tax price variance across their populations. According to our model, the different property assessment regimes imply that Binghamton residents would be as much as five times as tolerant of Leviathan extraction as the residents of Minneapolis. This suggests that property tax assessment regimes, and the resulting tax payment uncertainty, could be a key factor determining voter support for these laws.

The methodological contribution of this paper is to introduce voters who forecast the impact of alternative policies before they vote using the agent-based model that they are themselves embedded in. We call this 'simulated rational expectations,' because we sample the space of possible outcomes and generate a joint belief distribution for all random variables as a function of policy. The resulting belief distribution is then endowed to all agents as a common prior and all agents maximize expected utility with regard to this common prior. While the policy considered here is a property tax ceiling, this method of simulated rational expectations to calculate policy support could be paired with other agent-based models to predict support in completely different economic settings, such as pairing with market models to predict support for the minimum wage or with an environmental model to predict support for resource rationing.

The policy contribution of this paper is to show that, all else equal, assessment policy can significantly change the freedom that a local government has to raise revenues on a scale that we estimate could plausibly explain which cities support, and which don't support, a given tax ceiling. This is a noteworthy contribution because existing models in the literature, with the exceptions of Vigdor (2004) and Anderson and Pape (2013), offer Leviathan extraction as the only explanation of support. In this, we contribute to a empirical literature investigating support for tax ceilings. Unlike the existing literature investigating voter support for tax ceilings, we estimate how *uncertainty in tax payments* affects support for tax ceilings, and we use new data: household-level, panel tax-price data. It suggests future research into the whether variation in assessment policies predicts passage of these laws.

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7. Appendix

7.1. Maps of Binghamton with Estimated Support
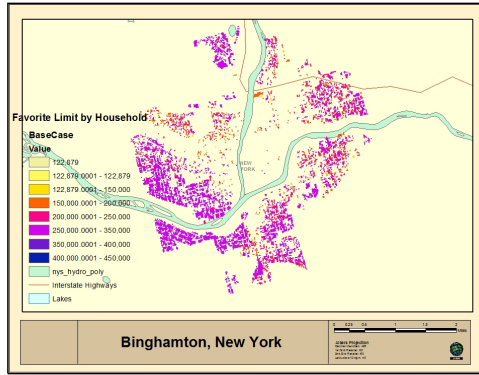
Figure 9: Binghamton, support for tax ceiling base case.
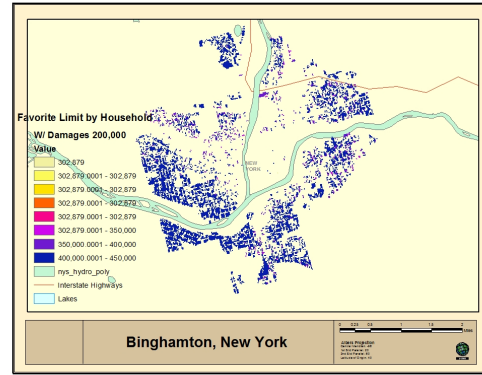
Figure 10: Binghamton, support for tax with high common risk. Note that support is reduced from the base case.
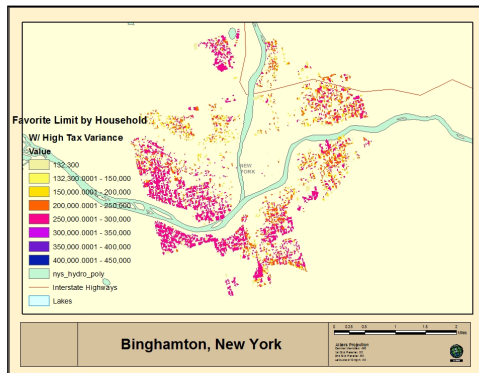
Figure 11: Binghamton, support for tax with high individual risk. Note that support is increased from the base case.
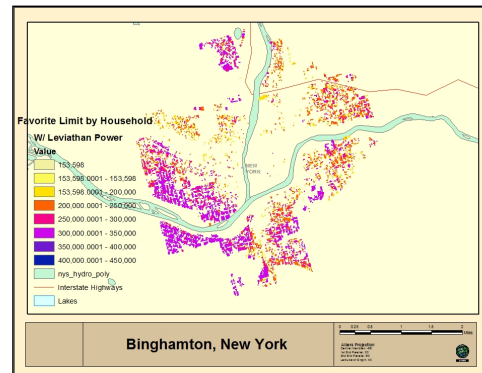
Figure 12: Binghamton, support for tax with high Leviathan extraction. Note that support is increased from the base case.

7.2. Results: Statistics

	Mean	Std Dev	Max	Min
Base Case	228,893	31,705	252,879	122,879
W/ Leviathan	248,213	49,642	313,598	153,598
W/ Damages	428,793	31,884	452,830	302,879
W/ High Variance	234,660	51,388	292,300	132,300
N	6,821			

Figure 13: Binghamton: Median Ideal Tax Ceilings

	Mean	Std Dev	Max	Min
Base Case	1,918,832	152,982	2,038,893	1,418,893
W/ Leviathan	2,089,058	331,726	2,553,617	1,423,617
W/ Damages	2,044,273	230,609	2,238,893	1,448,893
W/ High Variance	293,891	10,959	522,711	292,711
N	2,644			

Figure 14: Minneapolis: Median Ideal Tax Ceilings

7.3. All Graphs of Leviathan Extraction Choice Sets

This subsection contains all graphs of Leviathan Extraction Choice Sets discussed in Section 5 of the text. Please see that section for details about how these graphs were created.

The first set of figures look at the choice sets within each city. Figure 15 shows the Leviathan Extraction Choice Sets in the city of Binghamton under Risk Aversion for levels of Calamity Severity ranging from 0% to 1% of total Wealth, and Figure 16 shows the same set of graphs under Loss Aversion. Figure 17 and 18 show the corresponding graphs for Minneapolis under risk aversion and under loss aversion.

The second set of figures compare Binghamton against Minneapolis. Figure 19 compares the Leviathan Extraction Choice Sets between Binghamton and Minneapolis for a range of Calamity levels under risk aversion, and Figure 20 does the same under loss aversion.

The third and final set of figures compare Risk versus Loss Aversion within city. Figure 21 depict the Leviathan Extraction Choice Sets for Binghamton under levels of Calamity Severity varying from 0% to 1% of total Wealth, and Figure 22 does the same for Minneapolis.

How Leviathan Extraction Choice Sets vary as Calamity Severity D Varies from 0% to 1% of Wealth

Calamity Severity $D = 0\%$ of Housing Wealth

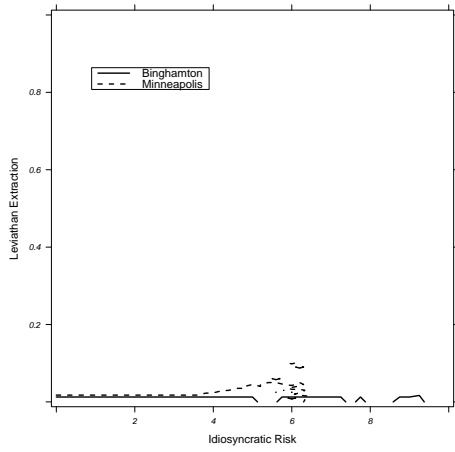Calamity Severity $D = 0.25\%$ of Housing Wealth
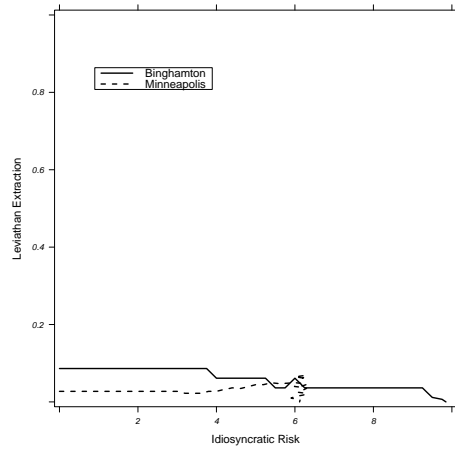

Calamity Severity $D = 0.5\%$ of Housing Wealth
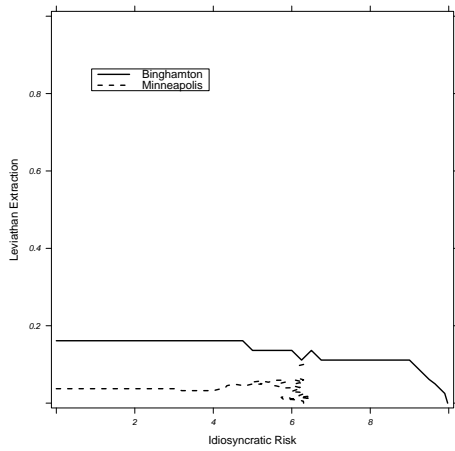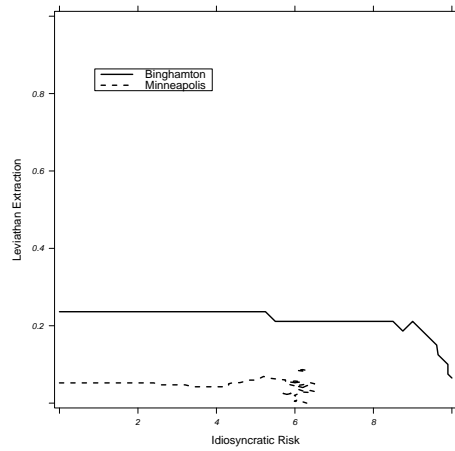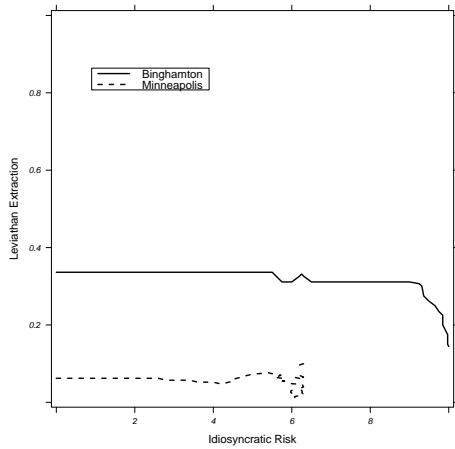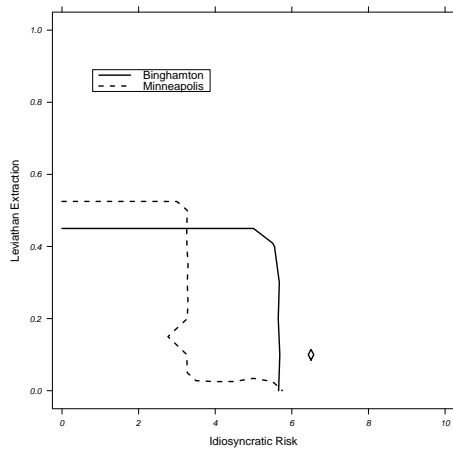

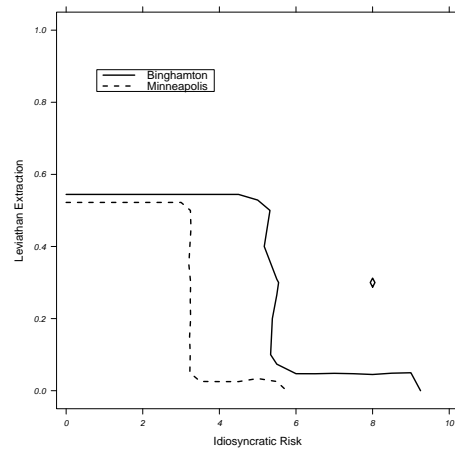Calamity Severity $D = 0.75\%$ of Housing Wealth
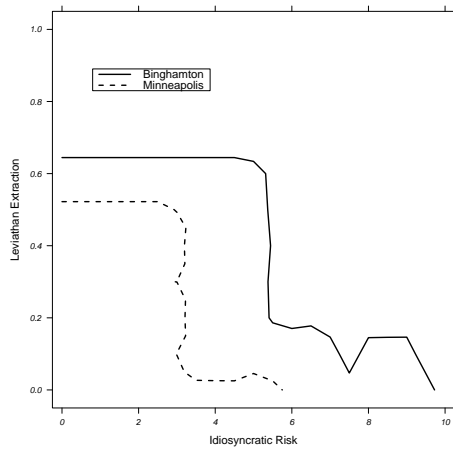

Calamity Severity $D = 1\%$ of Housing Wealth

28

Figure 15: Binghamton, Probability That Most Restrictive Passing Limit Binds, Risk Aversion

How Leviathan Extraction Choice Sets vary as Calamity Severity D Varies from 0% to 1% of Wealth
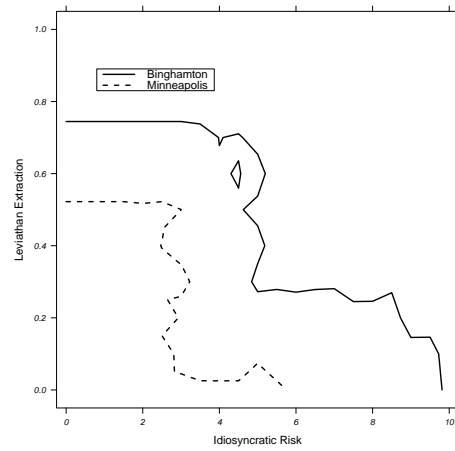

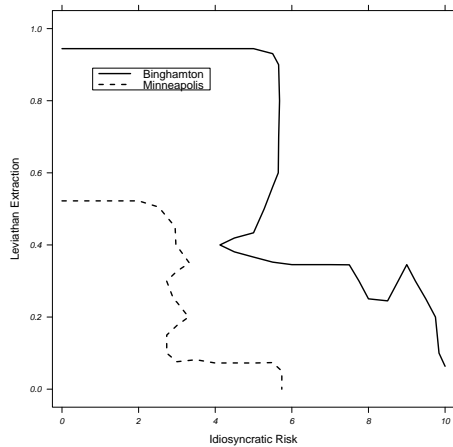Calamity Severity $D = 0\%$ of Housing Wealth

Calamity Severity $D = 0.25\%$ of Housing Wealth

Calamity Severity $D = 0.5\%$ of Housing Wealth

Calamity Severity $D = 0.75\%$ of Housing Wealth

Calamity Severity $D = 1\%$ of Housing Wealth

29

Figure 16: Binghamton, Probability That Most Restrictive Passing Limit Binds, Loss Aversion

How Leviathan Extraction Choice Sets vary
as Calamity Severity D Varies from 0% to
1% of Wealth

Calamity Severity $D = 0\%$ of Housing Wealth

Calamity Severity $D = 0.25\%$ of Housing
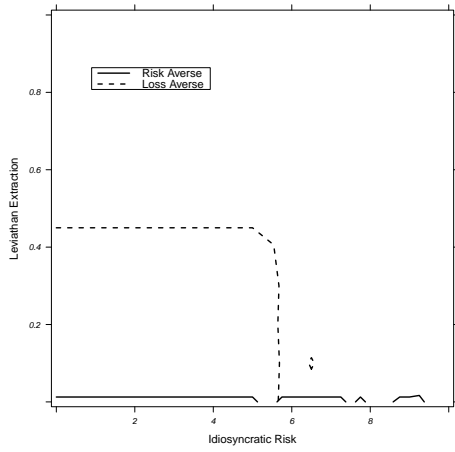Wealth

Calamity Severity $D = 0.5\%$ of Housing
Wealth

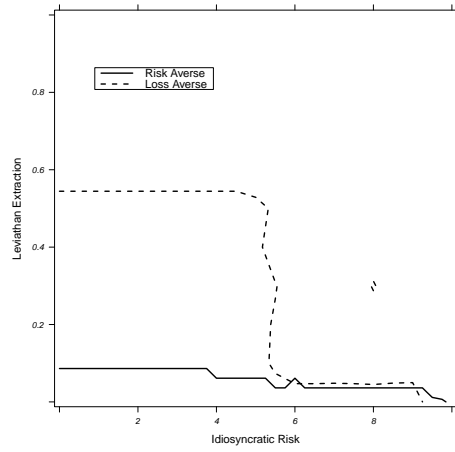Calamity Severity $D = 0.75\%$ of Housing
Wealth

Calamity Severity $D = 1\%$ of Housing Wealth

30

Figure 17: Minneapolis, Probability That Most Restrictive Passing Limit Binds, Risk Aversion

How Leviathan Extraction Choice Sets vary as Calamity Severity D Varies from 0% to 1% of Wealth

Calamity Severity $D = 0\%$ of Housing Wealth

Calamity Severity $D = 0.25\%$ of Housing Wealth

Calamity Severity $D = 0.5\%$ of Housing Wealth

Calamity Severity $D = 0.75\%$ of Housing Wealth
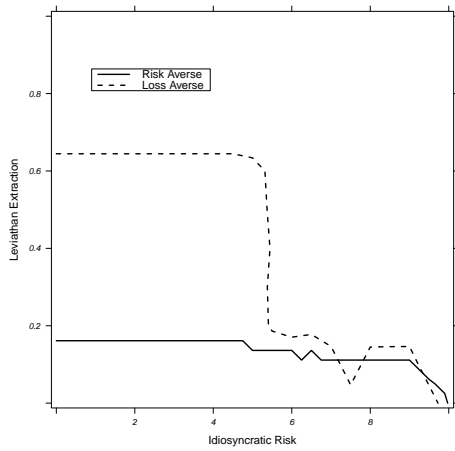

Calamity Severity $D = 1\%$ of Housing Wealth

31

Figure 18: Minneapolis, Probability That Most Restrictive Passing Limit Binds, Loss Aversion
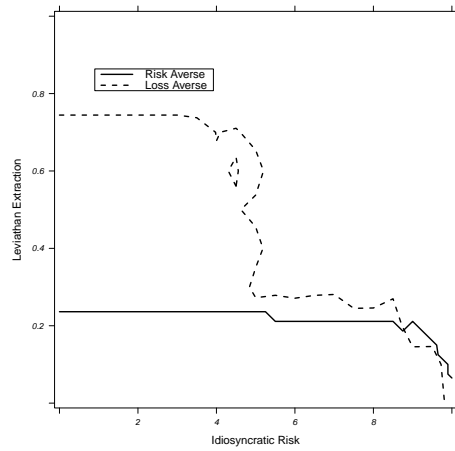
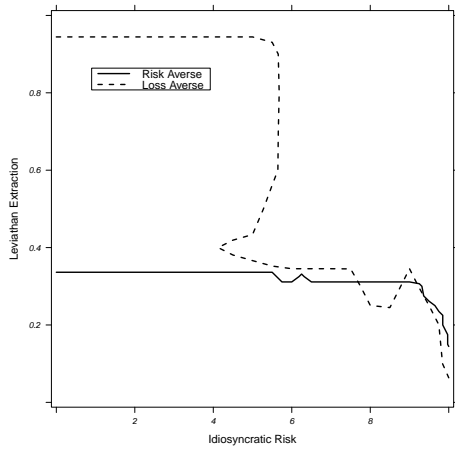Calamity Severity $D = 0\%$ of Housing Wealth

Calamity Severity $D = 0.25\%$ of Housing Wealth

Calamity Severity $D = 0.5\%$ of Housing Wealth

Calamity Severity $D = 0.75\%$ of Housing Wealth

Calamity Severity $D = 1\%$ of Housing Wealth

Figure 19: Binghamton v. Minneapolis, Probability That Most Restrictive Passing Limit Binds under Risk Aversion

Calamity Severity $D = 0\%$ of Housing Wealth

Calamity Severity $D = 0.25\%$ of Housing Wealth

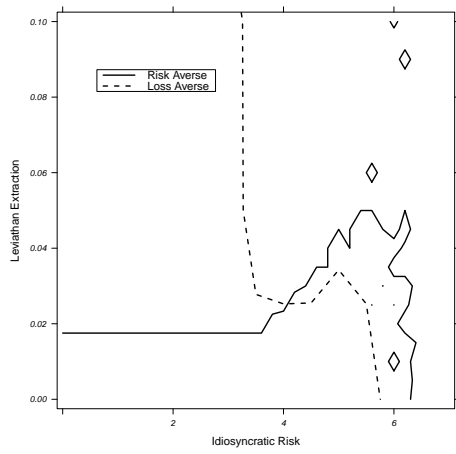Calamity Severity $D = 0.5\%$ of Housing Wealth

Calamity Severity $D = 0.75\%$ of Housing Wealth

Calamity Severity $D = 1\%$ of Housing Wealth

Figure 20: Binghamton v. Minneapolis, Probability That Most Restrictive Passing Limit Binds under Loss Aversion

Calamity Severity $D = 0\%$ of Housing Wealth

Calamity Severity $D = 0.25\%$ of Housing Wealth

Calamity Severity $D = 0.5\%$ of Housing Wealth

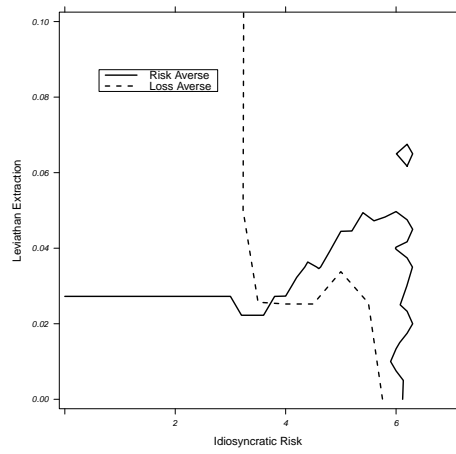Calamity Severity $D = 0.75\%$ of Housing Wealth
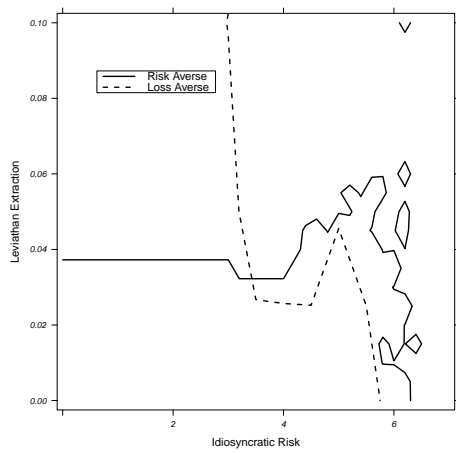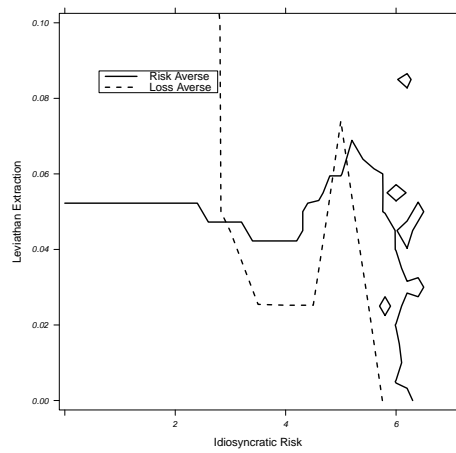

Calamity Severity $D = 1\%$ of Housing Wealth

Figure 21: Binghamton, Probability That Most Restrictive Passing Limit Binds: Risk v Loss Aversion

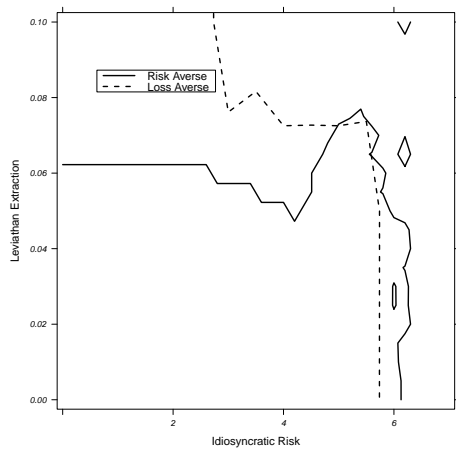Calamity Severity $D = 0\%$ of Housing Wealth

Calamity Severity $D = 0.25\%$ of Housing Wealth

Calamity Severity $D = 0.5\%$ of Housing Wealth

Calamity Severity $D = 0.75\%$ of Housing Wealth

Calamity Severity $D = 1\%$ of Housing Wealth

Figure 22: Minneapolis, Probability That Most Restrictive Passing Limit Binds: Risk v Loss Aversion