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Abstract:

Replication is a critical step in the scientific process. This paper is an effort to contribute to the growing literature on the replication of Agent-Based Computational Models. We present a replication of Kollman, Miller & Page's (1997) model of Tiebout sorting. In that model, individual agents with heterogeneous preferences for government policies select among jurisdictions that offer the most satisfactory package of government services. This project makes four contributions to the literature. First, our successful replication provides the research community with a modernized version of that seminal model. Second, we confirm that earlier results with respect to the single jurisdiction setting are highly robust with respect to voter preferences, while the results for multiple jurisdiction settings are sensitive. Third, we find little evidence to suggest that any of the alternative voting rules we consider achieve greater voter satisfaction or improve the competitiveness of local elections. Finally, we demonstrate a technique for conducting sensitivity analyses that leverages a high-dimensional experimental design.

JEL Classifications: D72, H72, C63
Keywords: Tiebout competition, agent-based modeling, local government, docking, replication

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[Draft – Not for Attribution]

I. Introduction

Replication is a critical step in the scientific process. It confirms earlier findings and identifies exceptions to those findings. While Agent-Based Computational Models have grown in popularity in recent years, the effort to replicate the results of earlier researchers has grown only slowly. Axtel, et al (1996) are generally credited with the first attempt to dock two different simulation models, while Hales, Rouchier, and Edmunds (2003) report the results of a model-to-model workshop, the intent of which was to encourage the replication of computational models. Wilensky and Rand (2007) argue that replication is even more important for computational models, because it "increases our confidence in the model verification, leads to a reexamination of the original validation of the model, and at the same time, facilitates a common language and understanding among modelers." See Sansores and Pavon (2005), North and Macal (2009), and Zhong and Kim (2010) for relatively recent examples of efforts to replicate computational models, while Miodownik, Cartrite, and Bhavnani (2010) extend and build upon a previously developed agent-based model that examines civic traditions in Italy.

This paper is an effort to contribute to this growing literature. We present a replication of Kollman, Miller & Page's (1997) model of Tiebout sorting (hereafter KMP). In that model, individual agents with heterogeneous preferences for government policies select among jurisdictions that offer the most satisfactory package of government services. We replicate the model in Java using the Recursive Porous Agent Simulation Toolkit (REPAST)[1]. We then extend the analysis along a number of margins. First, we determine how sensitive the results in KMP (1997) are to a wider array of types of voter preferences. We also employ additional voting institutions, including several non-standard voting rules, and consider additional measures of effectiveness in an effort to measure whether certain institutions facilitate more intense

[1]For more information on REPAST, see: http://repast.sourceforge.net.

competition between political parties than others. Finally, we borrow from the operations research literature on data farming and employ a high-dimensional experimental design in support of a thorough sensitivity analysis.

This project makes four contributions to the literature. First, we build a replication of KMP97 that achieves acceptable relational alignment overall, and distributional equivalence in certain aspects, thus providing the research community with a modernized version of that seminal model. Second, we find that KMP's results with respect to the single jurisdiction setting are highly robust with respect to voter preferences, while their results for multiple jurisdiction settings are sensitive to variations. Third, our examination of alternative voting rules finds that, in this particular context, there is little evidence to suggest that any of the rules considered are more efficient with respect to achieving greater voter satisfaction or improving the competitiveness of local elections. Finally, we demonstrate a technique for conducting sensitivity analysis that leverages a high-dimensional experimental design.

II. The Tiebout Hypothesis

A vast literature exists that examines the ability of local governments to provide public goods efficiently. However, most of the literature overlooks the differential effects of the collective choice institutions. In addition, the distribution of voter preferences may enhance or hinder the performance of political institutions. The dynamics between political institutions and voter preferences may greatly affect a local government's ability to leverage its monopoly position in order to extract rents from the constituencies.

In his seminal paper, Tiebout (1956) argues that, given certain assumptions, local governments provide a supply of public goods that approaches the competitive level. "If consumer-voters are fully mobile, the appropriate local governments, whose revenue-expenditure patterns are set, are adopted by the consumer-voters" (1956: 424). Because local governments offer a variety of services and service levels, and constituents "vote with their feet", local governments' production of public goods will approach the efficient level. Local governments that succeed in providing those public goods that consumer-voters demand tend to be rewarded with new constituents (taxpayers) and those that fail tend to be faced with declining populations. Some of the assumptions upon which Tiebout relies include (1) consumer-voters are fully mobile and can move freely; (2) consumer-voters have full knowledge; (3) large number of communities; (4) restrictions due to employment are neglected; and (5) public services exhibit no externalities upon other jurisdictions (1956: 419).

In short, the Tiebout hypothesis states that voters will move to localities that offer that package of government services and taxation that fits their preferences. The present paper examines the extent to which Tiebout's conclusion holds, given a somewhat richer model that relaxes several of his assumptions – namely, those pertaining to the knowledge levels of local politicians and their abilities and incentives to compete politically for the favor of constituents.

Epple and Zelenitz (1981) conclude that given fixed jurisdictional boundaries, competition among jurisdictions alone does not prevent local governments from leveraging their monopoly power. Mileszkowski and Zodrow (1989) find that under certain circumstances the property tax approximates the non-distortionary head tax implied in Tiebout's model. The authors contrast this with an alternative view that capital bears the average burden of the tax (1989: 1141). They conclude that the latter view prevails under more plausible circumstances. Arnott and Stiglitz (1979) consider the role of Georgist taxation of land rents and find that given certain assumptions, differential land rents provide the optimal revenue for public goods. For a survey of the empirical literature, see Dowding, et al (1994).

In a critique of the theory underlying Tiebout's model, Bewley (1981) demonstrates in a series of examples that Tiebout's hypothesis does not possess the same qualities as general equilibrium. Under a wide range of assumptions, there exist equilibria that are not Pareto efficient. He argues that the assumptions that form the foundation for Tiebout's analysis are overly restrictive and essentially change public goods into private (1981: 713). The author concludes that the only way to ensure that Tiebout holds is if there are as many jurisdictions as there are voters. The models we develop and analyze in this paper are capable of examining the relationship between number of voters and number of jurisdictions.

More recent contributions to the literature include Nechyba (1997), who uses a simulation model to examine the interplay between state and local governments, in an environment of economic and political competition. Caplan (2001) formulates a model that shows that Tiebout competition is unable to reduce the monopoly power of local governments at all, due to the presence of tax capitalization which makes it impossible for land owners to move to avoid monopolistic pricing of government services (2001: 1-5). His model leverages an exogenous party preference term that characterizes voters' willingness to trade utility in order to see their preferred party in power, which the parties then exploit once in power. Along those lines, the present paper measures the effectiveness with which different voting rules allow for an endogenous level of separation between parties to emerge, which incumbent parties could then exploit.

A local government that is able to shield itself from the competitive process of constantly offering the mix of services and taxes that most satisfies voters' demands for governance would be able to exercise a certain amount of monopoly power to extract rents from its constituents. As in market transactions, firms that face stiff competition must constantly innovate and strive to please customers, while firms that enjoy a monopoly position are not necessarily under the same constraints. It is difficult even in a computational model to measure the amount of competition between the parties within jurisdictions, a surrogate of platform separation is developed later in this paper. The key characteristic is that this phenomenon emerges endogenously.

III. The KMP97 Model

In KMP (1997), the authors develop a computational model to measure the ability of different voting institutions to sort individuals who possess preferences over the allocation of public goods into different jurisdictions. (We refer hereafter to the model as KMP97.) Heterogeneous agents are endowed with fixed, linearly separable preferences over a specified number of binary issues. Agents reside in one of a fixed number of jurisdictions, within which political platforms are determined by collective choice using one of the following institutions: democratic referendum, direct competition, or proportional representation. Jurisdictions select their platforms and resolve the collective choice problem regarding the issues, and agents are then free to move to the jurisdiction that offers them the highest expected utility. Agents are unable to forecast the effects that their presence will have on the platforms selected in jurisdictions to which they may move, which is a key aspect of their bounded rationality.

One of the authors' overarching conclusions is the process through which the agents seek their optimal jurisdiction, and through which the imperfectly informed parties pursue the election winning platform, is significantly more stable than McElvey (1976) findings would suggest. In addition, they find that the order of how well political institutions perform relative to one another (in terms of increasing aggregate utility) in a single jurisdiction setting is generally opposite of how they perform in a multiple jurisdiction setting. Namely, democratic referendum, an institution that provides highly stable outcomes is found to be superior to the other collective choice mechanisms in a single jurisdiction model, followed by direct competition and proportional representation. When the number of jurisdictions is increased, proportional representation is found to outperform the others. In fact, as the number of jurisdictions increase, so too does the relative ability of proportional representation to sort voters according to their preferences (KMP, 1997). This relationship is due to the propensity for unstable political outcomes under proportional representation and direct competition, thus allowing jurisdictions to "break out" of sub-optimal equilibria, with greater regularity than democratic referendum.

A. Institutions and Hill-Climbing Parties

KMP consider the following voting institutions:

Democratic Referendum. A democratic referendum involves a simple majority rule vote on each issue. The outcome is the median level for each issue in the jurisdiction. This is the only institution examined that does not involve party participation.

Direct competition. Direct competition is a plurality contest between parties. Agents vote for the party proposing the platform that yields them the highest utility and the jurisdiction wholly adopts the winning party's platform.

Proportional Representation. Under a proportional representation regime, each voter votes for the party proposing the platform that yields her the highest utility. Each party is then allocated "seats" according to the proportion of votes received.[2] The parties then vote separately and sincerely on each issue in a democratic referendum.

For political institutions that involve the participation of parties, such as direct competition and proportional representation, a given number of parties compete within each jurisdiction during the electoral process. They stand separate and distinct from the voting populace and lack complete information regarding the preferences of voters within the constituency. They gradually adapt their platform by employing various search mechanisms in an attempt to find the platform that will garner the most votes in the election. The parties seek only reelection, and have no policy preferences of their own. The adaptive technique primarily used by the parties in the present paper is known as the hill-climbing heuristic procedure. Hill-climbing is intended to simulate those parties that "fine-tune the policy positions of its candidate using polling and focus groups" (KMP, 1998: 144).[3]

For the hill-climbing algorithm, the party randomly selects no more than three issues of its current platform to perturb, in order to constrain the new platform to the neighborhood of the original. The party then conducts a poll over the entire constituency of the jurisdiction and determines if the platform will yield it a higher vote total than its current platform. If so, then the new platform becomes the party's platform, if not, the current platform remains. This process continues for eight iterations, at such time the next party is allowed to adapt its platform. Once all parties have adapted their platforms, another round of adaptation may occur. For the results presented in the following section, each party was allowed 5 rounds of adaptations, which means that each party considers a total of 8*5 candidate platforms during every election cycle. At the

[2] There is no minimum threshold of votes that parties must receive before attaining notional seats in this model.
[3] Though we do not present the results, we replicate the "random" party search as well.

conclusion of the campaign the general election is held where the parties run on their newly adapted platform.

B. Notation and Measures of Effectiveness

The following is a formal specification of the KMP97 model, the notation for which is drawn from KMP (1997, 1998). Let N_a agents select among N_j different jurisdictions. In each jurisdiction, a total of N_i issues are resolved collectively. Let $p_{ji} \in \{Yes , No\}$ give the position of jurisdiction *j* on issue *i*. When political parties are considered, let $p_{rji} \in \{Yes, No\}$ give the position of party *r* in jurisdiction *j* on issue *i*. Let Platform $\mathbf{P}_j \in \{Yes, No\}^{Ni}$ denote the vector of decisions across all N_i issues in jurisdiction *j*. Jurisdictions take binary positions on each issue, thus we think of such positions as the presence or absence of a particular public good, policy, or regulation.

Let $\nu_{ai} \sim \text{Uniform}[-400/N_i, 400/N_i]$ and give agent *a*'s utility for issue *i*. Furthermore, agent *a*'s utility from platform $\mathbf{P}_j$ is given by:

$$u_a(\mathbf{P}_j) = \Sigma\ \nu_{ai} \cdot \delta(p_{ji}) \qquad (1)$$

where $\delta(Yes) = 1$, and $\delta(No) = 0$. An agent's ideal platform will yield an expected value of 100, while the expected utility of a random platform is zero (KMP, 1997).

For the replication process, we consider three outputs as measures of effectiveness. The first is *per-capita utility*, which is simply the mean utility of all agents in the population. In addition to the influence of political institution, per-capita utility tends to increase with the number of jurisdictions and increase with the number of parties.

The second measure we examine is the number of agent *relocations* during a simulation run. An agent executes a relocation whenever it changes jurisdictions. If a particular voting institution tends to encourage a large number of voters to relocate to different jurisdictions, this could be beneficial for a number of reasons. A relatively high number of moves can be indicative of instability, which, if it happens early in the simulation could facilitate the sorting of voters into homogeneous constituencies that achieve high average utility.

We also look at a measure of *inter-jurisdiction distance*. The inter-jurisdiction distance between the platforms of two jurisdictions is equal to the number of issues for which policies differ, divided by the total number of issues (KMP, 1997: 989). We examine the mean inter-jurisdiction distance, which simply takes the mean of all pair-wise combinations in a given scenario.

III. A Successful Replication of KMP97

Wilensky and Rand (2007) describe six margins along which an original model and subsequent model may differ. They are: time, hardware, languages, toolikits, algorithms, and authors. Approximately sixteen years separates the creation of the two models by different authors. That fact, coupled with the fact that the current model is implemented in Java using the REPAST libraries, tools that did not exist when KMP developed their model, means that the two models differ in hardware, languages, and toolkits. We attempt to recreate the algorithms as faithfully as possible from their descriptions in the referenced works.

Table 1. Replication Summary

Replication Standard	Partial Distributional Equivalence Partial Relational Alignment
Focal Measures	Per-Capita Utility Inter-Jurisdiction Distance Agent Relocations
Level of Communication with Previous Authors	None
Familiarity with Language of Original Model	None
Examination of Source Code	None
Exploration of Parameter Space	None

Table 1 outlines additional details of the replication effort. We successfully achieve distributional equivalence and/or relational alignment along a number of margins, which we expound upon below. In addition, while in this section we only consider the parameter space that KMP examine in their 1997 paper, in subsequent sections we dramatically expand the parameter space and conduct a thorough sensitivity analysis of their results. Finally, it is a testament to KMP's scholarship and clarity of exposition that the current author is able to develop a replication of their model with no contact with the authors or with the original model in any form.

A. Replication Assessment

In this section, we compare the results of experiments with the present model to KMP's findings regarding similar experiments. Wherever possible, we choose parameter values the same as presented by KMP. As in that paper, all scenarios presented involve 1000 agents with preferences on 11 binary issues and 10 election cycles per run. In keeping with KMP, we replicate each design point 200 times.

We employ common random numbers in each scenario in a further effort to reduce variance between the estimates and enhance comparative ability (Law and Kelton, 2000). The random number generators that produce the agent's preferences and initial locations are "restarted" at the same point in the psuedo-random number sequence for each scenario. Thus, we test every scenario against the same sets of agents, and for those scenarios with equal numbers of jurisdictions, the agents start out in the same place each run. For instance, the agents in replication *r* of the scenario examining direct competition with two parties and three jurisdictions are the exact same agents (same preferences and starting locations) as those in replication *r* of the scenario examining democratic referenda with three jurisdictions. The agents in replication *r* of say, proportional representation with eleven jurisdictions are the same agents (same preferences) but obviously do not start out in the same jurisdictions as the previous two examples. As for the adaptive parties, they start out in the same places at the beginning of the runs, but common random numbers cannot be guaranteed throughout the party adaptation process, so we achieve only partial commonality.

1. Single Jurisdiction Per-Capita Utility

The results for the single jurisdiction model are shown in Table 2, as are KMP's findings for the same scenarios. In general, the model performs substantially similar to the KMP model. First, as in the KMP model, all estimates of per-capita utility differ significantly from zero[4]. More importantly, the relative ranks of the decision rules are nearly identical. The only difference in this regard is that for the present model, three-party proportional representation achieves greater per-capita utility than seven-party proportional representation, though the difference in not statistically significant. Thus, we sufficiently achieve relational alignment.

[4] Zero is the expected value to an agent of a "random" platform.

Table 2. Comparison of results of single jurisdiction models (200 replications each). Null hypothesis is there is no difference between the model outputs of per-capita utility.

Single Jurisdiction	KMP		Seagren			
	Per capita Utility	(s.e.)	Per capita Utility	(s.e.)	difference	p.value
Democratic referenda	2.69	0.12	2.32	0.10	0.37	0.02 **
Direct competition (2 parties)	1.45	0.13	1.81	0.11	-0.36	0.03 **
Direct competition (3 parties)	0.67	0.13	0.54	0.11	0.13	0.47
Direct competition (7 parties)	0.33	0.13	0.35	0.12	-0.02	0.92
Proportional representation (3 parties)	1.33	0.13	1.48	0.11	-0.15	0.39
Proportional representation (7 parties)	1.36	0.13	1.35	0.11	0.01	0.97

In fact, the model nearly achieves complete distributional equivalence. For each institution, we test the hypothesis that the mean per-capita utility estimates for both models are identical using a t-test with unequal variances (Hayter, 2007: 397). We find that the present model's output only differs significantly from that of KMP97 for democratic referenda and two-party direct competition.

2. Multiple Jurisdiction Per-Capita Utility

The results of the multiple jurisdiction scenarios are shown in Table 3, along with KMP's corresponding findings. As with the single jurisdiction configuration, the model output matches the KMP output well. The output for each decision rule differs significantly from zero, and the relative rank of each rule is nearly identical, thereby achieving (near) relational alignment. The only discrepancy occurs in the case of three jurisdictions, in which direct competition achieves greater per-capita utility than democratic referenda. For each jurisdiction, the present model estimates that proportional representation with three parties is superior to either democratic referenda or direct competition just like the KMP97 model[5]. While the KMP model shows that the performance of direct competition improves relative to that of democratic referenda as the number of jurisdictions increases, the present model's estimates for the performance of these two institutions cannot be distinguished below a 0.1 level of significance.

Table 3. Comparison of results of multiple jurisdiction models (200 replications each). Null hypothesis is that there is no difference between the model outputs of per-capita utility.

Multiple Jurisdictions	KMP		Seagren			
	Per capita Utility	(s.e.)	Per capita Utility	(s.e.)	difference	p.value
3 Jurisdictions						
Democratic referenda	34.39	0.15	33.78	0.16	0.61	0.01 **
Direct competition (2 parties)	34.15	0.14	33.93	0.14	0.22	0.27
Proportional representation (3 parties)	35.56	0.11	34.42	0.13	1.14	0.00 **
7 Jurisdictions						
Democratic referenda	48.29	0.13	48.18	0.12	0.11	0.55
Direct competition (2 parties)	49.90	0.13	48.84	0.13	1.06	0.00 **
Proportional representation (3 parties)	51.80	0.12	50.45	0.12	1.35	0.00 **
11 Jurisdictions						
Democratic referenda	55.46	0.12	55.34	0.11	0.11	0.47
Direct competition (2 parties)	57.03	0.13	55.55	0.14	1.87	0.00 **
Proportional representation (3 parties)	58.93	0.12	57.34	0.10	1.89	0.00 **

For each decision rule, we test the hypothesis that the mean per-capita utility estimates for both models are identical. The present model achieves distributional equivalence with the KMP model for direct competition in the three jurisdiction setting, as well as for democratic referenda in the seven and eleven jurisdiction settings.

3. Inter-Jurisdiction Distance

The results for inter-jurisdiction distance are less straightforward, as Table 4 illustrates. We are able to achieve distributional equivalence for all scenarios involving proportional

[5] We use a two-sample t test and find the p-values are all extremely small.

representation and democratic referenda with seven jurisdictions is borderline. However, it appears that our model has trouble replicating KMP's results for direct competition. In fact, we are unable to achieve complete relational alignment when it comes to the performance of direct competition.

Table 4. Comparison of results of multiple jurisdiction models (50 replications each). Null hypothesis is that there is no difference between the model outputs of inter-jurisdiction distance.

Multiple Jurisdictions	**KMP**		**Seagren**			
	Inter-Juris		**Inter-Juris**			
3 Jurisdictions	**Distance**	**(s.e.)**	**Distance**	**(s.e.)**	**difference**	**p.value**
Democratic Referenda	61.58	0.84	59.39	0.93	2.19	0.03**
Direct Competition (2 parties)	65.21	0.41	66.42	0.17	-1.21	0.00**
Proportional Representation (3 parties)	66.67	0.36	66.42	0.17	0.25	0.32
7 Jurisdictions						
Democratic Referenda	51.64	0.32	50.86	0.35	0.78	0.05
Direct Competition (2 parties)	53.96	0.23	56.02	0.12	-2.06	0.00**
Proportional Representation (3 parties)	56.12	0.15	56.17	0.13	-0.05	0.72
11 Jurisdictions						
Democratic Referenda	50.76	0.23	50.16	0.25	0.60	0.03**
Direct Competition (2 parties)	52.26	0.13	53.65	0.09	-1.39	0.00**
Proportional Representation (3 parties)	53.32	0.09	53.34	0.10	-0.02	0.88

4. Agent Relocations

The final response variable we consider is the aggregate number of agent relocations during a simulation run, as indicated in Table 5. In this case we achieve distributional equivalence for all scenarios involving democratic referenda, as well as proportional representation in three jurisdictions. However, we again fail to achieve even relational alignment when it comes to the direct competition scenarios.

Table 5. Comparison of results of multiple jurisdiction models (50 replications each). Null hypothesis is that there is no difference between the model outputs average relocations.

Multiple Jurisdictions	KMP		Seagren			
3 Jurisdictions	**Agent Relocations**	**(s.e.)**	**Agent Relocations**	**(s.e.)**	**difference**	**p.value**
Democratic Referenda	864.2	17.24	830.2	21.79	33.96	0.15
Direct Competition (2 parties)	915.7	14.67	1626.6	30.00	-710.92	0.00**
Proportional Representation (3 parties)	1277.6	34.41	1263.4	24.21	14.20	0.63
7 Jurisdictions						
Democratic Referenda	863.2	10.41	877.2	12.91	-14.00	0.32
Direct Competition (2 parties)	1162.5	8.63	2222.8	29.93	-1060.32	0.00**
Proportional Representation (3 parties)	1371.1	25.75	1632.0	31.67	-260.96	0.00**
11 Jurisdictions						
Democratic Referenda	887.3	5.26	901.4	7.07	-14.06	0.06
Direct Competition (2 parties)	1293.7	7.13	2545.7	21.82	-1251.98	0.00**
Proportional Representation (3 parties)	1420.3	21.74	1666.5	25.66	-246.18	0.00**

B. Replication Summary

In summary, we succeed in the effort to replicate the KMP97 model. With regard to per-capita utility, the replication achieves near complete relational alignment, and even achieves distributional equivalence in many instances. The replication performs adequately for inter-jurisdiction distance and agent relocations, achieving distributional equivalence for certain cases as well. However, we identify a potential difference in the implementation of direct competition, particularly in terms of these latter measures of effectiveness.

The manner in which the current model implements direct competition tends to result in slightly lower per-capita utility, greater inter-jurisdiction separation, and as a higher number of agent relocations, relative to KMP97. It is possible that the hill-climbing algorithm, as implemented, differs in some manner from that implemented in KMP97. However, the fact that the scenarios that involve three or more parties commonly achieve distributional equivalence coupled with the fact that the current model closely replicates the most important results concerning per-capita utility, mitigates any apprehension on this matter and justifies the conclusion that the current model tolerably replicates KMP97.

IV. Development and Analysis of the Extended Model

In this section, we extend the model along two margins. First, we implement the preference landscapes described in KMP (1998), and we consider additional voting institutions. We also consider additional measures of effectiveness.

In KMP (1998), the authors examine the behavior of adaptive parties who seek electoral victory by evolutionarily changing their platforms in the hopes of increasing their success at the ballot box. However, they compare party performance given constituencies with significantly more complex preferences. The voters in this model possess an ideal level of government for each issue, as well as a separate strength of that preference. The authors test a number of different combinations of voter ideologies and types of strength distributions. The intensities of their preferences may be independent, centrist, or extremist, and the intensities voters possess for each issue are either uncorrelated, more heavily weighted towards moderate preferences, or more heavily weighted towards extreme ideal points.

A. Model Formulation and Description

The notation for this model is identical to that in Section IIIB above, with the exception of the policy space and the manner in which agents' preferences regarding various policy levels are modeled. Let $p_{ji} \in \{0 , R\}$ give the position of jurisdiction *j* on issue *i*. The positions may be integers between 0 and R. When political parties are considered, let $p_{rji} \in \{0, R\}$ give the position of party *r* in jurisdiction *j* on issue *i*. Let Platform $\mathbf{P}_j \in \{0, R\}^{Ni}$ denote the vector of decisions across all N_i issues in jurisdiction *j*.

An agent possesses ideal point for issue *i*, d_{ai}, selected from the closed set {0, R}, where the parameter R is the maximum range for ideal points. Each ideal point has an associated intensity level, s_{ai} that is selected from the closed set {0,S}. Agents possess ideal points and intensities for each of the N_i issues under consideration. The results presented later in Section IIIE are for scenarios involving 10 issues under consideration, agents' ideal points are in the set [0, 8], and agent's intensities are drawn from the set [0, 2].

An agent's utility is the negative of the squared weighted Euclidean distance between the agent's ideal platform and the given platform, where the weights are the agent's strengths on each issue (KMP, 1998: 143).

$$U_a(\mathbf{P}_j) = - \sum s_{ai} \left(p_{ji} - d_{ai} \right)^2 \qquad (2)$$

Agents possess complete information regarding the level of government services offered in all jurisdictions. They move costlessly to the jurisdiction whose platform offers them the highest utility, without any expectation regarding the effect they may have on political outcomes in their prospective jurisdiction. External effects between issues are neglected so voters are assumed to vote sincerely.

B. Preference Landscapes

As in KMP97, agents possess a set of ideal points, which characterize its desired levels of government service for each issue, and possess a corresponding set of strengths which characterizes the relative importance of each issue to the voter (KMP, 1998: 143). The agents' preferences remain constant throughout the simulation, however, they may be correlated in two ways. Individual voter ideal points may be correlated on different issues, and individuals' strengths may be correlated to their ideal points.

Ideology is term used to describe the manner in which voters' ideal points are correlated (KMP 1998:145). An individual voter may have consistent or uniform ideology. A voter with consistent ideology has ideal points that are correlated across issues, with a bias towards a particular part of the issue spectrum. These ideal points are generated such that a bias point is selected which constrains all ideal points to within plus or minus one unit. For instance, if the bias point generated for a given agent is 2, then his ideal points for each issue must be an integer from the closed set [1, 3]. The ideal points for agents with uniform ideology are drawn from a uniform random distribution with no such biases.

An individual agent's ideal points and strengths may be correlated in one of three manners. Centrist strengths are higher for ideal points that are closer to the middle of the distribution. Suppose ideal points are distributed between 0 and 6. Then for centrists, the maximum strength for an issue will be given to ideal points of 3. The strength for an ideal point of 2 will be higher than the strength associated with an ideal point of 1, and so on. Extremist strengths are higher for ideal points that are closer to the extremes. So, in the previous example, ideal points of 3 would have 0 strength, while ideal points of 0 or 6 would be assigned the highest strengths. Independent strengths are randomly and independently distributed so that on average, they are uncorrelated with the underlying ideal points.

Table 6. Voters' preferences can vary according to Ideology and Strength Distribution. (KMP, 1998: 146)

Types of ideologies	Types of strength distributions
Uniform (random distributions of ideal points)	**Independent** (random distribution of strengths)
	Centrist (moderate ideal points are weighted)
Consistent (correlated ideal points)	**Extremist** (extreme ideal points are weighted)

Combining ideologies and strength distributions yields six potential electoral landscapes of preferences, as shown in Table 6. These categories are neither exhaustive nor intended to fit actual particular distributions of preferences. They represent polar cases on which to test the performance of political institutions. They do, however, tend to generally correspond to ways in which preferences may be distributed once people decide how to vote. Individuals often feel strongly about divisive issues with relatively polar alternatives such as abortion or gun control. While for other issues, voters may prefer positions far outside the mainstream, but not attach much weight to them.

KMP (1998) show that the electoral landscape formed by voter preferences with respect to the incumbent party's platform varies in terms of ruggedness and slope. Ruggedness is a measure of the relative number of local extrema, while slope is a measure of the magnitude of those extrema. Voters with uniform preferences (i.e. randomly drawn and unbiased) with independent intensities (i.e. uncorrelated strengths of opinion) tend to form landscapes that are the most rugged (1998:153). Rugged landscapes hinder the ability of the challenger to locate the global optimum that may defeat the incumbent. Consistent preferences with centrist intensities (i.e. biased towards the middle of the spectrum) seem to result in less rugged landscapes which enables party's to quickly converge toward the neighborhood of the median. The present paper tests the robustness of KMP's Tiebout sorting against a number of varied electoral landscapes.

C. The Political Institutions

In addition to the institutions considered in the above sections, we examine the following collective decision making institutions:

Borda Count. In the Borda count, voters rank the candidate parties from 1 (their favorite) to *m*, where *m* is the number of candidates. The votes for each candidate are tallied and the one with the lowest total is declared the winner. The jurisdiction then wholly adopts the winning party's platform. The nations of Slovenia, Kiribati, and Nauru use the Borda Count in some of their political elections. In the United States, the Borda Count is used to select the winner of the Heisman Trophy.

Hare System. In the Hare system, again voters rank candidate parties from 1 to *m*. The votes are tallied and the candidate receiving the fewest first place votes is removed from consideration. This process is repeated until only the winning candidate remains. The jurisdiction then wholly adopts the winning party's platform.

Coombs System. The Coombs system is similar to the Hare system, except that instead of removing the candidate with the fewest top ranked votes, the candidate ranked last by the most voters is removed. This procedure is continued until only the winning party remains. The jurisdiction then wholly adopts the winning party's platform. Various reality television shows that sequentially vote a contestant out of the competition at the end of each episode employ a modified form of the Coombs System. It is a modified form because of the multiple votes cast and the passage of time between votes.

Instant Runoff Majority Rule. In the instant runoff majority rule system, all voters vote for their favorite party. If any party receives more than half of the votes, they are declared the winner. If not, the top two parties then face each other in a run-off election. As before, the jurisdiction then wholly adopts the winning party's platform. This decision rule is used in a number of municipal jurisdictions in the United States, to include San Francisco, California and Minneapolis, Minnesota.

See Mueller (2003), especially Ch 7, for more on simple alternatives to majority rule.

D. Measures of Effectiveness

In addition to the measures of effectiveness described above, we consider two alternatives intended to capture the amount of competition within jurisdictions. One such measure is the minimum platform separation between parties competing within the same district, which we term *intra-jurisdiction separation*. This metric is the Euclidean distance between the platform of the incumbent party and the platform of the closest alternative party within its jurisdiction (KMP 1998). Consider it a loose surrogate for the incumbent's ability to leverage its monopoly power. An incumbent party whose closest challenger is relatively far away from finding a superior platform theoretically would be able to extract rent via overly high taxes much easier than an incumbent whose opposition is offering a very competitive platform, in terms of its location on the electoral landscape.

Just as "number of firms" in a particular market is not sufficient, or in some respects even necessary, to determine the competitiveness of that market, neither is separation a perfect measure of the responsiveness of local governments to the interests of their constituents. However, the idea is to test the effectiveness with which various rules of collective decision making have in regards to enabling competing parties to narrow that gap. In general, if an institution is consistently unable to allow multiple parties to converge at or near the optimum, then that institution will be vulnerable to incumbent parties that are less responsive to the demands of voters.

The other alternative we examine is the number of times during a simulation run that an incumbent loses an election. Presumably, institutions within which incumbents have a higher probability of losing reelection are more responsive to voter's needs. In different instances below we present both total number of incumbent losses, as well as the probability an incumbent wins reelection, which is calculated from the former.

E. Results for the Extended Model

The purpose of this section is to gain insight into the sensitivity of KMP's (1997) results with respect to voter preference landscapes. A finding that the qualitative relationships hold, even while testing over a variety of landscapes, lends additional credibility to their conclusions. However, to discover exceptions to their findings provides a more nuanced understanding of the way in which local voting rules affect the efficiency with which individuals collectively acquire public goods.

We vary institution, jurisdictions, voter ideology, and voter intensity in a full-factorial experimental design with levels outlined in Table 7. The experiment consists of 336 design points, which we replicate 50 times each for a total of 16,800 runs. As above in the replication section, we employ common random numbers to the greatest extent possible in order to reduce the variance between design points and improve statistical power.

Table 7. Full Factorial Experimental Design

Full Factorial Experimental Design			
Institution	**Jurisdictions**	**Ideology**	**Intensity**
Democratic Referenda	1	Consistent	Random
Direct competition (2 parties)	3	Uniform	Centrist
Direct competition (3 parties)	7		Extremist
Direct competiton (7 parties)	11		
Proportional representation (3 parties)			
Proportional representation (7 parties)			
Borda count (3 parties)			
Borda count (7 parties)			
Coombs system (3 parties)			
Coombs system (7 parties)			
Hare system (3 parties)			
Hare system (7 parties)			
Majority runoff (3 parties)			
Majority runoff (7 parties)			

The parameters held constant during this experiment are shown in Table 8. Since issue levels are integers, they can take on integer values between 0 and 8. Similarly, intensity can take on integer values on the closed set [0,2]. The factor levels in Table 8 were selected due to their proximity to the factors levels in KMP (1998). The duration of each simulation run is 30 timesteps, in contrast to 10 in KMP (1997) because the dynamics of the model, given the richer electoral landscapes of preferences, were such that equilibrium is not always attained in 10 timesteps. For the results presented, the response variables are all at time t=30.

Table 8. Parameters held constant in experiment

Static Factors		
Description	**Factor**	**Level**
Number of issues under consideration	Number Issues	10
Maximum preference level for issue	Issue Range	8
Maximum intensity strength for issue	Intensity Range	2
Maximum distance from ideal point	Variance Range	1
Number of cycles for adaptive parties	Campaign Length	8
Number of adaptive iterations per cycle	Campaign Iterations	5
Issues to perterb in campaign cycle	Perterb Issues	3
Proportion of voters polled	Polling Sample	0.1

1. Single Jurisdiction

The results for the single jurisdiction model are shown in Table 9. Recall that utility is the negative weighted Euclidean distance between an agent's ideal platform and the platform offered in her jurisdiction. The means shown are the overall mean per-capita utilities achieved by the particular institution. We conduct a one-way ANOVA on the effect of the institution while blocking on the effects of the six different landscapes. We use the Tukey-Kramer multiple comparison technique (Tukey 1953; Kramer 1956) to then determine which, if any, institutions generate statistically significant differences at a 0.05 level of significance. In the tables, the levels that do not share a letter are significantly different. For example, that fact that democratic referenda and two-party direct competition share an "A" indicates that the two levels are not significantly different. However, seven-party proportional representation is assigned a "B", which indicates it is significantly different than democratic referenda.

Table 9. Single Jurisdiction; Per-capita Utility after 30 elections.

1 Jurisdiction		
Institution		**Mean**
Democratic referenda	A	-73.30
Direct competition (2 parties)	A B	-76.34
Proportional representation (7 parties)	B	-78.30
Rroportional representation (3 parties)	C	-86.10
Direct competition (3 parties)	C	-88.89
Direct competition (7 parties)	D	-121.74

Levels not connected by same letter are significantly different.

Table 9 confirms that the order between the institutions for the single jurisdiction case is nearly identical to that of KMP (1997). The only difference is that seven-party proportional representation is slightly higher than three-party proportional representation. This order is based on the overall means for each treatment (institution). It is possible that the particular performance of each institution relative to the others may depend on the landscape of voter preferences. Table 10 outlines the per-capita utility (at time 30) for each institution and its relative ranking by landscape.

Table 10. Single Jurisdiction; Per-capita Utility after 30 elections by preference landscape. (Within-block rank in parantheses.)

1 Jurisdiction	Uniform Ideology						Consistent Ideology					
	Random Strengths		Centrist Strengths		Extremist Strengths		Random Strengths		Centrist Strengths		Extremist Strengths	
Institution												
Democratic referenda	-66.69	(1)	-33.33	(1)	-122.42	(1)	-63.91	(1)	-36.66	(1)	-116.79	(1)
Direct competition (2 parties)	-69.51	(2)	-34.65	(4)	-126.69	(2)	-66.37	(2)	-39.47	(2)	-121.34	(2)
Proportional representation (7 parties)	-70.90	(4)	-34.35	(2)	-128.79	(3)	-68.48	(3)	-40.10	(3)	-127.21	(3)
Rroportional representation (3 parties)	-70.56	(3)	-34.37	(3)	-128.99	(4)	-81.79	(4)	-54.80	(4)	-146.06	(4)
Direct competition (3 parties)	-72.18	(5)	-35.15	(5)	-133.31	(5)	-85.90	(5)	-57.67	(5)	-149.11	(5)
Direct competition (7 parties)	-81.62	(6)	-37.14	(6)	-150.50	(6)	-141.54	(6)	-100.16	(6)	-219.45	(6)

Referenda has the highest per-capita utility for each landscape, while seven-party direct competition has the lowest for each. Most other deviations from the order presented in Table 10 (above) are slight. For example, two-party direct competition is ranked 2nd, as it is in Table 10, in all but one landscape. Also of note, landscapes with centrist intensities tend to yield higher per-capita utility levels, while extremist intensities are achieve dramatically lower levels.

In the single jurisdiction scenario, the rank-order of the aggregate performance of the voting institutions closely resembles that of KMP (1997). Closer inspection of the relative performance of the institutions over each landscape reveals that this ordering holds with only minor exceptions. Thus, we firmly conclude that the original findings with respect to the single jurisdiction case are robust across a wide-range of possible voter preference landscapes.

2. Multiple Jurisdictions

In this section, we consider additional jurisdictions. As in KMP, we observe that the availability of additional jurisdictions tends to increase aggregate utility, due to the ability of voters to sort themselves into more homogeneous constituencies. The results for the multiple jurisdiction scenarios are displayed in Table 11.

Table 11. Multiple Jurisdictions; Per-capita Utility after 30 elections.

Institution	**3 Jurisdictions**		**7 Jurisdictions**		**11 Jurisdictions**	
Democratic referenda	B	-59.67	A	-31.02	A	-26.17
Proportional representation (7 parties)	A	-39.58	A	-31.01	B	-27.54
Proportional representation (3 parties)	A	-39.41	A	-31.38	C	-28.71
Direct competition (2 parties)	A	-39.29	B	-32.63	D	-29.85

Levels not connected by same letter are significantly different.

Recall that KMP find proportional representation to be superior to the other voting rules in all multiple jurisdiction cases. We find that two-party direct competition is superior for three jurisdictions, but democratic referenda returns to the top in the seven and eleven jurisdiction cases. Though the difference between the top voting rules and three-party proportional representation is not statistically significant in the three and seven jurisdiction cases, as we increase the number of jurisdictions to eleven and beyond, the differences among the each institution becomes statistically significant.

While the relationship between preference landscape and the voting institution that achieves the highest utility is unclear at three jurisdictions, as the number of jurisdictions increases to eleven, a more robust pattern emerges. Table 12 outlines the per-capita utility for each voting institution and eleven jurisdictions. It shows the relationship in which democratic referenda achieves the highest per-capita utility, followed closely by seven-party proportional representation, is consistent across preference landscapes.

Table 12. Eleven Jurisdictions; Per-capita Utility after 30 elections, by preference landscape. (Within-block rank in parentheses)

11 Jurisdictions	**Uniform Ideology**						**Consistent Ideology**					
Institution	**Random Strengths**		**Centrist Strengths**		**Extremist Strengths**		**Random Strengths**		**Centrist Strengths**		**Extremist Strengths**	
Democratic referenda	-37.80	(1)	-24.92	(2)	-72.64	(1)	-6.14	(1)	-6.63	(1)	-8.87	(2)
Proportional representation (7 parties)	-39.93	(2)	-24.83	(1)	-77.11	(2)	-6.89	(2)	-7.77	(2)	-8.68	(1)
Proportional representation (3 parties)	-41.05	(3)	-25.95	(3)	-78.01	(3)	-7.38	(3)	-8.66	(3)	-11.22	(4)
Direct competition (2 parties)	-42.90	(4)	-27.23	(4)	-81.24	(4)	-8.14	(4)	-9.75	(4)	-9.85	(3)

For multiple jurisdictions (namely, greater than three), we find that the superior voting rule with respect to achieving the highest per-capita utility is democratic referenda. In contrast, KMP find that proportional representation is superior. One possible symptom of proportional representation's relatively poorer performance is illustrated in Figure 1.

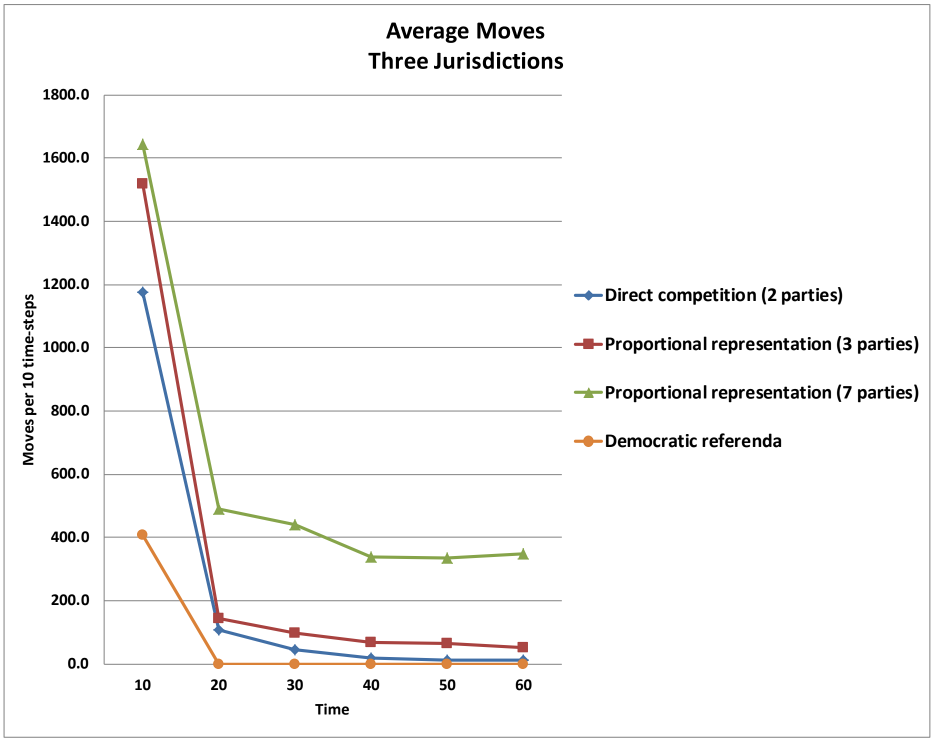

Figure 1. Average Relocations; Three Jurisdictions

Figure 1 shows the average number of agent relocations tallied in each 10 time-step segment of the simulation run in the three jurisdiction scenario. All voting institutions experience a large number of relocations in the first ten time-steps of the simulation. However, by the 30th time-step, the average number of moves is very low for democratic referenda, two-party direct competition, and three-party direct competition; while three and seven-party proportional representation and seven-party direct competition show little sign of convergence after even 60 time-steps. While a large number of relocations are necessary early in a simulation run in order to facilitate sorting, proportional representation, as an institution, appears to have trouble coping with the complexity of the preference landscapes.

KMP's (1997) overarching conclusion concerning the stability of the electoral process involving boundedly-rational agents is essentially confirmed. However, more particular conclusions regarding the relative performance of collective decision making rules is clearly not robust over various electoral landscapes. While it is ultimately an empirical question as to whether the voters' preferences in a particular set of jurisdictions conform to one or more of the electoral landscapes considered in this model, further investigation of the link between electoral landscape will likely yield interesting results.

3. Measures of Competition

A number of researchers, to include Epple (1981) and Caplan (2001), model local governments as monopolists who leverage their power to tax to extract rents from the public. Both of these models assume full and complete information on the part of local government, such that the exact tax rate to charge, the amount of rent to extract, and the potential detrimental effect upon probability of reelection is simply the outcome of an optimization. Caplan imposes a separation effect between parties by using a party preference parameter (2001: 8). In the present model, parties do not have full information regarding the distribution of voter preferences. They must adaptively search the issue space for platforms they expect will beat their opponents and attract constituents. Thus, parties that arrive in the vicinity of the highest portion of the electoral landscape may maintain their position as incumbent for some time. We examine the *intra-jurisdiction separation* between the incumbent party and the next best challenger as a possible measure of intensity of competition within the jurisdiction.

Table 13 shows the average minimum intra-jurisdiction separations in each scenario. Direct competition is relatively less effective with respect to separation than the other voting institutions. In contrast, proportional representation is superior to the other institutions in this regard. The institutions that generally tend to most efficiently improve utility are also the same institutions that encourage low levels of separation. This relationship is especially true as the number of jurisdictions increase and is relatively robust across electoral landscapes.

Table 13. Intra-Jurisdiction Separation. (relative rank in parentheses)

Intra-Jurisdiction Party Platform Separation				
Institution	**1 jurisdiction**	**3 jurisdictions**	**7 jurisdictions**	**11 jurisdictions**
Proportional representation (7 parties)	2.26 (1)	2.83 (1)	3.30 (1)	3.70 (1)
Direct competition (7 parties)	4.47 (3)	3.57 (3)	3.77 (2)	4.21 (2)
Proportional representation (3 parties)	5.32 (4)	3.36 (2)	4.25 (3)	4.91 (3)
Direct competition (3 parties)	6.79 (5)	3.81 (4)	4.38 (4)	5.12 (4)
Direct competition (2 parties)	3.41 (2)	4.00 (5)	5.12 (5)	5.97 (5)

** All within-jurisdiction differences are statistically signficant at 0.05 level of significance.

An incumbent party that successfully leverages its position may enjoy some electoral distance between its position and its rivals, but this only matters to the extent that this distance enables the party to maintain its incumbent position. Table 14 outlines the probability that an incumbent loses a given election in a given jurisdiction, for a particular voting institution. We find that proportional representation offers incumbent parties the least protection, while two-party direct competition tends to offer the most protection[6].

Table 14. Probability of Incumbent Reelection (Per Jurisdiction, Per Election)

Probability of Incumbent Reelection				
Institution	**1 jurisdiction**	**3 jurisdictions**	**7 jurisdictions**	**11 jurisdictions**
Proportional representation (7 parties)	0.568 (1)	0.656 (1)	0.755 (1)	0.799 (1)
Proportional representation (3 parties)	0.787 (5)	0.767 (3)	0.849 (2)	0.880 (2)
Direct competition (7 parties)	0.568 (1)	0.760 (2)	0.862 (3)	0.893 (3)
Direct competition (3 parties)	0.787 (5)	0.822 (4)	0.884 (4)	0.911 (4)
Direct competition (2 parties)	0.754 (3)	0.830 (5)	0.889 (5)	0.914 (5)

[6] For proportional representation the incumbent party is the party with the most votes.

In this section, we endogenously generate the sort of separation that Caplan (2001) shows is sufficient to allow local governments to leverage monopoly power over their constituents despite the pressure from Tiebout competition. We find that the relative performances of the different voting rules with respect to separation mirror their performances with respect to probability of incumbent reelection and we find that while the institutions differ in their performance in regard to this measure, the conclusions are not robust over parameter choices such as the number of jurisdictions. Further investigation is required in order to determine the full extent of the usefulness of this metric.

4. Additional Voting Rules

Agent-Based Computational Models provide a unique opportunity to experiment with various social institutions in ways that would be impossible or infeasible in reality. One way we leverage this model is to test the performance of a number of alternative voting rules which are rarely employed in practice at the level of governance we consider in this project. Table 15 outlines the performance of all voting rules in the single jurisdiction instance. We find that the alternative rules neither perform as well as the best rules that KMP considers nor perform as poorly as the worst.

Table 15. Single Jurisdiction; Per-Capita Utility; Alternative Voting Rules

1 Jurisdiction		
Institution		**Mean**
Democratic referenda	A	-73.30
Direct competition (2 parties)	A B	-76.34
Proportional representation (7 parties)	B C	-78.30
Borda count (3 parties)	B C	**-79.38**
Coombs system (3 parties)	C D	**-81.09**
Coombs system (7 parties)	C D	**-81.51**
Borda count (7 parties)	C D	**-81.86**
Hare system (3 parties)	D E	**-84.23**
Majority runoff (3 parties)	D E	**-84.60**
Proportional representation (3 parties)	E F	-86.10
Direct competition (3 parties)	F	-88.89
Hare system (7 parties)	G	**-98.16**
Majority runoff (7 parties)	G	**-99.76**
Direct competition (7 parties)	H	-121.74

Levels not connected by same letter are significantly different.

This single jurisdiction case is an important relative assessment of these rules. While other researchers have assessed them with regard to metrics such as Condorcet efficiency (see Merrill (1984; 1985), none have assessed their performance with regard to aggregate utility using voters with such complex preference structures.

As we increase the number of jurisdictions a pattern emerges in which the alternative rules settle in on the lower positions of the list. Ultimately, we are unable to find a voting rule-jurisdiction-landscape combination in which an alternative voting rule is either the best or worst rule, in terms of per-capita utility.

The alternative voting rules fare better when considering intra-jurisdiction separation. Table 16 shows the relative performance of all institutions in the eleven jurisdiction case. There is a distinct division in that all seven-party institutions are superior to those with three or fewer.

Table 16. Eleven jurisdictions; Mean Minimum Intra-Jurisdiction Separation.

11 Jurisdictions		
Institution		**Mean**
Proportional representation (7 parties)	A	3.70
Coombs system (7 parties)	B	**4.02**
Hare system (7 parties)	B	**4.04**
Borda count (7 parties)	B	**4.04**
Majority runoff (7 parties)	B C	**4.08**
Direct competition (7 parties)	C	4.21
Proportional representation (3 parties)	D	4.91
Hare system (3 parties)	D	**4.94**
Borda count (3 parties)	D	**4.94**
Majority runoff (3 parties)	D	**4.95**
Coombs system (3 parties)	D	**4.96**
Direct competition (3 parties)	E	5.12
Direct competition (2 parties)	F	5.97

Levels not connected by same letter are significantly different.

Finally, we examine the extent to which incumbent parties are likely to remain in power under various voting rules. Table 17 shows the estimated probability that the incumbent party in any particular jurisdiction will be reelected in any particular election.

Table 17 Eleven Jurisdictions; Per Election Per Jurisdiction Probability of Incumbent Reelection

11 Jurisdictions		
Institution		**Mean**
Proportional representation (7 parties)	A	0.799
Proportional representation (3 parties)	B	0.880
Direct competition (7 parties)	C	0.893
Direct competition (3 parties)	D	0.911
Majority runoff (7 parties)	D E	**0.912**
Direct competition (2 parties)	D E F	0.914
Majority runoff (3 parties)	D E F G	**0.918**
Coombs system (3 parties)	E F G	**0.918**
Borda count (3 parties)	E F G	**0.919**
Hare system (7 parties)	E F G	**0.919**
Coombs system (7 parties)	F G	**0.920**
Hare system (3 parties)	F G	**0.920**
Borda count (7 parties)	G	**0.921**

Levels not connected by same letter are significantly different.

With the exception of seven-party majority runoff, all alternative rules under consideration exhibit the highest levels of incumbent reelection probability. Thus, of the standard voting rules KMP considers, those that allow greater separation between the platform of the incumbent party and the next best challenger also allow greater protection to incumbents in terms of reelection probability. In contrast, we find that the alternative rules achieve lower levels of separation between parties, yet actually offer more protection to incumbents. While extant voting rules have deficiencies, the evidence suggests that these simple alternatives may have their own deficiencies as well.

V. The Extended Model Exhibits Low Sensitivity to Arbitrary Parameter Values

In the years since KMP developed and analyzed their models, computing power has grown exponentially. In addition, the state of the art of simulation analysis pushed forward by researchers working the operations research field of data farming, has also improved substantially[7]. We leverage both in this section in order gain further insight into the robustness of our conclusions.

We examine a total of thirteen factors. The factors include important qualitative variables such as voting institution and preference landscape that we examine above, but also simulation parameters such as the number of issues or the number of campaign iterations that are essentially arbitrary. A full factorial analysis of the factors listed in Table 18 requires 97,977,600 design points. Alternatively, a Nearly Orthogonal and Balanced (NOB) Latin Hypercube design accommodates both continuous and categorical variables, and only requires 512 design points (Viera, et al, 2011). We replicate each design point 20 times for a total of 10,240 runs. The design achieves near-orthogonality of the factors, which improves the power of the statistical analysis, while requiring only a fraction of the design points for a full-factorial analysis[8].

Table 18. Experimental Design

Nearly Orthogonal and Balanced Latin Hypercube Experimental Design				
Description	**Factor**	**Type**	**Levels**	**Values**
Number of voters in polity	voters	continuous		[1000, 5000]
Number of jurisdictions in system	jurisdictions	continuous		[1,20]
Number of political parties per jurisdiction	parties	categorical	9	[2,3,4,5,6,7,8,9,10]
Number of issues under consideration	numberIssues	continuous		[8, 24]
Maximum distance from ideal point	varianceRange	categorical	3	[0, 1, 2]
Maximum preference level for issue	issueRange	categorical	5	[4,6,8,10,12]
Maximum intensity strength for issue	intensityRange	categorical	4	[1,2,3,4]
Number of cycles for adaptive parties	campaignLength	categorical	9	[4,5,6,7,8,9,10,11,12]
Number of adaptive iterations per cycle	campaignIterations	categorical	10	[1,2,3,4,5,6,7,8,9.10]
Proportion of voters polled	pollProp	categorical	3	[0.1, 0.7, 1.0]
Issues to perterb in campaign cycle	perterbIssues	categorical	2	[0.2, 0.5]
Preference Landscapes	landscape	categorical	6	[0,1,2,3,4,5]
Voting rule employed in system	instituiton	categorical	7	[0,1,2,3,4,5,6]

[7] For more information on data farming, to include research papers, tutorials, and spreadsheets, see <harvest.nps.edu>.
[8] The maximum pairwise correlation between any two factors in our design is 0.0233.

We examine the response variables *per-capita utility*; *minimum intra-jurisdiction separation*; *agent relocations*; and *incumbent losses*, and fit an Ordinary Least Squares Regression meta-model with main effects to the each of the response surfaces. The coefficient estimates are shown in Table 19. Note that the separation model and the incumbent losses model have fewer observations because democratic referenda does not contribute to those response variables.

Table 19. Meta-Models

Response	**E [per capita utility]**		**E[separation]**		**E[moves]**		**E[incumbent losses]**	
Adj R^2	0.781		0.777		0.580		0.696	
Observations	512		431		512		431	
Term	**Estimate**	**p-value**	**Estimate**	**p-value**	**Estimate**	**p-value**	**Estimate**	**p-value**
Intercept	-46.87	<.0001	4.58	<.0001	-2840.67	0.010	3.94	0.506
jurisdictions	1.65	<.0001 **	0.07	<.0001 **	118.79	<.0001 **	1.85	<.0001 **
parties	-0.05	0.827	-0.12	<.0001 **	183.92	0.0007 **	1.70	<.0001 **
voters	0.00	0.238	0.00	<.0001 **	1.95	<.0001 **	0.00	0.014
institution[borda]	3.00	0.071 *	0.10	0.077 *	-693.81	0.0514 *	-7.88	<.0001 **
institution[coombs]	0.30	0.856	0.03	0.644	-1389.59	<.0001 **	-10.86	<.0001 **
institution[direct comp]	2.59	0.089 *	0.13	0.020 *	819.96	0.012 *	-0.32	0.844
institution[hare]	0.46	0.778	-0.06	0.281	-1236.89	0.000 **	-8.73	<.0001 **
institution[maj runoff]	-3.14	0.052 *	0.15	0.007 *	-101.40	0.769	-5.66	0.001 *
institution[prop rep]	3.86	0.013 *	-0.35	<.0001 **	5233.29	<.0001 **	33.44	<.0001 **
institution[referenda]	-7.07	<.0001 **			-2631.57	<.0001 **		
landscape[unif -indep]	-12.06	<.0001 **	0.78	<.0001 **	-409.12	0.175	-10.33	<.0001 **
landscape[unif - cent]	8.11	<.0001 **	-0.08	0.145	-1843.95	<.0001 **	-20.56	<.0001 **
landscape[unif - ext]	-52.78	<.0001 **	1.29	<.0001 **	1972.52	<.0001 **	4.63	0.001 *
landscape[consist - indep	20.93	<.0001 **	-0.90	<.0001 **	251.10	0.434	5.70	0.001 *
landscape[consist - cent]	22.41	<.0001 **	-0.62	<.0001 **	587.17	0.068 *	11.86	<.0001 **
landscape[consist - ext]	13.39	<.0001 **	-0.47	<.0001 **	-557.72	0.064 *	8.70	<.0001 **
numberIssues	0.05	0.734	0.00	0.774	3.10	0.917	0.17	0.302
intensityRange	-0.10	0.864	-0.05	0.048 *	-68.37	0.587	-0.33	0.635
varianceRange	-1.02	0.200	0.01	0.858	-44.53	0.795	0.26	0.781
issueRange	-0.19	0.378	-0.02	0.037 *	-51.13	0.277	-0.15	0.559
campaignLength	0.10	0.688	0.00	0.832	-3.52	0.948	-0.33	0.260
campaignIterations	0.04	0.853	0.02	0.060 *	104.45	0.026 *	0.14	0.594
perterbIssues	-0.07	0.121	0.00	0.428	4.40	0.631	0.00	0.921
pollProp	0.04	0.109	0.00	0.451	9.26	0.102	-0.02	0.555

The meta-models confirm that statistically significant relationships exist between the response variables and factors such as voting institution, preference landscape, and jurisdictions. More importantly for the present task, the models confirm that relatively few statistically significant relationships exist between basic model parameters (the lowest group of factors in Table 19) and the response variables. For example, none of the basic model parameters are statistically significant in either the per-capita utility model or the incumbent losses model. Thus, we conclude the qualitative findings with respect to per-capita utility and incumbent losses fleshed out in the previous section are relatively insensitive to arbitrary decisions such as how to specifically model voter preferences such as the number of issues, issue range, and intensity range or the mechanics of the electoral campaign.

The regression model for intra-jurisdiction separation contains the following statistically significant factors: *intensity range*, *issue range*, and *campaign iterations*. It makes sense that issue range is a statistically significant determinant of separation, since greater issue ranges would conceivably allow for larger separations between competing parties. The notion that a parameter like campaign iterations may affect inter-jurisdiction separation and agent-relocations is also intuitively consistent, since campaign iterations is theoretically correlated with how hard political parties work to find those areas of the policy domain space that increase utility and win elections. Ultimately, we confirm that the majority of the otherwise arbitrary simulation parameters tend not to affect our response variables, thus suggesting that the results discussed in Section V are relatively insensitive to changes in model parameters.

VI. Conclusion

Agent-based simulation is a relatively new tool in the social sciences, and it was more recently introduced to the field of political economy. The model we present in this paper applies this modeling technique in an attempt to gain insight into the efficiencies with which political institutions are able to sort voters by preferences. The technique shows potential for more rigorous analysis of political, fiscal, and economic competition on the part of local governments in the future. Our successful replication of a seminal model provides interested researchers with the means to pursue such interests.

The most convincing finding in our analysis of the extended model is that the conclusion drawn by KMP (1997) regarding the relative efficiencies of voting institutions in the single jurisdiction scenario is highly robust. However, when we consider multiple jurisdictions, the results are far less clear. As the number of jurisdictions increase a stable pattern emerges, but it is one where democratic referenda is the most efficient, rather than proportional representation as in KMP (1997). We find that for the standard voting rules, intra-jurisdiction separation and probability of incumbent reelection are directly related. Thus, those institutions that enable incumbent parties to achieve greater separation from their closest rival also protect those incumbent parties more from electoral competition.

We also consider some alternative voting rules, such as the Borda Count, Hare Count, Coombs System, and Instant Run-off Majority Rule. We find little evidence to suggest that any of the alternative voting rules we consider achieve greater voter satisfaction or improve the competitiveness of local elections. In fact, we find that the alternative rules all improve incumbents' chances for reelection, relative to the other voting rules.

Finally, we demonstrate a technique for conducting sensitivity analyses that leverages a high-dimensional experimental design. Our design requires only 512 design points in contrast to the 99 million required for a similarly rigorous full-factorial design. The Ordinary Least Squares meta-models constructed from the response surfaces reveal that our conclusions are relatively robust with respect to arbitrary simulation parameters.

Biosketch

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