Qualified, Diverse, and Random:
How to Fairly Choose an Independent Redistricting Commission for Pennsylvania

Alan Meert and Anne Hanna

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Abstract

Proposed Pennsylvania independent redistricting commission legislation provides for random selection of commissioners from amongst the qualified applicants, but also requires that the final commission appointments **"shall reasonably reflect the racial, geographic, and gender diversity of this Commonwealth"**.[1] Some interested parties have expressed concern that the requirements for randomness, diversity, and qualification may be difficult to satisfy simultaneously, which may result in the final commission being effectively handpicked by the Secretary of the Commonwealth, a political appointee.

The authors have been asked by Fair Districts PA to analyze the question of how to simultaneously achieve randomness and diversity in the selection of a qualified commission, according to the rules described in proposed legislation supported by that organization, PA Senate Bill 22[2] and the original version of House Bill 722[3]. For this purpose, we constructed a simulated applicant population with racial/ethnic, geographic, gender, and partisan demographics matching the diversity of Pennsylvania, and developed and tested prototype selection algorithms.

Our algorithms use weighted random sampling from the initial qualified applicant pools and repeated drawing and replacement of candidate panels to produce a randomly selected commission matching desired diversity criteria. The results of our tests demonstrate that it is not only possible, but in fact easy, from a technical perspective, to randomly select a diverse commission within the guidelines described in the proposed legislation, without enabling powerful political actors to put their thumbs on the scales.

Many aspects of the commission selection process, as presently specified in the proposed constitutional amendment, will likely be subject to modification and refinement, either during negotiations toward its passage, or by later enabling legislation. However, our methodology is easily adaptable to any reasonable selection process, regardless of its precise details, so the applicability of our results is unlikely to be affected by minor tweaks. We discuss, where relevant, some of these possible changes, their likely effects, and adjustments that might be made to our exemplar selection methodologies to account for such changes.

[1] PA Senate Bill 22, 2017 Session, Printer's No. 397, pg. 7, lines 12–13
[2] 2017 Session, Printer's No. 397
[3] 2017 Session, Printer's No. 1671

Expert Qualifications

Alan Meert[4] is a Data Scientist living and working in Philadelphia, PA. His education includes a PhD in Astrophysics from the University of Pennsylvania, a Masters of Science in Physics and Astronomy from the University of Pennsylvania, and a Bachelors of Science in Physics from Purdue University. His PhD thesis focused on measuring the properties of 700,000 galaxies in the nearby universe and applying these measurements to constrain models of galaxy formation in the Universe. As a data scientist, Alan designs statistical solutions to issues of data quality, sampling, experimental design, and predictive inference.

Anne Hanna[5] is a PhD Candidate in Mechanical Engineering at the Georgia Institute of Technology, and a resident of Philadelphia, PA. Her previous education includes a Bachelors of Science in Physics from the California Institute of Technology and a Masters of Science in Physics from the University of Illinois at Urbana-Champaign. She studies data science and analytics, computational modeling of complex physical systems, and redistricting, with a special focus on Pennsylvania. Over the past year, as the redistricting issue has heated up, she has provided expert analysis, advice, and assistance to redistricting reform groups across Pennsylvania.

The analysis and opinions presented in this report represent the views of the named authors only, not necessarily those of their employers. The authors have not received any payment or other consideration for this report or the supporting analysis.

[4] alan.meert@gmail.com
[5] ahanna7@gatech.edu

1. Introduction

SB 22 proposes to amend Article II, Section 17 of the Constitution of Pennsylvania to require that congressional and legislative districts be drawn by an independent citizens' commission. This 11-member commission is to be composed of a diverse group of qualified Pennsylvanians, chosen to ensure that they are able to fairly assess and represent the wide array of issues faced by citizens across our geographically and demographically varied state. At the same time, the selection process includes stringent restrictions on political entanglements by commissioners, as well as multiple randomization steps, in order to prevent partisan actors from distorting the process for their own ends.

The purpose of the present document is to demonstrate how the requirements for diversity, randomness, and qualification can be satisfied simultaneously in a way that ensures that all of these goals are met. We first describe the key features of the commission selection process, as laid out in the present version of SB 22.[6] We then explain, at a high level, how the prescriptions of SB 22 can be implemented, via enabling legislation, administrative processes, and computerized selection algorithms, in such a way as to obtain the desired results. A technical appendix provides more detailed explanations of the prototype computer algorithms we used to test the feasibility of SB 22's selection process, along with supporting data and results.

[6] 2017 Session, Printer's No. 397

2. SB 22 Commission Selection Requirements

The proposed minimum qualifications and an outline of the selection process for members of the independent redistricting commission are described on pages 4–7 of SB 22, beginning at line 29 of page 4.[7] As is stated in that section, **"The General Assembly shall prescribe by law the qualification to serve as a commission member."**

The bill requires that commissioner qualifications must include, at minimum, an established and consistent history of voter registration, party affiliation (or absence of affiliation), and actual voting, as well as a lack of direct, personal connection to any political officials, staffers, or lobbyists. **Additional qualification criteria and procedures would be added legislatively by the General Assembly, and could easily address many other potentially desirable factors, such as applicants' subject matter expertise, ability to bring a distinctive and valuable perspective to the issues facing the commission, demonstrated history of strong ethical grounding, or interpersonal skills.**[8]

With the qualification procedures established, the commission selection process would proceed as follows:

1. Interested Pennsylvanians file applications with the Secretary of the Commonwealth to join the commission.
2. The Secretary of the Commonwealth determines which applicants meet the commission qualifications and divides these applicants into three pools:
    - Pool 1, consisting of qualified applicants registered to vote in the largest party in the state, by total voter registration.
    - Pool 2, consisting of qualified applicants registered to vote in the second-largest party in the state, by total voter registration.
    - Pool 3, consisting of qualified applicants registered to vote in any other party or with no party affiliation.
3. The Secretary of the Commonwealth randomly selects 40 applicants from each of the three pools described above, to form three corresponding subpools.

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[7] 2017 Session, Printer's No. 397

[8] In California, the process of defining qualifications included a period of public comment, town hall meetings and legislative hearings. See the section "Archive of Documents Related to Regulatory Proceedings Regarding the Application and Selection Process" at http://wedrawthelines.ca.gov/regulation_archive.html.

4. The Majority and Minority Leaders of the Senate and House may each choose to strike up to two applicants from each of these three subpools, resulting in a maximum of 8 strikes from each subpool.
5. The Secretary of the Commonwealth randomly selects 4 applicants from the remaining members of each of Subpools 1 and 2, and 3 applicants from the remaining members of Subpool 3, to form the final commission. These selections must be made in such a way as to “reasonably reflect the racial, geographic, and gender diversity of this Commonwealth”.

The key question in this process is how to ensure that the selections in step 5 result in a commission that is not only well-qualified and diverse, but also truly *random* in a way that does not permit the Secretary of the Commonwealth, or any other powerful political actor, to effectively select the final commission and thus exert undue control over the redistricting process.

3. Randomized Selection of a Diverse, Qualified Commission

There are several points in the above described commission selection process where questions may arise about how to ensure that the process results in a truly independent and qualified commission, capable of representing and respecting the concerns of all Pennsylvanians and of operating independently from the influence of powerful political actors. A brief summary of possible issues and ways to address them is below, with more detailed explorations to be presented in the sections that follow.

- ***Commissioner qualifications:*** It is essential that a large, diverse group of qualified applicants be available to enable truly random selection of the membership of the party affiliation subpools. SB 22 specifies that the General Assembly may pass legislation outlining additional qualifications for commissioners, beyond the bare minimum qualifications listed in the bill. These qualification requirements are used to pre-filter the applicant pool before any randomized or diversity-based selection steps. Targeted recruitment efforts can be used at this stage to boost applicant numbers and diversity.
- ***Random selection of 40-member subpools:*** The demographic distribution of qualified applicants could potentially be very different from the desired commission demographics. The chance for each qualified applicant to be selected into the appropriate 40-member subpool can be reweighted to correspond to the desired commission demographics. This ensures that, even though each subpool member's selection is still random, all subpools have the desired diversity balance, rather than being constrained by the demographics of the original applicant base.
- ***Legislative strikes:*** Legislative strikes could potentially impair the diversity of one or more party affiliation subpools. However, as long as legislative strikes are not strongly biased, this issue is not likely to be significant. Additionally, protective weighting at the subpool selection phase, or minor post-strike corrections, can alleviate concerns about the effects of strikes on diversity.
- ***Final commission selection:*** The final commission selection from the post-strike party affiliation subpools must simultaneously be random and meet desired diversity targets. A relatively simple computer algorithm can address this issue by repeatedly drawing random candidate commissions and discarding those that fail to match desired diversity requirements, until it hits on one that works. Empirical testing shows that such an algorithm can reliably find a commission satisfying reasonable diversity requirements in less than a minute,

without requiring any specialized hardware, and with auditable logging of the entire process.

3.1. Commissioner Qualifications

As discussed above, legislative acts can establish appropriate qualifications for redistricting commissioners, beyond the bare minima specified in the proposed constitutional amendment. Such qualifications might include applicants' general or subject-matter expertise, the value of the unique perspectives they can bring to the table, or their personal histories of working to resolve difficult issues fairly and cooperating in potentially divisive environments. Long-form written answers or interviews can be used to aid such a process, as is done in selecting California's independent redistricting commission.

The drafters of the proposed amendment have carefully refrained from tying the hands of future policymakers too tightly, choosing not to include a stringent list of such additional qualifications in Pennsylvania's difficult-to-amend constitution. However, the option to refine the qualification process later on by ordinary legislation makes it possible to ensure that the qualified applicant pools from which later random selections are made consist only of citizens already evaluated as well-equipped to face the technical, political, and ethical challenges of the redistricting process.

It is, of course, possible that a too-rigorous selection process, or demographic differences in access to or interest in participation, could make it difficult to recruit a sufficiently large and varied pool of applicants to meet desired commission diversity requirements. However, this issue can be addressed in two ways: first, by monitoring the size and diversity of the applicant pool and performing targeted recruitment in any areas of weakness (as was done in California), and, second, by the weighted random selection methodology to be discussed below. This latter methodology was the focus of our analytical work.

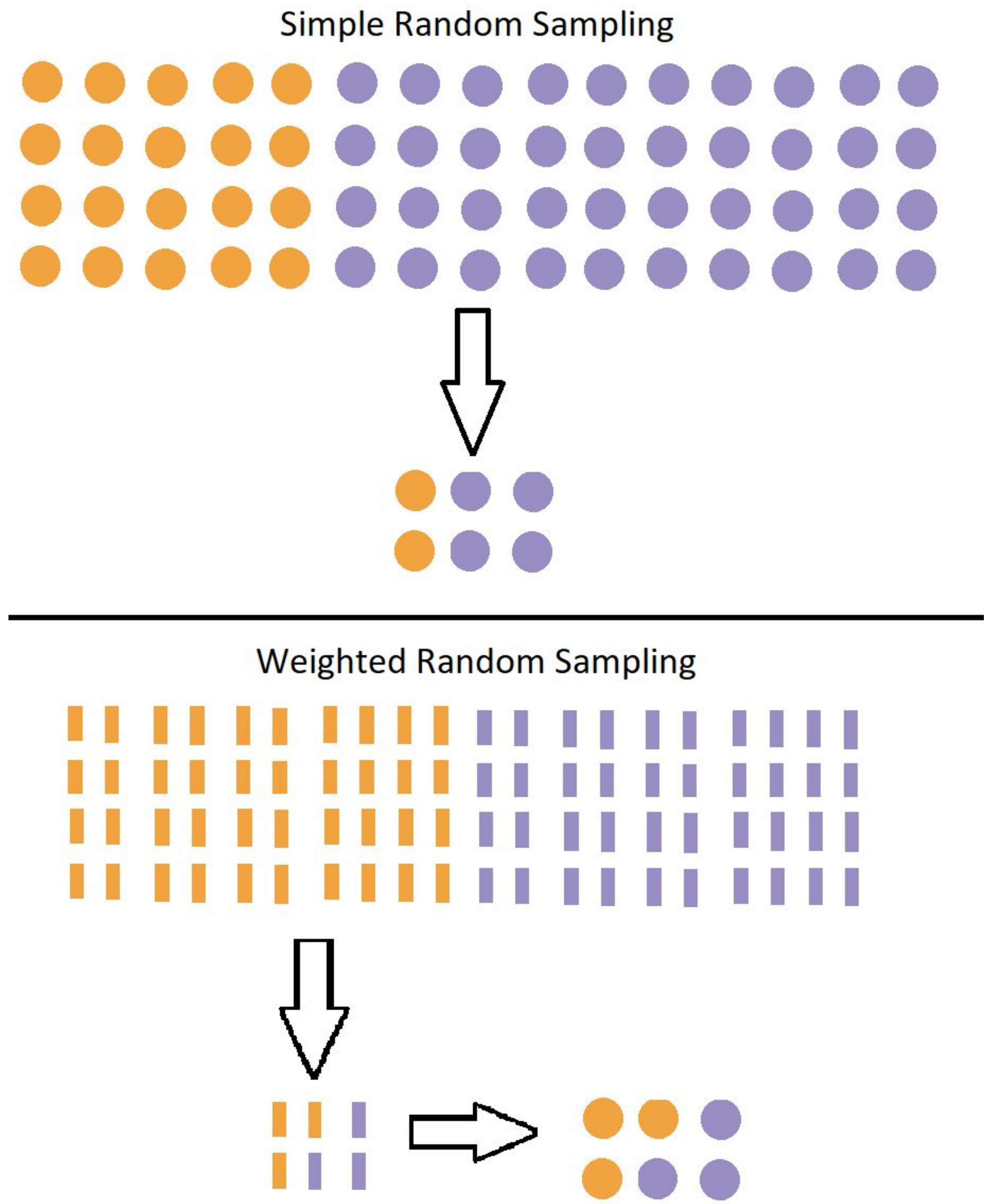
3.2. Random Selection of 40-Member Subpools

Once the applicants have been filtered by qualifications and categorized into the initial pools by party affiliation, the first randomized selection step is performed. 40 applicants are randomly chosen from each of the three party-affiliation pools to create the subpools from which the final commission will be drawn. As of this writing, it is difficult to predict how many Pennsylvanians might apply to become redistricting commissioners, or how many of those applicants might pass all required qualification tests. However, it is useful to note that, in 2010, 31,000 Californians applied to join their state's redistricting commission, 26,000 passed the basic qualification tests, and almost 5,000 of those applicants completed the second, significantly more rigorous, written qualification process. Applicant numbers may be somewhat lower in Pennsylvania, with a population of only about ⅓ that of California, but it seems not unreasonable to expect a similar process here to attract many hundreds, and likely thousands, of qualified applicants.

The question before us, then, is how to randomly select 120 of these qualified applicants in a way that ensures that it will later be possible to (again randomly) select an appropriately diverse 11-member commission from those who remain after strikes by legislative leadership. The answer is weighted random sampling.

Weighted random sampling allows a random sample drawn from a population to have a different average composition than the population from which it is drawn. For example, suppose we have 20 orange marbles and 40 purple marbles in a bag. When we draw 6 marbles from the bag, we expect that, on average, 2 marbles will be orange and the other 4 marbles will be purple. Sometimes we may get 3 oranges and 3 purples, other times we may get 1 orange and 5 purples, but over many attempts at random selection, the average sample, as well as the most likely sample, will tend to show a bias in favor of purple. But what if we prefer to end up with a selection that is more likely to be equally balanced between orange and purple?

The trick is to give each orange marble an extra shot at being selected compared to each purple marble. Rather than directly selecting marbles from the bag, we can imagine giving each marble a certain number of "raffle tickets" and choosing marbles based on equal-opportunity random selection from the bucket of raffle tickets instead of from the bag of marbles. We can see that if we give each orange marble 2 raffle tickets, and each purple marble only 1 raffle ticket, our bucket of raffle tickets will have $2 \times 20 = 40$ raffle tickets for orange marbles and $1 \times 40 = 40$ raffle tickets for purple marbles. So now, when we choose 6 tickets, we can expect that on average we will select tickets corresponding to 3 orange marbles and 3 purple marbles, as desired.



Weighted random sampling of marbles: This diagram illustrates how weighted sampling can result in random samples with different distribution characteristics than the original population. In the first image, 6 marbles are drawn with equal probability from a collection of 20 orange and 40 purple marbles. The average sample will thus have 2 orange and 4 purple marbles. In the second image, the color distribution has been weighted by drawing from a collection of "raffle tickets" instead, in which each orange marble gets 2 raffle tickets and each purple marble gets only 1. Now the average sample will have 3 orange marbles and 3 purple marbles.

A similar process can be applied to ensure that the 40-member subpools selected for the independent redistricting commission will have membership consistent with the desired diversity balance of the final commission, regardless of the demographic composition of the qualified applicant population. Given current PA demographics and other concerns expressed about the commission balance, one possible set of diversity targets might be:

- ½ men, ½ women
- ⅓ of commission members hailing from each of Western, Central, and Eastern Pennsylvania
- ⅓ of commissioners hailing from each of rural, suburban, and urban Pennsylvania
- At least 1 black commissioner and 1 other non-white commissioner (*i.e.*, a commission balance of approximately 1/11 black, 1/11 other race, and 9/11 white)
- At least one Hispanic/Latino commissioner (*i.e.*, approximately 1/11 Hispanic/Latino representation and 10/11 non-Hispanic/Latino representation)
- At least 1 commissioner in the third party/unaffiliated delegation must be unaffiliated, and no third party may have more than 1 commissioner.

If there are strong concerns about a particular group being underrepresented, the baseline diversity target for that group can be somewhat increased to further enhance representation for that group in the final subpools.

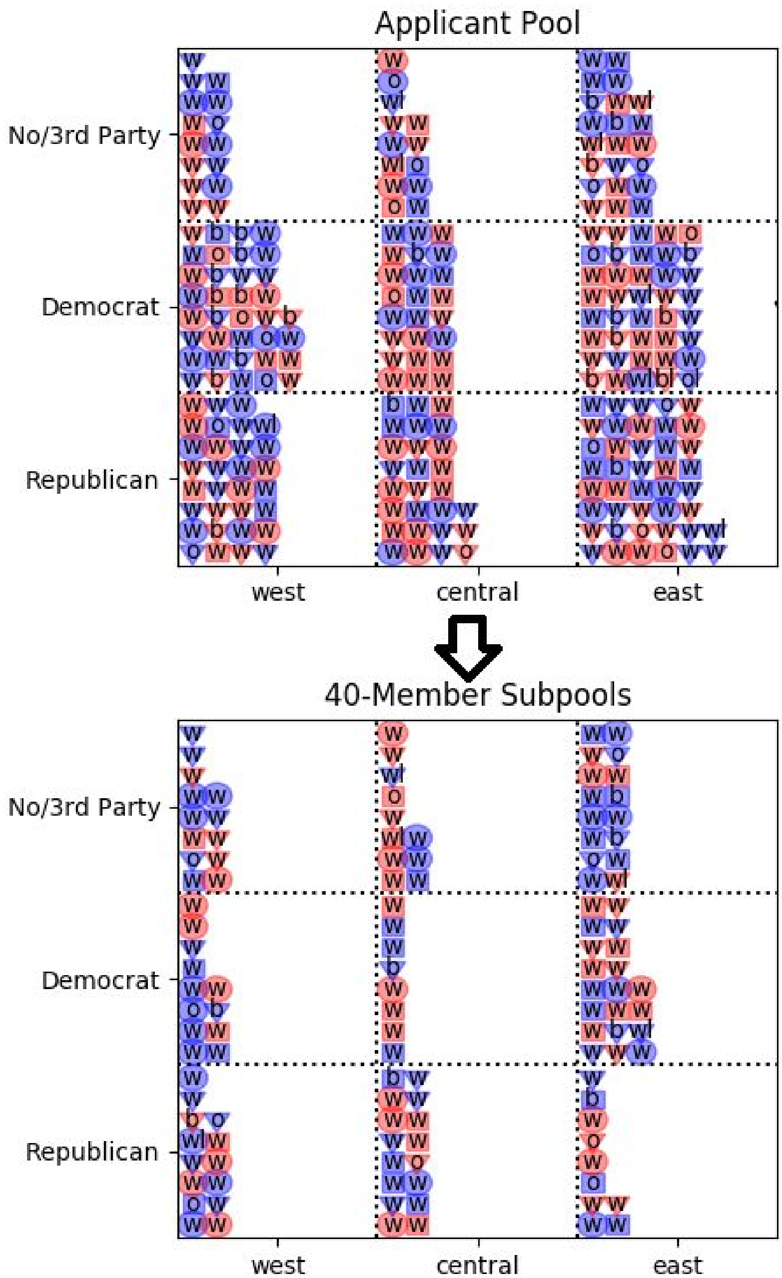
It should be emphasized that the target commission balances above are presented only as examples for the purpose of discussion and should not be construed as being specifically recommended by the authors of this report or by Fair Districts PA. The actual diversity requirements to be used in practice could be specified in enabling legislation, and would also likely need to be adjusted over time to account for demographic changes in the population of Pennsylvania.

It is quite likely, due to demographic variability in application or qualification rates, that the actual qualified applicant pools will not match diversity targets intended to represent the overall population distribution of the state. This issue arose early in California's 2010 commission selection process, when the state became aware that 74% of the applicants to date described themselves as "non-Hispanic white", despite the fact that only 42% of the population of the state as a whole identified that way. Additional diversity challenges can also be present within party affiliation pools due to correlations amongst party preference, gender, race/ethnicity, and region of residence. California chose to address its applicant diversity problems with a combination of targeted recruitment efforts and non-random selection of some commission members by their fellow commissioners, but for Pennsylvania, weighted random sampling can offer an alternative approach.

With diversity requirements like those outlined above, weighted random sampling becomes slightly more complicated than in our marble example. Now we must rebalance selection chances for each applicant across 5 different demographic categories instead of the single category we used for the marbles. Yet the principles remain the same — rather than directly selecting amongst the applicants at random, with each person having an equal selection chance, we give each applicant a certain number of "raffle tickets" corresponding to their demographic profile, and select randomly from amongst these "tickets" instead. Applicants from groups demographically underrepresented in their party pool compared to the desired composition of the commission receive extra "tickets", while applicants from overrepresented groups receive fewer "tickets". For example, if women and people from Central PA are underrepresented in a particular party pool, while men and people from Eastern PA are overrepresented and people from Western PA are represented "just right", then a woman from Central PA will get the most extra tickets, a woman from Western PA would get a small number of extra tickets, a man from Western PA would get slightly fewer than average tickets, and a man from Eastern PA would get the fewest tickets.

Once each applicant is assigned an appropriate number of "tickets", a standard randomization process can be used to select 40 "tickets" from each party pool to create the party sub-pools, with each "ticket" having an equal chance of being selected.[9] The graphic below shows an example of the results of this process.

[9] When a particular applicant's "ticket" is selected, all of their other "tickets" are of course removed from the corresponding pool to avoid selecting any applicant twice.



Selection of subpools: The above diagram shows an example of redistricting commission applicants being selected into 40-member subpools by weighted random sampling. The image on the top shows the full collection of qualified applicants, categorized by party preference (vertical axis), region of the state (horizontal axis), gender (blue = male, red = female), urbanness (rural = circle, suburban = square, urban = triangle), and race/ethnicity (w = white non-Hispanic/Latino, b = black non-Hispanic/Latino, o = other race non-Hispanic/Latino, wl = white Hispanic/Latino, bl = black Hispanic/Latino, ol = other race Hispanic/Latino). In the second image, 40 members from each party pool have been randomly selected into corresponding subpools.

With 5 types of demographic data to track, plus party preferences, for hundreds or thousands of applicants, the "ticket" assignments and randomized drawing would be best performed by a computer. For purposes of transparency, the computer code can be made public, along with the data used and logs of all stages of computation, for examination by ordinary Pennsylvanians and validation by independent experts.

It should be noted here that, even with careful attention to recruitment of a diverse group of qualified applicants, it is in principle possible for extremely bad luck in randomized subpool selection to result in a set of 40-member pools which are completely unable to meet diversity requirements. For example, the third party/unaffiliated subpool could accidentally wind up with no unaffiliated applicants, rendering it impossible to satisfy the requirement for at least one unaffiliated commissioner. With a sufficiently large and diverse applicant pool and appropriate weighting, this kind of problem will be extremely statistically unlikely (and, indeed, it never occurred in all of our testing, without any special precautions being taken), but in the rare case where it might happen, it is easily resolved: simply discard the offending subpool or subpools and select afresh, repeating if necessary until a usable set of subpools arises.

"Bad luck" in subpool selection can also be averted in advance by choosing to give a few extra "tickets" to members of groups with expected low prevalence in the subpools. If we want to be extra certain that it will be possible to have *at least* 1 unaffiliated commissioner, we could, for example, give unaffiliated applicants a 1 in 2 chance of being selected into the corresponding subpool, rather than the 1 in 3 chance that would correspond to having an expectation of *exactly* 1 out of the 3 commissioners from that subpool be unaffiliated.

3.3. Legislative Strikes

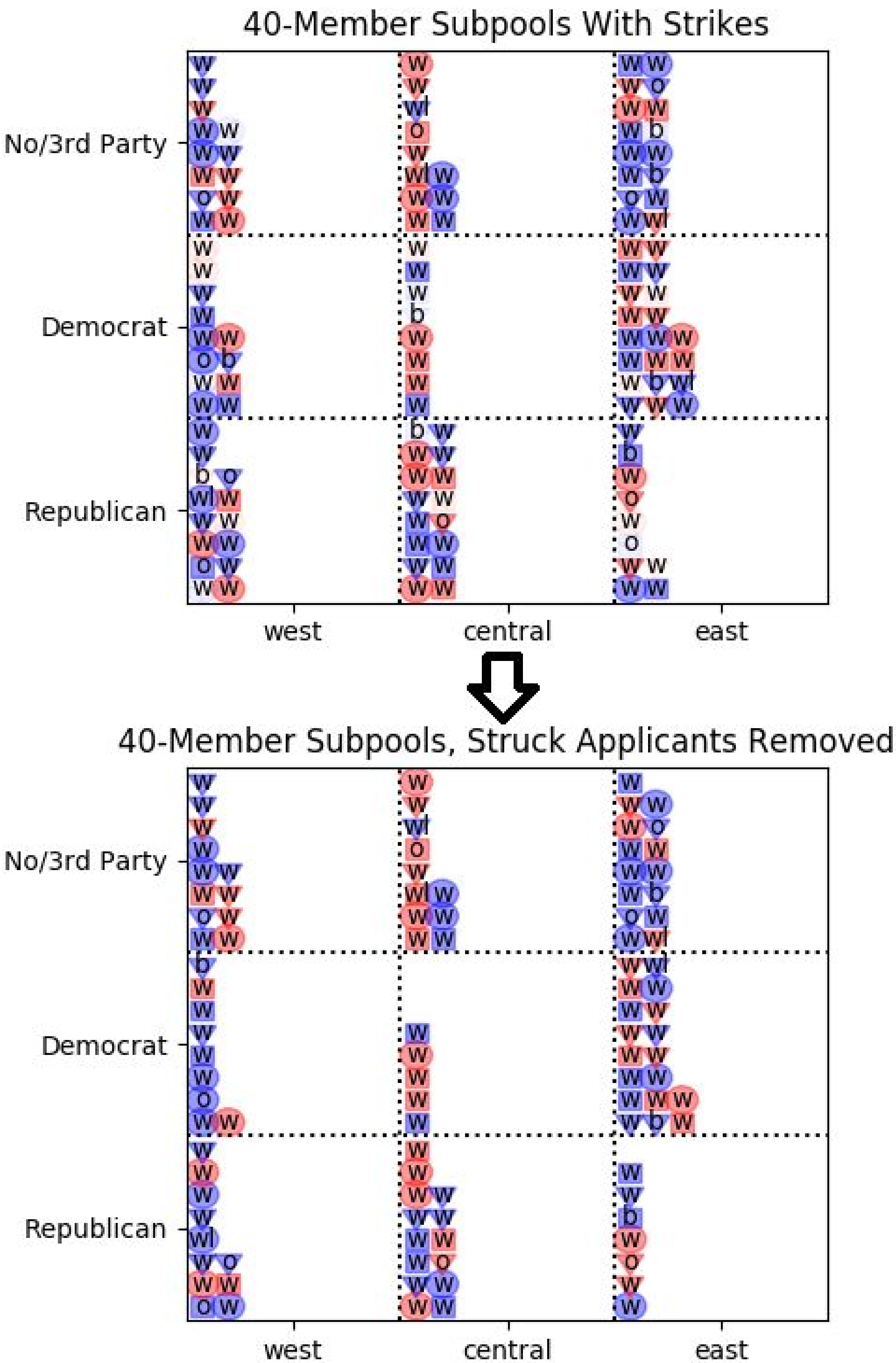
At this stage, the legislative leadership is permitted to strike members from all three party affiliation subpools, resulting in up to 8 arbitrary strikes from each subpool. It is possible for these strikes to create the same kind of difficulties in meeting diversity requirements as bad luck in subpool selection might.[10] For example, if our weighted random sampling has a target of approximately 1/11 of the applicants in each subpool being Hispanic/Latino, this corresponds to an average of 3–4 Hispanic/Latino applicants per subpool. 8 strikes per subpool could, in principle, eliminate all of these applicants,

[10] Our simulations suggest that this is extremely unlikely with an 11-member commission and 40-member subpools, absent unified and overt bias on the part of legislative leadership.

rendering that diversity requirement unsatisfiable. There are a number of possible approaches to this issue, in those rare cases where it might arise:

- Adjust the random sampling weights used in creating the subpools to ensure that no demographic group is likely to have so few members in any subpool as to be potentially eliminated by the legislative strikes.
- After strikes, randomly select from the corresponding party affiliation pool(s) an appropriate number of additional subpool members who can fulfill any desired diversity requirements that were made unsatisfiable by the strikes.
- Discard the subpool or subpools which cannot satisfy diversity requirements and repeat the subpool selection, and possibly the strike process, afresh.

Unbalanced legislative strikes or bad luck in subpool selection could also potentially significantly skew the demographic composition of one or more subpools away from the desired diversity targets, even if selection of an appropriately balanced commission is still possible. This can be remedied by again using weighted random sampling to rebalance the selection of the final commission from the post-strike subpools.



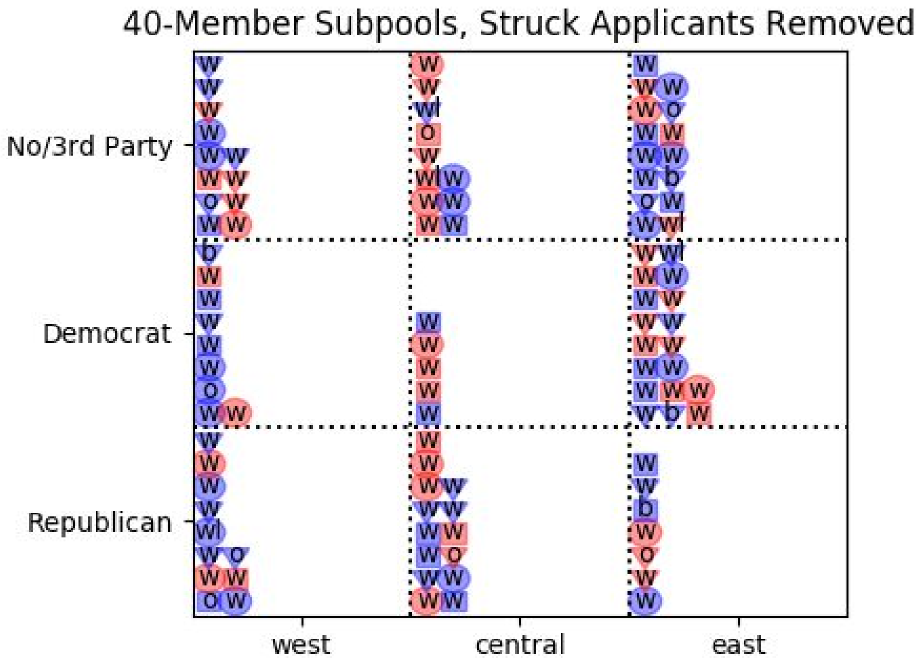
Legislative strikes: This diagram demonstrates the process of legislative strikes. In the first image, the applicants chosen to be struck are shown in lighter colors. In the second image, the struck applicants have been removed.

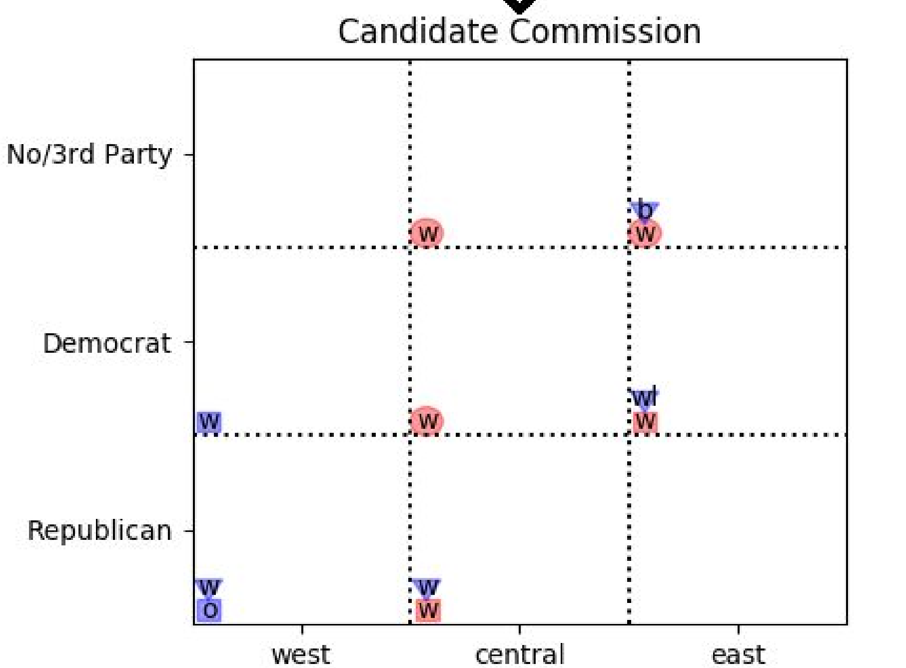
3.4. Final Commission Selection

Once the legislative strikes are complete, a final, appropriately diverse commission must be randomly selected from the remaining qualified applicants in the three party affiliation subpools. SB 22 explicitly specifies that 4 commissioners must be selected from each of Subpools 1 and 2 (applicants registered with each of the two largest parties in the state, by voter registration), and that 3 commissioners must be selected from Subpool 3 (unaffiliated and third party applicants). Specifics of the other demographic diversity requirements (gender, race, and geography) are not written into the bill, but could be spelled out in subsequent legislation and adjusted over time to account for changing population demographics. The details of an appropriate commission selection method to achieve desired diversity targets will depend somewhat on the priorities developed during the legislative process, but most reasonable diversity goals can be made workable by combining weighted random sampling with repeated drawing and replacement of possible candidate commissions.

As before, weighted random sampling can be used to ensure that the average and most likely outcomes of a single attempt at commission selection will have the desired diversity characteristics.

However, if we have minimum or maximum representation thresholds for any particular demographic group, any particular candidate commission might, by sheer random chance, fail to meet those targets. For example, if we want at least 1 of the 11 commissioners to be black, and so weight our commission sampling algorithm to ensure that we have a 1/11 chance of picking a black commissioner with each selection, we will end up with 0 black commissioners more than ⅓ of the time. Even if we boost the chance of selecting a black commissioner to 2/11, we will still end up with a commission lacking any black commissioners more than 10% of the time.





Candidate commission selection: This diagram shows the results of randomly selecting 11 commissioner candidates from the final, post-strike subpools. The demographics of the candidate commission can be checked against any desired minimum or maximum representation targets and, if one or more tests are failed, the candidates can be returned to the pool and a new random selection generated, repeating until the chosen criteria are fulfilled. This process can be performed extremely quickly and, under our test conditions, always found a satisfactory commission in less than a minute.

Fortunately, the risk of “failing” desired diversity thresholds in this fashion turns out to be very easy to mitigate. After using weighted (or even unweighted) random sampling to choose a candidate 11-member commision, we simply test the proposed commission against any desired diversity thresholds and caps, and then discard the commission and draw a new one if it fails one or more tests. One possible set of thresholds/caps corresponding to the diversity targets described above might be as follows:[11]

- At least 5 and no more than 6 each of men and women
- At least 3 and no more than 4 commissioners from each of Western, Central, and Eastern PA
- At least 3 and no more than 4 commissioners from each of rural, suburban, and urban PA
- At least 1 commissioner identifying with each of the following three racial groups: black, white, other race
- At least 1 commissioner identifying with each of the following two ethnic designations: Hispanic or Latino, not Hispanic or Latino
- At least 1 commissioner from third party/unaffiliated delegation must be unaffiliated, and no more than 1 commissioner may be affiliated with each third party

The cycle of drawing, testing, and discarding candidate commissions can be performed extremely quickly with appropriate software, and all draws can be logged for auditing purposes. Care taken in structuring the previous stages of the random selection process will ensure sufficient diversity in the final subpools to enable quick discovery of an appropriately diverse commission, with no human intervention required. In tests performed on hundreds of sets of randomly selected subpools (with strikes), using the above diversity thresholds/caps, this process never failed to produce a satisfactory commission and always did so in under a minute, running on an ordinary laptop computer. The algorithms we used to perform these tests are not complicated for competent professionals to design or understand and can be easily audited without requiring any particularly esoteric skills.

[11] As previously noted, these diversity criteria are only an illustrative example. Legislative and administrative processes would determine the actual criteria to be used in practice, and any chosen set of criteria would likely require regular updating to track the changing demographics of the state.

4. Conclusion

With a sufficiently large, varied, and well-vetted applicant base, random selection of a qualified and diverse redistricting commission can be done extremely quickly, with the assistance of relatively simple computer software operating on an ordinary desktop or laptop machine. Legislators can easily set the conditions for this process to function effectively, by:

- Specifying an appropriately rigorous process to assess applicant qualifications,
- Monitoring applicant numbers and diversity to detect needs for targeted recruitment,
- Mathematically reweighting randomized selection procedures to produce appropriately diverse subpools for final commission selection, and
- Using weighted random sampling and draw-and-replace procedures during final commission selection to satisfy representation balance targets, thresholds, and caps.

These procedures can help ensure that Pennsylvania's congressional and legislative districts will be drawn by a highly-qualified and diverse group of citizens who, instead of being beholden to narrow political interests, will represent and be accountable to the people of the entire state.

A. Technical Appendix

In this appendix, we describe the details of the Pennsylvania population model and exemplar selection algorithms supporting the results presented in the main text. Our computer code and the population data used are available upon request. All of our work relies only on free, open-source tools and datasets, none of which require special licensing. Our code was written in the Python and Octave programming languages, both of which are commonly used in technical fields.

A.1. Population model

SB 22[12] would require that the proposed independent redistricting commission "reasonably reflect the racial, geographic, and gender diversity of this Commonwealth", as well as that the commissioners have a balanced distribution of party registration. The need to satisfy all of these diversity requirements simultaneously, while still ensuring meaningful randomness in the commission selection, has the potential to be technically challenging, especially when one accounts for the fact that different demographic factors are often strongly correlated with each other and with party registration. Thus, when testing whether it is feasible to perform commission selection in the manner described in the bill, it is useful to have a reasonably realistic model of the distribution of relevant diversity characteristics amongst the population of Pennsylvania, and of the correlations of those characteristics with each other and with party preferences.

Our population model is somewhat heuristic in its present state and could easily be refined with use of more comprehensive and detailed demographic and political datasets. However, its purpose in the current context is not to provide a precise report of Pennsylvania demographics, but rather to serve as the basis for a "worked example" of random-but-diverse commission selection from an applicant population that has similar challenges to those which might be expected to be present in Pennsylvania.

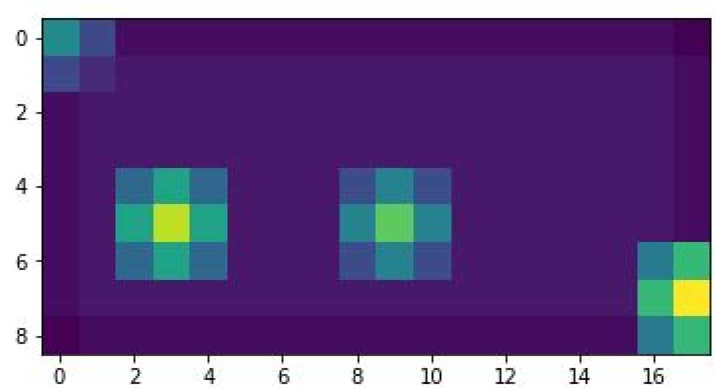
For this purpose, we created a "virtual Commonwealth" of 10 million "synthetic voters" (approximately the number of voting-eligible citizens in Pennsylvania). These synthetic voters are assigned demographic characteristics as listed below. These characteristics, and the categories listed for each characteristic, were selected based on concerns raised by interested individuals during the legislative processes surrounding SB 22/HB

[12] 2017 Session, Printer's No. 397

722. Many additional characteristics and alternative categorization structures might be worth considering. The most appropriate choices in this area would properly be the subject of targeted demographic studies and enabling legislation. With that said, the demographic characteristics and categorizations used for our modeling were:

- Gender (male or female)
- Region of the state (resident in western, central, or eastern Pennsylvania)
- “Urbanness” (resident in rural, suburban, or urban Pennsylvania)
- Race (white, black, or other race)
- Hispanic/Latino ethnicity (yes or no)
- Party registration (affiliated with the Republican Party, the Democratic Party, minor party A, minor party B, minor party C, or no party)

The “virtual Commonwealth” is a rectangular “state” with four large “cities”. The “city” locations and synthetic voter populations roughly correspond to those of the four largest Core-Based Statistical Areas (CBSAs) in the state: Philadelphia (4 million), Pittsburgh (2.5 million), Harrisburg (1.2 million), and Erie (300,000), overlaid on a uniformly distributed “rural” population base of 4 million. The “state” is divided into a grid of 9 ✕ 18 squares (numbered 0–8 from north to south and 0–17 from west to east on the “map” below). Each “city” initially occupies a single grid square, and the population distribution is then mathematically “blurred” to spread its population into the surrounding squares, creating “suburbs” in the squares immediately adjacent to the “city”. The “state” is evenly divided by area into “western” (grid squares 0–5), “central” (squares 6–11), and “eastern” (squares 12–17) regions. A map of the “state” is shown below. Darker blue regions have lower population density, and higher population densities are shown in greens and yellows.



Gender is assigned to each synthetic voter completely at random (50% male, 50% female). Synthetic voter racial and ethnic identifiers are also randomly assigned based on the racial/ethnic demographics of representative rural, urban, and suburban regions of the state.[13] Generally speaking, the proportion of white, non-Hispanic voters is highest in the rural areas and lowest in the urban areas.

In the present version of the model, party affiliation is chosen randomly using correlations between race and party preference only[14], as this correlation is by far the strongest across all demographic factors considered. Other demographic correlations could also be addressed using data sources that better differentiate the relationships amongst the demographic factors under consideration.

The party preference data used reports voter self-identification, as well as the party "lean" information for self-identified independents. As Pennsylvania has closed primaries, most self-identified independents do in fact choose to register with one or the other major party, so the Republican and Democratic lean categories were also treated as corresponding to Republican or Democratic registration. The category of independent voters who self-identified as having no lean was treated as corresponding to unaffiliated/third party registration, with those voters assumed to be equally distributed amongst our three simulated minor parties and unaffiliated status. This assignment actually somewhat underrepresents unaffiliated and third party voters in our virtual Commonwealth. The fact that we are nevertheless able to easily generate virtual redistricting commissions satisfying demographic criteria originally proposed for the real Commonwealth of Pennsylvania demonstrates the strength of our reweighting methodology.

A.2. Reweighting methodology

If a random 11-person commission were drawn from the synthetic population described above, its average membership would be:

- 5.0 Republicans, 5.5 Democrats, 0.125 unaffiliated, 0.125 minor party A, 0.125 minor party B, 0.125 minor party C
- 5.5 men, 5.5 women
- 3.9 western PA, 2.5 central PA, 4.6 eastern PA residents
- 3.1 rural, 3.9 suburban, 4.0 urban residents

[13] Suburban demographics source (Montgomery County): https://www.census.gov/quickfacts/fact/table/montgomerycountypennsylvania/PST045216
Urban/rural demographics source: https://pasdc.hbg.psu.edu/sdc/pasdc_files/researchbriefs/Urban_Rural_SF1_RB.pdf

[14] Race/party preference correlations source: http://www.people-press.org/2015/04/07/2014-party-identification-detailed-tables/

- 9.2 white-identified, 1.0 black-identified, 0.8 other race-identified
- 10.5 not Hispanic/Latino-identified, 0.5 Hispanic/Latino-identified

Our example commission diversity target, as discussed in the main text, is:

- 4 Republicans, 4 Democrats, 1 unaffiliated, 2 additional unaffiliated/third party
- 5.5 men, 5.5 women
- 3.66 western PA, 3.66 central PA, 3.66 eastern PA residents
- 3.66 rural PA, 3.66 suburban PA, 3.66 urban PA residents
- 9 white-identified, 1 black-identified, 1 other race-identified
- 10 not Hispanic/Latino-identified, 1 Hispanic/Latino-identified

Even if the demographics of our applicant pool match those of our "virtual Commonwealth" (definitely not something that can be relied upon!), unweighted random selection of the commission from such an applicant pool will tend to result in lower-than-desired representation of third party/unaffiliated voters, central and rural Pennsylvanians, and non-white or Hispanic/Latino Pennsylvanians.

SB 22 specifies that rebalancing of party affiliation demographics will be performed in part by the random selection of one 40-member subpool for each of three categories of party affiliation (largest party, second-largest party, unaffiliated and third-party voters). However, it is also important to ensure that each of these 40-member subpools is sufficiently demographically varied to allow the creation of an appropriately diverse commission at the final selection stage. To accomplish this end, we can use weighted random sampling to select subpools that match the desired demographics of the final commission, rather than those of the applicant pool.

The weightings are computed as discussed in the marble sampling example in the main text. Each commissioner begins with one virtual "raffle ticket". Commissioners demographically underrepresented in the applicant pool (which, for our example, we will take to be the entire "virtual Commonwealth"), are given additional "tickets" so that the total number of tickets assigned to each demographic category matches the total fraction of the commissioners we want from that category. Then, the final ticket counts are divided by the total number of tickets that have been handed out, in order to assign individual selection probabilities to each commissioner.

For example, 4059 of the voters in our virtual Commonwealth are white Hispanic women from rural western Pennsylvania who are registered as Democrats. These women constitute a fraction of 0.000818 of all Democrats in our sample. When reweighting applicant selection probabilities we want our Democratic subpool to be approximately 1/2 women, 1/3 western, 1/3 rural, 9/11 white, and 1/11 Hispanic/Latino, so one reasonable reweighting is to multiply all of these probabilities together to get the desired fraction of these women in the subpool, which will be approximately 0.00413. Thus, each of these women should be given approximately 0.00413 / 0.000818 = 5.05 “tickets”. On the other hand, white non-Hispanic men from urban eastern Pennsylvania constitute 0.0571 of all Democrats in our virtual Commonwealth, even though our reweighting computation suggests an optimal representation of 0.0413 for this group in each subpool. Thus, each applicant in this category should be given approximately 0.0413 / 0.0571 = 0.724 “tickets”.

An even simpler way to perform the reweighting computation is to note that each applicant’s individual selection probability should just be the target fraction of commissioners in their demographic category divided by the total number of applicants in that demographic category. Applying this to the white Hispanic Democratic rural western woman from the example above, we can see that her weighted selection probability into her party subpool should be (9/11 * 1/11 * 1/3 * 1/3 * 1/2) / 4059 = 1.02 $\times 10^{-6}$, while her unweighted selection probability would have been only 2.02 $\times 10^{-7}$. Similarly, a white non-Hispanic Democratic urban eastern man would have a weighted selection probability of 1.46 $\times 10^{-7}$, compared to his unweighted selection probability of 2.02 $\times 10^{-7}$.

An empirical test drawing 100 different sets of three 40-member party affiliation subpools from our virtual Commonwealth using this weighting scheme results in subpools consisting on average of:

- 59.23 men and 60.77 women
- 39.26 western PA, 40.34 central PA, and 40.40 eastern PA residents
- 39.84 rural PA, 40.28 suburban PA, and 39.88 urban PA residents
- 97.74 white-identified, 11.09 black-identified, and 11.19 other race-identified applicants
- 108.97 not Hispanic/Latino-identified and 11.03 Hispanic/Latino-identified applicants

These results closely match our specified target subpool demographics.

A.3. Legislative strike model

With the 40-member party affiliation subpools selected, the legislative leadership are then permitted to make up to 8 total arbitrary strikes from each subpool, reducing the subpool sizes to no fewer than 32 applicants each. It is essentially impossible to predict in advance how these strikes might proceed, either in terms of the number of strikes made or any possible demographic tilt. For the purpose of the present tests, the number of strikes and the identities of the struck applicants were therefore chosen with a uniform random probability — anywhere from 0 to 8 applicants might be struck from each pool, and each applicant in a given pool would have an equal chance of being struck.

Because of the choice to distribute strikes uniformly (on average), the mean demographic composition of the post-strike subpools is unaffected by our simulated strike process. Any particular set of strikes nevertheless has the potential to introduce significant demographic distortions in one or more subpools. Perhaps somewhat surprisingly, in all of our testing such distortions never once resulted in the creation of post-strike subpools for which it was impossible to satisfy our example diversity requirements. This becomes somewhat less surprising when one considers that, even for the rarest demographic categories in our subpools, our target subpool distributions are such that it is extremely unlikely that unbiased strikes will simultaneously remove all members of that demographic category from all three subpools, even if all or most are eliminated from one subpool.

Strongly biased strikes could nevertheless present a problem in meeting diversity targets for some of the less-populated demographic categories. However, if such a problem occurs it can easily be remedied by strategies like those discussed in the main text: protective overrepresentation of rare categories in the subpools, extra draws after the strike phase to fix any serious diversity problems, or a do-over of all or part of the subpool creation process in the case of an unusable result.

A.4. Final commission selection

After the random strikes are complete, there are a few different possible ways one can randomly select the final commission from the remaining applicant subpools to achieve desired diversity targets. If one is not particularly concerned about the possible effects of unlucky subpool draws or biased legislative strikes on the composition of the post-strike subpools, and no specific minimum or maximum representation criteria are required, one can simply give all applicants in each party affiliation subpool an equal selection chance, draw the specified number of commissioners from each subpool, and accept whatever the result may be. With our current simulation methodology, the average resulting commission will have exactly the same statistical balance we set as our target for the subpool selection phase, but the variance in representation of different groups can be significant.

This is true even if we perform a new reweighting step before the final commission selection (using the same methodology as for the subpool creation). In 100 commission selection trials by this method, the mean and standard deviation of each group's representation were:

- 5.48 ± 1.66 men, 5.52 ± 1.66 women
- 3.66 ± 1.39 western PA, 3.66 ± 1.53 central PA, 3.66 ± 1.59 eastern PA residents
- 3.66 ± 1.48 rural PA, 3.66 ± 1.49 suburban PA, 3.66 ± 1.49 urban PA residents
- 8.99 ± 1.54 white-identified, 0.93 ± 0.96 black-identified, 1.08 ± 0.97 other race-identified
- 9.96 ± 1.85 not Hispanic/Latino-identified, 1.04 ± 0.91 Hispanic/Latino-identified

(In these tests, we did not track the party affiliation distribution within the 3-member unaffiliated/third party delegation.)

These standard deviations are large enough that it will often be the case that one or more of the lower-prevalence demographic groups fail to achieve any representation at all on a commission selected by such a method. This concern can be alleviated somewhat by deliberately increasing the selection weights assigned to threatened groups at the subpool creation and final commission selection stages, but, as discussed in the main text, even doubling selection weights can still leave a significant chance for lack of representation.

Fortunately, it is possible to avoid this problem almost entirely using a draw-test-retry scheme. The process is conceptually very simple. First we choose a candidate commission at random from the three post-strike subpools and check whether it satisfies the minimum/maximum representation requirements. If the demographics of the candidate commission are satisfactory, it becomes the final commission. If not, the applicants are placed back in their respective subpools, and a new random draw is attempted. This process is repeated until a satisfactory commission has been drawn.

With the draw-test-retry procedure, it hardly matters whether we bother to reweight the candidate selection probabilities after legislative strikes or not. The draws and tests can be performed incredibly quickly, at a rate of hundreds per second, on an ordinary laptop computer. In all of our testing, this always resulted in rapid generation of an acceptable commission, even when using the relatively stringent and complex example representation criteria discussed in the main text, *i.e.*:

- At least 5 and no more than 6 each of men and women
- At least 3 and no more than 4 commissioners from each of Western, Central, and Eastern PA
- At least 3 and no more than 4 commissioners from each of rural, suburban, and urban PA
- At least 1 commissioner identifying with each of the following three racial groups: black, white, other race
- At least 1 commissioner identifying with each of the following two ethnic designations: Hispanic or Latino, not Hispanic or Latino
- At least 1 commissioner from third party/unaffiliated delegation must be unaffiliated, and no more than 1 commissioner may be affiliated with each third party

Across 100 different sets of sample subpools drawn from our "virtual Commonwealth", the methodology described in this report never resulted in a single case where it was impossible to randomly generate a commission satisfying these criteria, and the generation process never took more than a minute. This suggests that even if for some reason a particular set of subpools *did* pose difficulties, such that the selection algorithm continued to run for minutes or hours without producing a usable result, the problem would be trivial to resolve. One could simply randomly select a few more applicants from the original party affiliation pools to bolster any demographics with low representation in the post-strike subpools, and then run the commission selection algorithm again, to almost certain success.

A.5. Logging and Auditing

Each stage of the process described above, including the outcome of every single random choice, can easily be recorded as it is happening and checked later to confirm that its results match the reported selection outcome. If full, independent reproducibility is desired, algorithms can be written to accept a single large random number to be selected in a public, transparent, and difficult-to-manipulate fashion (such as with a lottery machine). This random number can then be used to control all later random choices made in the program by using it as the initiating seed for a well-chosen pseudorandom algorithm. (This is a standard randomization procedure used in many computing applications.)

Independent auditors can then confirm that the commission selection process was not manipulated simply by obtaining a copy of the commission selection code and applicant demographic database and plugging in the random seed generated for selection of that commission. By inspecting and running the code and comparing their logs and results to those produced during the official selection process, auditors can confirm that the random selection was performed fairly and well.