Supplemental Materials for Urban-Rural Disparities in Spatio-Temporal Accessibility of Pharmacy Care: A Case Study of Vermont, USA

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We have provided all procedures, data, code, analysis plans, and analysis reports for our study in our OSF Project at https://doi.org/10.17605/OSF.IO/BCQ9S and associated GitHub repository at https://github.com/HEGSRR/OR-VT-Pharmacy. Should the GitHub repository become unavailable, all of its contents are backed up in the OSF project and the InternetArchive. The materials do not contain confidential data on pharmacy staffing levels, for which we have created a synthetic dataset for public use with the same statistical properties. The study was completed primarily on the CyberGISX JupyterHub system (Kernel Python 3-0.9.0) hosted at the University of Illinois Urbana-Champaign, available at https://cybergisxhub.cigi.illinois.edu/.

In addition to the study as presented in this manuscript, the code includes Python notebooks for conducting sensitivity and robustness checks by altering selected study parameters and generating alternative sets of results. Modifiable study parameters include:

- Pharmacy data version (December 2023 or June 2025)
- Additional or modified distance thresholds
- Geographic level of aggregation (county subdivisions or census blocks)
- Demand population (total population, or total elderly population)
- Distance weights use the mean or minimum distance weight for each distance band
- Distance weights determined by alternative Gaussian function Beta coefficient
- Service value of pharmacy technicians compared to pharmacists (0.3, 0.5 or 0.7)

Change over Time

Data for this study was collected and verified as of December 2023. However, since that time seven pharmacies have closed, and Rite Aid has announced bankruptcy plans to close operations at four additional locations. In total, at least eleven pharmacies will have closed by the end of 2025 (Figure S1). Three community pharmacies have opened, but two are reopening after service disruptions of one year or less. In Ludlow, the Rite Aid was flooded in July 2023 and ceased operation. The adjacent Shaw's grocery store expanded into the space to open new pharmacy services a year later. Fall Mountain Pharmacy in Bellows Falls, VT opened in January 2024 after Greater Falls Pharmacy closed at the same location in September 2023. It appears that the location was only closed for a few months, during which time we conducted our survey. The only truly new service location is Mountainside Pharmacy in Stowe, a new location associated with the Lakeside independent pharmacy in Burlington. Without considering the two reopening locations, Vermont has seen a net loss of ten pharmacy locations in the past year and a half.

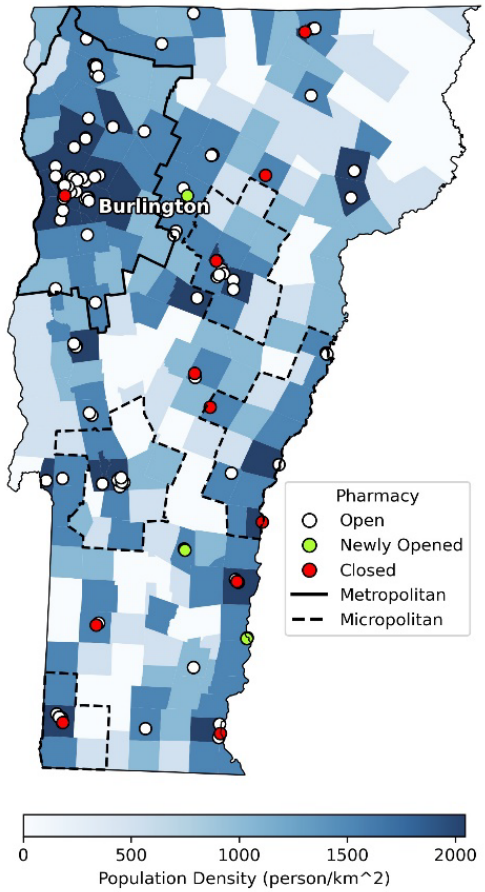

Figure S1. Vermont Study Area with population density across all towns (n = 255) and in-state pharmacy locations (n = 117). Metropolitan and micropolitan towns are outlined. Three pharmacies have opened while eleven have closed or announced plans to close within the year.

We altered the study design to simulate spatial accessibility in Vermont, taking into consideration the three openings and eleven closings illustrated in Figure S1. For the purposes of this simulation, we did not research or update the status of pharmacies outside of Vermont. Results for weekdays, Saturdays, and Sundays are shown in Figure S2. Subtracting accessibility as of December 2023 from the simulation as of June 2025, we can visualize the differences in accessibility caused by restructuring in community pharmacies (Figure S3).

As seen in Figures S2 and S3, the recent changes are disproportionately affecting rural areas. There have been fewer closures in urban areas, and those urban closures have less of an impact due to the presence of other pharmacies nearby. In contrast, many of the rural closures represent the loss of the only “keystone” pharmacy. A pair of independent pharmacies closed in Manchester and Bennington, causing a decline of almost three pharmacist-equivalents per 10,000 people in southwestern Vermont. In northeastern Vermont, three Walgreens locations closed in Montpelier, Hardwick, and Newport. For Hardwick in particular, the closure created a new gap in access representing long-term impacts from the flood disasters of 2022 and 2023, resulting in drive times of at least 25 minutes to reach a pharmacy.

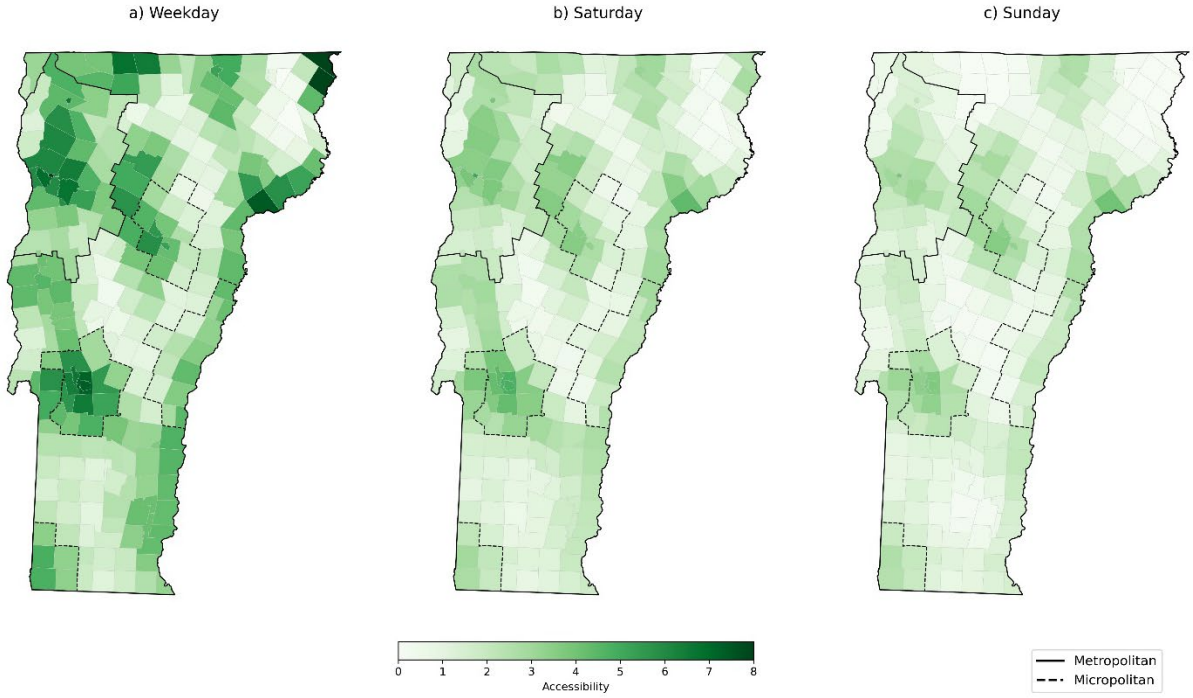

Figure S2: Accessibility as of June 2025.

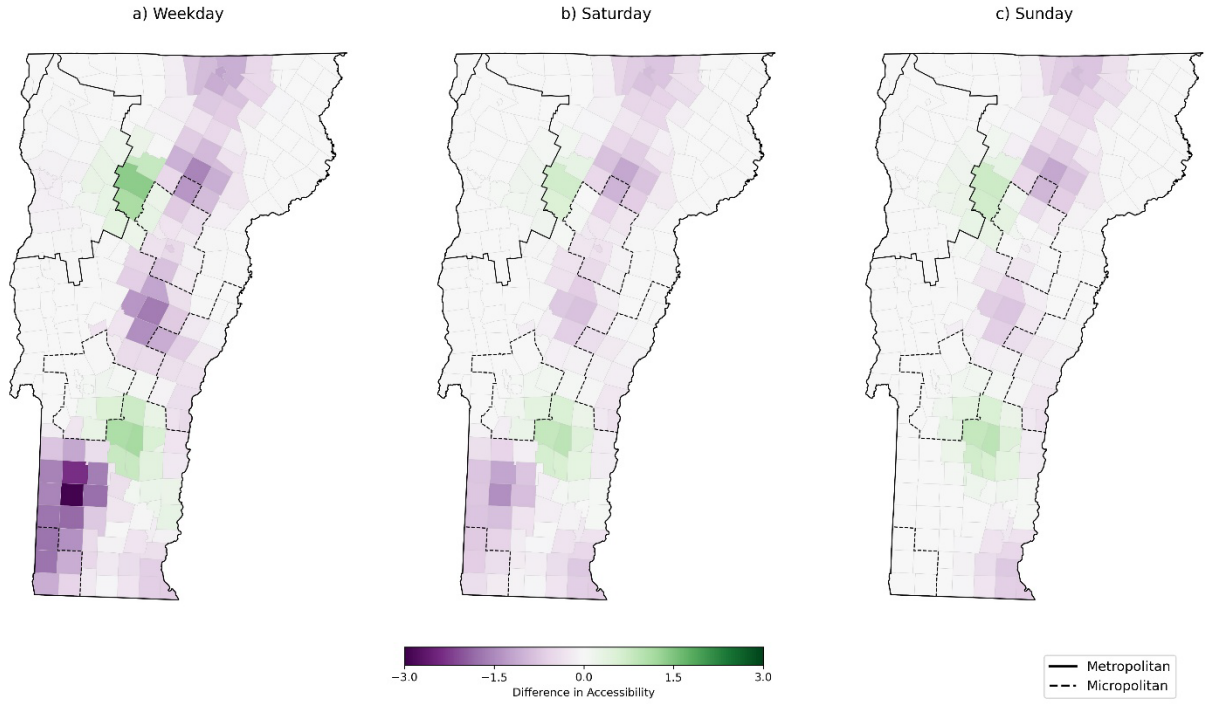

Figure S3: Difference in accessibility from December 2023 to June 2025.

The results above are only an informative simulation. For a more accurate model of change, researchers should also update the hours of operation, staffing levels, and pharmacies in adjacent states. Further, it is possible that investors could purchase any of the four Rite Aid locations to maintain a higher level of service in northeastern Vermont.

Granularity of Distance Bands and Population Data

There is a tension in spatial analysis between precision and granularity on one hand and data volume and computational complexity on the other hand. In this study, we chose the E2SFCA method and county subdivision level of aggregation to balance these tensions. However, we also explored increasing the granularity of the E2SFCA by adding more incremental distance thresholds (5, 10, 15, 20, 30, and 40) and by using census blocks as the source of population data. Together, these changes approach the precision of results that could be achieved with a Gausian-2SFCA while avoiding the simplification of population areas into centroid points.

With these changes, Metropolitan and Rural areas see a negligible decrease in mean weekday accessibility (both by 0.06), while Micropolitan areas see large decrease in accessibility (0.16 on average). When population and distance decay are both modelled with more granularity, the county subdivisions with more varied population distributions and partial coverage of E2SFCA distance bands are most affected.

Over the whole study area, a more granular study results in slightly lower mean access for each type of area (-0.06 for metropolitan, -0.16 for micropolitan, and -0.06 for rural). The more granular study appears to more accurately model higher accessibility for county subdivisions on the eastern border with New Hampshire, where population is concentrated in the Connecticut River valley with access to Interstate Highway 91. Nonetheless, this study version yields the same overall patterns and conclusions as the original study version. This analysis shows that slightly more accurate results may be achieved at the cost of larger data volumes, processing time, and complexity.

Elderly Population

For some pharmacy services, policymakers will be more interested in a particular segment of the population. Modeling this alternative population base of people aged 65 or greater on its own is unrealistic because the broader population will continue to use other services at the pharmacy. As an example, even if we are interested in administering flu and pneumonia vaccines to elderly patients, the pharmacy will continue to devote service resources to filling prescriptions for children. Nonetheless, an analysis of one segment of the population can yield insight into whether results would change if we applied weights to different segments of the population according to the demand they place on pharmacy services in a given scenario.

In this version of the analysis, we observed higher magnitudes of access overall (due to modelling only a portion of the population) and proportionally greater access in metropolitan areas compared to micropolitan and rural areas. In Vermont, rural areas tend to be composed of older populations while the metropolitan area of Burlington contains a significantly younger population. Micropolitan areas are younger, but to a less significant degree. In sum, a focus on

the elderly population increases the magnitude of the patterns of urban-rural disparity found in our original study.

Distance Weights

When researchers discretize the distances within each E2SFCA distance band, they may choose the mean or the minimum distance of the band for assignment of a weight based on the Gaussian function. Switching from the minimum to the mean simulates faster distance decay with weights of 1.0, 0.42 and 0.09. It is conventional to keep the most proximate distance band as 1.0 even when a mean is used, such that 100% of the closest populations to a service location are modeled as having access.

In this version of the analysis, the overall magnitude of access decreases and the significance of difference between rural areas and metropolitan and micropolitan areas increases slightly. This is an intuitive result, as access to urban pharmacies is more constrained to the urban area itself. The same pattern of difference in weekdays, Saturdays and Sundays is observed, with slightly less difference than in the original study (p still less than 0.0001).

Distance weights could be further adjusted with the Beta variable in the Gaussian function if more data becomes available on the rate of distance decay for pharmacy services. We can expect based on the results above that the overall patterns will hold, faster distance decay may result in more severe disparities, and slower distance decay over greater distances may result in less severe disparities.

Pharmacy Technicians

E2SFCA models require an estimate of the capacity or level of service at each location, often measured by proxy variables such as the number of practitioners or units in a health care setting. For pharmacies, one option is to quantify the staffing level of each location in terms of pharmacists and pharmacy technicians. This raises the question of how much service a pharmacy technician adds to a location compared to a licensed pharmacist. We can alter the assumption of a pharmacy technician as 0.5 pharmacist-equivalents to test sensitivity to this assumption.

In a version of the analysis where a pharmacy technician is 0.3 pharmacist-equivalents, the magnitude of access naturally declines while the patterns remain virtually the same. Conversely, a version with pharmacy technicians as 0.7 pharmacist-equivalents results in greater magnitudes of access, while the patterns and conclusions remain virtually the same. It appears that decisions about the pharmacy technician weight are more important for targeting policy objectives with an absolute threshold (e.g. 3 pharmacist-equivalents per 10,000 people available for mobilizing a public vaccination campaign) than for identifying relative differences or gaps between places and times.

Conclusions

The sensitivity and robustness checks above show both the flexibility of our open science research and the robustness of our main findings to research design decisions and parameters. The results from our checks demonstrate the consistency of our findings with modified parameters and add support to our original findings.