Am. J. Trop. Med. Hyg., 99(6), 2018, pp. 1390–1396
doi:10.4269/ajtmh.17-0652

Do Incarcerated Populations Serve as a Reservoir for Tuberculosis in South Africa?

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Abstract. Tuberculosis (TB) prevalence among incarcerated populations is as much as 1,000 times higher than in the general population. This study evaluates whether correctional facilities serve as a reservoir through which TB is transmitted to surrounding communities. Tuberculosis test data were extracted from the South African National Health Laboratory Service database for patients tested for TB between 2005 and 2011. We conducted graphical analysis to assess the relationship of TB rates between incarcerated and non-incarcerated populations over time. We performed generalized linear modeling with a log link function to assess TB risk in communities surrounding correctional facilities, net of confounders. We assessed linkages between incarcerated and non-incarcerated populations over time using Granger causality analysis. Tuberculosis prevalence among incarcerated populations was four times higher than in the general population. Tuberculosis incidence rates in incarcerated and non-incarcerated populations followed similar trends over time. The presence of a correctional facility in a municipality was associated with 34.9% more detected TB cases (confidence interval: 11.6–63.2; $P < 0.01$), controlling for potential confounders. Detected TB in incarcerated populations did not have predictive power in explaining detected TB rates in the non-incarcerated population after controlling for serial correlation in the time series data. Despite high TB prevalence, trends in correctional facilities do not appear to be driving temporal trends in the general population. However, correctional facilities still act as a TB reservoir that raises the overall TB risk in the vicinity. Intensified TB control policies for correctional facilities, formerly incarcerated individuals, and surrounding communities will reduce TB prevalence overall.

INTRODUCTION

More than 10.3 million people are incarcerated worldwide, accounting for 144 of every 100,000 people.[1] Incarcerated populations are at high risk for tuberculosis (TB) because they are more likely to be human immunodeficiency virus (HIV)-positive, suffer from malnutrition or general poor health, and live in overcrowded or poorly ventilated places.[2] These factors contribute to rates of TB infection as much as 1,000 times higher than in the general population.[3] Limited infrastructure, severe underfunding, discrimination, inadequate health systems, and poor health management policies in many low-income countries result in incarcerated populations that are not provided with timely TB diagnosis or uninterrupted treatment.[3,4] The Global Plan to End TB 2016–2020 identifies incarcerated populations as a vulnerable and underserved group at high risk for TB infection.[5]

Correctional facilities have been described as a high-prevalence "reservoir" for TB through which TB and multidrug-resistant TB (MDR-TB) may be transmitted to surrounding populations via formerly incarcerated individuals, visitors, and the correctional facility workforce.[6] One study described the TB epidemic in correctional facilities as a "time bomb," given the correctional system's limited capacity to treat and isolate these patients.[7] However, there are few quantitative evaluations of the link between the TB epidemic in correctional facilities and surrounding communities. A number of studies have used the genotyping of TB strains to measure the overlap in the genetic profile between a potential reservoir (source) population and the general population.[8–10] This method produces rigorous, quantitative data on transmission dynamics, but is limited by the need for large-scale genotyping and is, therefore, not scalable for use by national TB control programs.

This study addresses the gap in the literature by evaluating whether high-TB prevalence–incarcerated populations serve as a TB disease reservoir that transmits TB to surrounding communities via formerly incarcerated individuals, visitors, and the correctional workforce.[11] We examine trends in TB incidence rates over time between incarcerated and non-incarcerated populations (henceforth general population), perform multivariate regression modeling to assess the TB risk in communities surrounding correctional facilities, and quantify linkages between TB trends in incarcerated and general populations using Granger causality estimation.

We focus on South Africa because little quantitative research has been performed on correctional facility transmission dynamics despite it having the fifth highest TB incidence rate[12] and the ninth largest correctional facility population in the world.[1] Tuberculosis prevalence in South African correctional facilities has been estimated to be as high as 3.9%, almost seven times higher than in the general population.[13] Several factors contribute to high rates: HIV prevalence is as high as 41% among incarcerated populations,[14] occupancy rates are above 130% of correctional facility capacity,[15] and crowded communal holding cells are used for those with short sentences or who are awaiting trial.[16] A reliance on passive case finding results in an estimated 3.5% of the incarcerated population having undiagnosed, smear-positive TB.[17] Because South Africa collects high-quality, geocoded data on TB testing in public health and correctional facilities, this context enables a rigorous quantitative analysis of TB transmission dynamics.

MATERIALS AND METHODS

Tuberculosis test data were extracted from the South African National Health Laboratory Service (NHLS) database for patients aged 18–64 years and tested for TB between 2005–2011 in public health facilities and correctional facilities. The data include unique patient identifiers created by the

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NHLS as well as information on the date, type of test performed, test result, drug resistance profile, testing facility location and type, and patient gender and age. Incarcerated populations were identified from the TB testing location identifier in the database. We excluded TB tests performed within 2 years of a TB-positive or MDR-TB–positive test result to focus the analysis on incident cases, not follow-up testing. We excluded KwaZulu-Natal Province because of limited NHLS coverage during the period of study.

Cross-sectional analysis of TB risk. Counts of TB tests and TB cases captured in the NHLS data (i.e., detected TB cases) were aggregated by quarter to plot national trends over time. To evaluate the impact of correctional facilities on TB in surrounding communities, we estimated the relationship between TB and MDR-TB incidence rates and the presence of a correctional facility in a municipality using generalized linear regression modeling with a log link function.

To model the relationship between the mean of the detected number of TB cases (i.e., expected value) and the municipality characteristics, we used the following generalized linear regression model with a log link function and a Poisson distribution:

$$E[\text{Detected TB}_m] = e^{\beta_0 + \beta_1 \text{muniprison}_m + X_m}, \quad (1)$$

where X is a vector of municipality-level demographic, socioeconomic, and health system controls.[18] Standard errors are robust to heteroscedasticity. We also perform this regression using a set of binary variables for municipalities having one, two, and three or more correctional facilities and include the total number of TB tests in the X vector.

We linked aggregated TB testing data from 2011 to municipality-level demographic data from the South African 2011 Census.[19] District-level data on health systems, HIV testing, and TB smear conversion rate were taken from the District Health Barometer.[20] The model controlled for demographics (municipality population, population density, proportion Black African, and males per 100 females), socioeconomic indicators (unemployment rate, percent of population with no schooling, percent of households headed by females, percent informal housing, and percent of households with flushable toilets, refuse removal, piped water, and electricity for lights), population health (mortality under 5 years, immunization coverage, and maternal mortality rate), metrics of health systems (government health expenditure per uninsured and percent of health spending on primary health care), and measures of the quality of TB and HIV care (condom distribution rate, TB smear conversion rate, TB cure rate, TB defaulting rate, HIV testing rate, antenatal HIV-positive rate, and antenatal clients started on anti-retroviral therapy [ART]). Annual population data were drawn from Statistics South Africa for the general population[21] and the United Nations Office on Drugs and Crime.[15] Because of high mobility within metropolitan areas, each of the five major metropolitan zones was aggregated to its own single municipality for these analyses.

Time series analysis and Granger causality test. Following the methodology developed by Lopez and Weber,[22] we performed a set of multivariate Granger causality tests, which assess linkages between the TB epidemic in the incarcerated population and general population in our time series data net of any serial correlation. We calculated the number of detected TB cases per quarter for the incarcerated and general populations from June 2005 to September 2011 for municipalities that contain at least one correctional facility and then aggregated the data to district level to obtain sample sizes large enough for the methodology. Our data included 40 districts because KwaZulu-Natal is not part of the analysis due to data limitations. There were too few cases to perform the district-level analysis for MDR-TB.

First, we estimated the following regression separately for each district with N = 1, 2, 3, and 4 lags in the dependent variable:

$$\text{LogGr}_t = \beta_0 + \sum_{k=1}^{n} \beta_k \text{LogGr}_{t-k} + \varepsilon_t, \quad (2)$$

where LogGr_t is the log growth in detected TB cases for the general population in quarter t. For each n, we averaged the Akaike information criterion (AIC) values across districts and repeated the process to determine the number of lags in the dependent variable that minimizes the average AIC for the set of districts. Second, we estimated a set of district-specific regressions according to the following regression, including the set of lags in levels, first-differences, or log growth in detected TB in correctional facilities that minimized the AIC:

$$\text{LogGr}_{i,t} = \beta_0 + \sum_{k=1}^{n} \beta_k \text{LogGr}_{i,t-k} + \sum_{k=1}^{n} \gamma_k \text{IncarGr}_{i,t-k} + \varepsilon_i, \quad (3)$$

where $\text{IncarGr}_{i,t-k}$ is the log growth in detected TB cases for the incarcerated population in quarter t–k for district i. The Granger causality test is predicated on whether the set of lags have explanatory power in the regression, conditional on other control variables. Third, we repeated this methodology at the national level.

In accordance with the Granger causality methodology, we calculated the natural log of the growth rate in detected TB cases in the general population to stationarize (i.e., detrend) the dependent variable and its lags in all regressions.[22] We stationarized detected TB cases in the incarcerated population using first differences in the district analysis for Eq. (3) because of small sample sizes and log growth in the national analysis for Eqs. (2) and (3). All analyses were performed in Stata 14 (StataCorp, College Station, TX).

Ethics approval was obtained from the University of Michigan Institutional Review Board and the University of Cape Town Faculty Ethics in Research Committee in South Africa.

RESULTS

Temporal trends in TB and MDR-TB. A total of 13,188,651 TB tests were performed in public health facilities from 2005 to 2011, resulting in 2,059,957 detected cases of TB. After adjusting for population size, the number of detected TB cases was approximately four times higher among incarcerated persons than in the general population. Figure 1A shows that the number of detected TB cases in the general population and the incarcerated population at the national level followed a similar decline from 2005 through the end of 2007. Both then rose and stabilized toward the end of 2011. The trends between the two populations appear to be correlated before 2008 but only weakly positively correlated

FIGURE 1. Total number of detected incident cases of tuberculosis (TB) (**A**) and multidrug-resistant TB (MDR-TB) (**B**) in the incarcerated population and the general population over time. Notes: quarterly totals calculated from original sample of 13,188,651 TB tests. Incarcerated populations were identified by testing location. Source: National Health Laboratory Service database. This figure appears in color at www.ajtmh.org.

subsequently. The trends in MDR-TB cases do not appear to be correlated between the general population and incarcerated population (Figure 1B).

Overall, the proportion of TB tests with positive results (i.e., the case-positive TB test rate) was higher among the general population than in the incarcerated population (Figure 2A). The TB-positive rate in correctional facilities (dashed line) decreased steadily from an average quarterly high of 21% in 2005 to 11% in 2011. Similarly, TB-positive rates declined in the general population (solid line) between 2005 and 2011 from an average quarterly high of 21% in 2005 to 12% in 2011. Despite slightly higher case-positive rates in the general population, the TB rates over time in both the general and incarcerated populations follow similar trends. Similarly, MDR-TB case-positive rates in the two populations appear to be weakly correlated (Figure 2B).

Similar patterns in TB detection may be driven by similar changes in the intensity of case finding. Figure 3 shows the number of TB tests performed in the incarcerated versus general population. In the 2005–2011 period, the number of tests increased in both populations and the trends appear to follow highly similar patterns between these two populations. Overall, quarterly testing intensity in the general population nearly doubled between 2005 and 2011 and nearly tripled in correctional facilities over this period.

Figure 4 compares the number of detected TB and MDR-TB cases per quarter over time for incarcerated individuals (dashed line) versus non-incarcerated individuals. Non-incarcerated individuals were disaggregated by whether their municipality of residence contains a correctional facility (dash-dot line) or not (solid line). Overall, general population TB rates are not highly correlated with incarcerated population TB rates (Figure 4A). However, the correlation between TB rates for incarcerated populations and municipalities with correctional facilities appears somewhat weakly correlated. A similar pattern emerges for MDR-TB rates (Figure 4B).

Cross-sectional analysis of TB risk. We evaluate the relationship between detected TB cases and the number of correctional facilities in a municipality to determine whether correctional facilities have a closer association with disease patterns in nearby communities compared with those farther away. In our sample, 42% of municipalities do not have a correctional facility within their borders, 38% of municipalities have one correctional facility, and 20% have two or more. Table 1 reports coefficients from regression Eq. (1), which are interpreted by exponentiating the coefficient and subtracting 1 to obtain the implied percentage change in the outcome variable (see Supplemental Table 1 for full set of coefficients on control variables). The presence of at least one correctional facility in a municipality was associated with a statistically

FIGURE 2. Case-positive test rates for tuberculosis (TB) (**A**) and multidrug-resistant TB (MDR-TB) (**B**) in the incarcerated population and the general population over time. Notes: case-positive rate is the number of incident TB or MDR-TB cases per 100 TB tests performed. Incarcerated populations were identified by testing location. Source: National Health Laboratory Service database. This figure appears in color at www.ajtmh.org.

significant 34.9% more detected TB cases after adjusting for a comprehensive set of demographic, socioeconomic, and health indicators (34.9 = $e^{0.299}$ – 1; confidence interval [CI]: 11.6–63.2; $P < 0.01$). The inclusion of the number of TB tests performed in a municipality quarter, which was highly correlated between the incarcerated and general population and may, therefore, account for some of the correlation in the TB incidence, slightly attenuates the estimate of the association to 27.6% (27.6 = $e^{0.244}$ – 1; CI: 7.3–52.2; $P < 0.01$). Table 1 shows a higher rate of detected TB cases in municipalities with more than one correctional facility: municipalities with two correctional facilities have 52.5% more detected TB cases (52.5 = $e^{0.422}$ – 1; CI: 8.5–114.2; $P = 0.15$) than municipalities without correctional facilities and districts with three or more correctional facilities have 87.2% more detected TB cases (87.2 = $e^{0.627}$ – 1; CI: 40.1–150.0; $P < 0.01$). These patterns are consistent with municipalities with correctional facilities being at higher risk for TB transmission from incarcerated populations than municipalities without correctional facilities.

FIGURE 3. Total number of tuberculosis (TB) tests performed in incarcerated and general population over time. Notes: quarterly counts of TB tests. Incarcerated populations identified by testing location. Source: National Health Laboratory Service database. This figure appears in color at www.ajtmh.org.

Time series analysis and Granger causality test. We found that detected TB in incarcerated populations did not have predictive power in explaining detected TB rates in the general population once we controlled for potential serial correlation in the time series data. Neither the lagged levels nor lagged first-difference of detected TB in incarcerated populations were statistically significant in the district-level Granger causality analysis (levels: average coefficient –0.01, Wald statistic 1.29, and P value 0.40; first-difference: average coefficient –0.01, Wald statistic 1.01, and P value = 0.26,

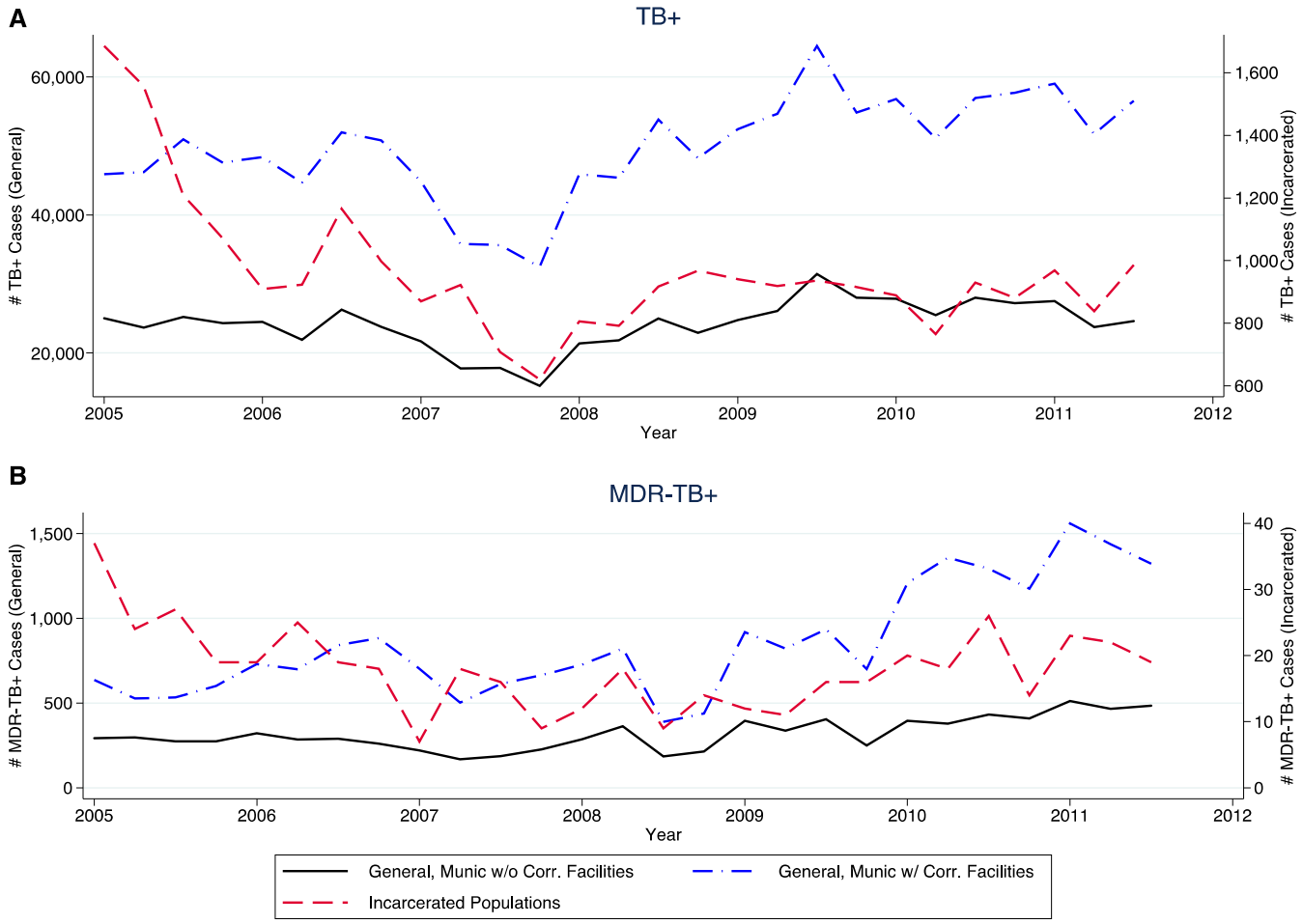

FIGURE 4. Total number of detected incident cases of tuberculosis (TB) (**A**) and multidrug-resistant TB (MDR-TB) (**B**) in municipalities with correctional facilities, municipalities without correctional facilities, and the incarcerated population over time. Notes: quarterly counts of TB cases. Cases defined as positive test result more than 2 years since last positive test. Multidrug-resistant TB cases identified from test results for specimen resistant to both rifampicin and isoniazid. Incarcerated populations were identified by testing location. Source: National Health Laboratory Service database. This figure appears in color at www.ajtmh.org.

respectively). We included one lag of the dependent variable (i.e., log growth in detected TB in the general population) in Eq. (2) because that specification minimized the average AIC (AIC = –0.072).

Table 2 shows that a the national level, neither the lags in log growth of TB nor of MDR-TB in incarcerated populations had explanatory power for TB or MDR-TB cases, respectively, in the general population after controlling for potential serial correlation in the time series (TB *F*-stat 0.94, *P* value 0.41; MDR-TB *F*-stat 0.15, *P* value 0.86). Adding two lags of the dependent variable minimized AIC for both TB and MDR-TB cases.

DISCUSSION

High TB disease burden among incarcerated populations raises concern that this population could serve as a reservoir for the TB epidemic, through which TB is transmitted to the general population. Our results showed that trends in incarcerated and general populations follow similar patterns over time for both detected TB and MDR-TB cases. In addition, the cross-sectional analysis found that municipalities with correctional facilities had higher numbers of detected TB cases than those without, controlling for a comprehensive set of potential confounders. However, in the Granger

TABLE 1
Relationship between municipality TB rate and the presence of correctional facilities

	Specification 1			Specification 2			Specification 3		
Number of correctional facilities	Coefficients	95% CI	*P* value	Coefficients	95% CI	*P* value	Coefficients	95% CI	*P* value
≥ 1	0.299 (0.096)	0.11, 0.49	0.002	0.244 (0.091)	0.07, 0.42	0.008	–	–	–
1	–	–	–	–	–	–	0.241 (0.092)	0.06, 0.42	0.009
2	–	–	–	–	–	–	0.422 (0.173)	0.08, 0.76	0.015
3	–	–	–	–	–	–	0.627 (0.148)	0.34, 0.92	0.000

CI = confidence interval; TB = tuberculosis. Notes: table reports coefficients, standard errors in parentheses, and 95% CIs from regression of municipality TB rate on the set of control variables (see Eq. (1) and text for control variables). Sample includes 170 municipalities (note that KwaZulu-Natal Province is omitted). Data sources: Census 2011, District Health Barometer, National Health Laboratory Service. See Supplemental Table 1 for full set of covariate coefficients.

TABLE 2

Time series relationship between TB rates in incarcerated populations and the general population at the national level (Granger causality analysis)

	Log growth TB (general population)	Log growth MDR-TB (general population)
Coefficients		
Log growth (incarcerated) lag 1	0.01 (0.24)	–0.05 (0.26)
Log growth (incarcerated) lag 2	–0.33 (0.37)	–0.08 (0.20)
Granger causality *F*-statistic (df: 2, 19)	0.94	0.15
F-statistic *P* value	0.41	0.86

TB = tuberculosis. Notes: table reports coefficients from Granger causality regression in Eq. (3), with standard errors in parentheses. See text for calculation method. Source: National Health Laboratory Service database. Twenty four quarters of data June 2005–September 2011.

causality analysis that controlled for potential serial correlation in the district time series data, linkages in TB trends between general and incarcerated populations were not statistically significant.

Communities surrounding correctional facilities are likely to be at the highest risk from high TB burdens in incarcerated populations: municipalities that contain at least one correctional facility had approximately one-third more detected cases of TB than municipalities that did not contain a correctional facility. This result holds even after controlling for a comprehensive set of demographic, socioeconomic, and health indicators, which suggests that confounders are unlikely to account for the observed relationship. This result is not driven by correlations in the number of patients tested for TB because controlling for this factor only slightly attenuates the association. However, part of the observed difference may be driven by the fact that correctional facilities are likely to be located in less-desirable locations and among more vulnerable populations in ways not captured by the Census and District Health Barometer data. It is also possible that these communities may perform more intensive case finding, which can produce artificially higher estimates of incidence than in communities with more limited testing programs.

The findings from the cross-sectional regression analysis suggest that correctional facilities may amplify the TB epidemic in the general population via local transmission from people who were previously incarcerated (even for short periods of time) or through the correctional workforce. Our methods cannot distinguish the relative impact of these two transmission mechanisms; however, the size of the population of previously incarcerated individuals relative to the correctional workforce suggests that they would account for a greater proportion of the transmission.

The lack of a statistically significant correlation in the time series data suggests that South African incarcerated populations are unlikely to be the primary driver of temporal trends in the TB epidemic, despite the extremely high TB prevalence in incarcerated populations and similar data patterns between the two populations over time. Our data and methods are not, however, powered to completely rule out the impact of direct transmission from correctional facilities to the general population. In addition, different rates of under-detection between incarcerated and general populations may add noise to the data and mask a closer linkage. Studies should be undertaken to assess the relative importance of proximity to correctional facilities on TB rates compared with other underlying drivers of the TB epidemic.

CONCLUSION

Although TB trends in correctional facilities do not appear to be the primary driver of temporal trends in the general population, they may still act as a TB reservoir that raises the overall TB risk in their vicinity. This highlights the importance of the implementation of TB testing and treatment policies in correctional facilities and suggests that these services should be expanded because they likely also benefit surrounding communities. Discharge planning for incarcerated individuals that includes TB screening and treatment initiation would more promptly diagnose and treat TB cases acquired in correctional facilities. Investments in TB care in vulnerable communities to which formerly incarcerated individuals often return and improved linkages to health providers for these individuals would reduce transmission from the reservoir. Targeting TB control policies toward those who were formerly incarcerated and the communities in which they live will address the enduring disparity between the incarcerated and general population and reduce TB prevalence overall.

Received August 17, 2017. Accepted for publication July 22, 2018.

Published online October 1, 2018.

Note: Supplemental table appears at www.ajtmh.org.

Acknowledgments: We thank Sue Candy, Michelle Potgieter, and Andrew Whitelaw for assistance with the data and helpful comments. We thank Michael Budros, Elizabeth Brouwer, David Ederer, and Kathryn Fischer for research assistance.

Financial support: Financial support was provided by the University of Michigan School of Public Health Global Public Health Program, the Center for Global Health, and the University of Michigan Health Management and Policy Department McNerney Award.

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REFERENCES

1. Walmsley R, 2016. *World Prison Population List*, 11th edition. London, United Kingdom: International Centre for Prison Studies.
2. Rubenstein LS, Amon JJ, McLemore M, Eba P, Dolan K, Lines R, Beyrer C, 2016. HIV, prisoners, and human rights. *Lancet 388:* 1202–1214.
3. Biadglegne F, Rodloff AC, Sack U, 2015. Reviews of the prevalence and drug resistance of tuberculosis in prisons: a hidden epidemic. *Epidemiol Infect 143:* 887–900.
4. Stop TB Partnership, 2016. *Key Populations Brief: Prisoners*. Available at: http://www.stoptb.org/assets/documents/resources/publications/acsm/KP_Prisoners_Spreads.pdf. Accessed May 20, 2018.
5. Stop TB Partnership, 2015. *Global Plan to End TB: The Paradigm Shift 2016–2020*. Available at: http://www.stoptb.org/assets/documents/global/plan/GlobalPlanToEndTB_TheParadigmShift_2016-2020_StopTBPartnership.pdf. Accessed May 20, 2018.
6. Stott KE, de Oliviera T, Lessells RJ, 2013. Combined antiretroviral and anti-tuberculosis drug resistance following incarceration. *South Afr J HIV Med 14:* 135–137.

7. O'Grady J, Mwaba P, Bates M, Kapata N, Zumla A, 2011. Tuberculosis in prisons in sub-Saharan Africa—a potential time bomb. *S Afr Med J 101:* 107–108.
8. Sacchi FP, Praca RM, Tatara MB, Simonsen V, Ferrazoli L, Croda MG, Suffys PN, Ko AI, Andrews JR, Croda J, 2015. Prisons as reservoir for community transmission of tuberculosis, Brazil. *Emerg Infect Dis 21:* 452–455.
9. Barniol J, Niemann S, Louis VR, Brodhun B, Dreweck C, Richter E, Becher H, Haas W, Junghanss T, 2009. Transmission dynamics of pulmonary tuberculosis between autochthonous and immigrant sub-populations. *BMC Infect Dis 9:* 197.
10. Haas WH, Engelmann G, Amthor B, Shyamba S, Mugala F, Felten M, Rabbow M, Leichsenring M, Oosthuizen OJ, Bremer HJ, 1999. Transmission dynamics of tuberculosis in a high-incidence country: prospective analysis by PCR DNA fingerprinting. *J Clin Microbiol 37:* 3975–3979.
11. Viana M, Mancy R, Biek R, Cleaveland S, Cross PC, Lloyd-Smith JO, Haydon DT, 2014. Assembling evidence for identifying reservoirs of infection. *Trends Ecol Evol 29:* 270–279.
12. WHO, 2016. *Global Tuberculosis Report 2016*. Geneva, Switzerland: World Health Organization. Available at: http://apps.who.int/iris/bitstream/10665/250441/1/9789241565394-eng.pdf?ua=1. Accessed May 20, 2018.
13. Mukinda FK, Mahomed H, 2014. A systematic review of the epidemiology of and programmatic response to tuberculosis in inmates and the correctional services in South Africa. *Evidence to Inform South African Tuberculosis Policies (EVISTAT) Project*. Tygerberg, South Africa: Stellenbosch University.
14. Reid SE et al., 2012. Tuberculosis and HIV control in sub-Saharan African prisons: "thinking outside the prison cell." *J Infect Dis 205 (Suppl 2):* S265–S273.
15. World Prison Brief data, Institute for Criminal Policy Research, Birbeck, University of London, 2017. Available at: http://www.prisonstudies.org/country/south-africa. Accessed May 20, 2018. Accessed October 11, 2018.
16. Johnstone-Robertson S, Lawn SD, Welte A, Bekker L, Wood R, 2011. Tuberculosis in a South African prison—a transmission modeling analysis. *South Afr Med J 101:* 806–813.
17. Telisinghe L, Fielding KL, Malden JL, Hanifa Y, Churchyard GJ, Grant AD, Charalambous S, 2014. High tuberculosis prevalence in a South African prison: the need for routine tuberculosis screening. *PLoS One 9:* e87262.
18. Deb P, Norton EC, Manning WG, 2017. *Health Econometrics Using Stata*. College Station, TX: Stata Press.
19. Statistics South Africa, 2012. *Census 2011 Metadata*. Pretoria, South Africa: Statistics South Africa.
20. Massyn N, 2013. *District Health Barometer 2011/12*. Durban, South Africa: Health Systems Trust.
21. Statistics South Africa, 2012. *South African Statistics, 2011*. Pretoria, South Africa: Statistics South Africa.
22. Lopez L, Weber S, 2017. *Testing for Granger Causality in Panel Data*. IRENE Institute of Economic Research Working Paper: 17-03. Neuchatel, Switzerland: University of Neuchatel.