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Mass Incarceration can explain increases in Tuberculosis and Multi-Drug Resistant Tuberculosis in populations of Post-Communist European Countries

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Abstract

Several micro-level studies have pinpointed prisons as an important site for tuberculosis and multi-drug resistant tuberculosis in Eastern European and former Soviet countries. To date, no comparative analyses have examined whether rises in incarceration rates can account for puzzling cross-country differences in overall tuberculosis trends. Using longitudinal tuberculosis and cross-sectional multi-drug resistant tuberculosis data for 26 Post-Communist Eastern European and former Soviet countries, we examined whether and to what degree increases in incarceration account for differences in population tuberculosis and multi-drug resistant tuberculosis burdens. We find that each percentage point increase in incarceration rates relates to an increased tuberculosis incidence of 0.34% (PAR, 95% CI: 0.10% to 0.58%, $p<0.01$), after controlling for tuberculosis infrastructure, HIV prevalence, and several surveillance, economic, demographic, and political indicators. Net increases in incarceration account for a 20.5% increase in tuberculosis incidence, or nearly three-fifths of the average total increase in tuberculosis incidence in Post-Communist countries from 1991 to 2002. While the number of prisoners is a significant determinant of differences in tuberculosis incidence and multi-drug resistant tuberculosis prevalence between countries, the rate of prison growth is a larger determinant of these outcomes, and its effect is exacerbated but not confounded by HIV. Differences in incarceration rates are a major determinant of differences in population tuberculosis outcomes among Post-Communist countries, and treatment expansion alone does not appear to resolve the effect of mass incarceration on tuberculosis incidence.

Introduction

Rates of tuberculosis and its multi-drug resistant phenotype (MDR) have increased markedly in Eastern European and former Soviet Union countries (1-4). Tuberculosis incidence has risen from 45.2 per 100,000 in 1990 to 58.2 per 100,000 population in 2005 (5). In parallel, reported MDR TB, defined as a resistance to both rifampicin and isoniazid, has increased substantially, even allowing for improved surveillance, and now accounts for roughly 25% of all treated cases in post-communist European countries (6).

These aggregate figures obscure considerable geographical variations. Several Central & Eastern European countries (CEE), such as Poland and Slovakia, experienced declines of over 50% in both incidence and mortality while in Russia these measures more than doubled from historic lows in 1991 to the highest rates in Europe at 119 per 100,000 and 22 per 100,000, respectively, in 2005. The extent to which national fortunes have differed can be seen in Table 1, which contrasts the trajectory of the five best and five worst performing countries, as assessed by their change in incidence and mortality relative to 1991. Both groups of countries began from similar starting points. One explanation for this recent divergence is heterogeneity in access to directly-observed treatment short-course (DOTS) and treatment adherence and quality (treatment success rates). However, Table 1 also shows that these factors alone cannot account for the observed differences in population tuberculosis trends (7).

Relationship between Incarceration and Tuberculosis Spread

Prisons have been identified as a critical social vector for the transmission of tuberculosis and selection of MDR strains, primarily due to three aspects of the prison environment:

1) *Higher Effective Contact Rate:* proximity of large numbers of individuals (8) in poorly ventilated facilities for extended periods (9),
2) *Decreased Cure Rate*: delayed diagnosis, difficulties identifying and isolating inmates for treatment (10), "perverse" incentives among inmates to falsely start or prolong treatment (such as being excused work, receiving better treatment, or profiting from sale of drugs) (9, 11, 12), and release to community before completion of treatment with interrupted follow-up thereafter (13); and,
3) *Greater Population Susceptibility*: including risk factors such as poverty(9), substance abuse (3, 14), previous unhealthy lifestyles(9), inadequate nutrition (11), and HIV infection (15).

Recent surveys of prisons in the WHO's European region found that prisoners have 84-times higher tuberculosis prevalence than civilians (16) and that the frequency of infections that are MDR also tend to be significantly higher than in the general population (9, 17).

Tuberculosis transmitted in prisons also poses risks to outside communities: prisoners may infect healthcare workers, prison guards, their spouses and children. There is often a failure to follow up infected prisoners following their release (11, 18). Prison outbreaks have been linked directly to increased community tuberculosis incidence (19), and there is some empirical evidence that history of incarceration increases the risk that an infected individual will develop MDR (11). Thus, it is plausible to hypothesize that imprisonment could be a driver of tuberculosis epidemics (3).

Mass Incarceration in Eastern Europe and the Former Soviet Union

Incarceration rates in transition countries currently rank among the highest in the world. In Russia, 670 per 100,000 population, or nearly 1% of the population, is currently in prison, making it second only to the United States, which imprisons 702 per 100,000 population (9). In the former Soviet Union, crime-sentencing rates rose by 75% from 1991 to 2002, which is three times faster than in CEE. This unprecedented rise in sentencing, and the associated growth in the number of prisoners, has been so alarming that criminologists have described these social changes as a "criminological transition."(20) Figure 2 displays the direct log relationship between average tuberculosis incidence and incarceration rates for post-communist countries. Table 1 also shows a closer association between tuberculosis-incidence and -mortality and incarceration rates, compared with measures of treatment quantity and quality. Among the "worst five performers", a 2.5-fold increase in tuberculosis incidence from 1991 to 2001 corresponds to a roughly equivalent increase in incarceration rates, while the best performing countries have seen a fall in incarceration rates, albeit less than the decline in tuberculosis.

In this article, we empirically evaluate whether "mass incarceration", defined as the rapid growth of the prison population, can in part account for the divergence in tuberculosis incidence and MDR tuberculosis prevalence among transition countries, using longitudinal data from 1991 to 2002. While several micro-level studies have pinpointed prisons as an important reservoir for tuberculosis and MDR tuberculosis in transition countries (1, 21-23), to date no comparative analyses have examined this hypothesis at a macro-level or between countries. At a population level, tuberculosis incidence and transmission can occur 1) within the general population, 2) from the general population to the prison population, 3) within the prison population and 4) from the prison population to the general population. Does the rise in incarceration rates, which increase the prominence of the population-to-prison, intra-prison and prison-to-population tuberculosis pathways, play a significant role in determining a population's overall tuberculosis burden? Such a hypothesis linking mass incarceration to population tuberculosis rises can only be tested at the population level, and the post-communist countries provide a unique setting for this experiment, which the rest of our study aims to accomplish.

Longitudinal Tuberculosis Results

Table 2 presents the results of the cross-national model from 1991 to 2002. Each percentage increase in the sentencing rate is associated with a 0.34% increase in tuberculosis incidence (all forms of tuberculosis; 95% CI: 0.10% to 0.58%, $p<0.01$). The average increase in the number of persons sentenced for the average country during this period jumped from 282 per 100,000 to 452 per 100,000, a 60% increase. Based on our model, the net effect of this rise was a 20.5% increase in tuberculosis incidence. Given that the overall percentage rise in tuberculosis for the average country was 35.5% during this period, incarceration can thereby on average account for nearly three-fifths of the entire tuberculosis rise observed during this period, after controlling for other reasonable explanatory variables, including a broad set of economic, policy and demographic measures.

Several of the main control variables have important effects. The coefficient on Log Gross Domestic Product per capita is -0.38, which means that a one percent increase in GDP levels corresponds to a 0.38% reduction in tuberculosis incidence. This sizable protective effect reinforces the notion that economic development is a powerful determinant of health, complementing growing evidence that better health contributes to economic development in this region (24). Thus, the precipitous decline in GDP per capita in most countries of this region following the market liberalization (25) seems likely to have exacerbated the tuberculosis crisis.

The Freedom House democratization index had no effect on tuberculosis rates in the countries studied. Military conflict had the effect of decreasing tuberculosis incidence by 22% in Model 1; however, since war has been noted to compromise health surveillance systems (26), a decline might have been expected as an artifact of reduced reporting, and other empirical studies have found similar results in this context (27). Urbanization, conversely, had a protective effect: each percentage increase in the proportion of the population living in urban settings corresponded to a 10.4% reduction in tuberculosis incidence. Surprisingly, urbanization is unrelated to DOTS population coverage (Pearson R = 0.05), and negatively correlated with DOTS treatment success (Pearson R = -0.34). Thus, the positive effect of urbanization is most likely due to its positive correlation with aspects of general social and economic development missed by GDP.

Modeling using country fixed effects is effectively the same as evaluating the effect of changes in incarceration rates, and not their overall levels, in each country over time. An alternative way to examine the data is to model only the variation between-countries' average levels. Using this approach, the coefficient on log incarceration rates becomes 0.73 and is again significant at $p<0.01$. The interpretation is a little more challenging than the fixed effects models; each 10% that a country deviates from the average incarceration rate among the sampled countries (407 per 100,000 population) accounts for a 7.30% difference in tuberculosis incidence rates in the same direction. Returning to the comparison of the "best and worst performing" tuberculosis countries (Table 1), and taking the average incarceration rate values for these two groups over the sample period (worst five performers: 498 per 100,000 per year; best five performers: 450 per 100,000 per year), gives rise to a 11.8% difference in terms of a 10% deviation from the sample mean. Thus, differences in incarceration levels are able to explain only 8.61% of the difference in tuberculosis incidence rates between best and worst countries. This is less than one-fifth of the magnitude of the differential tuberculosis incidence explained by relative increases in incarceration between the two groups. The epidemiological implication is that rapid growth in prison populations is a more critical driver of tuberculosis incidence than their overall size. This finding probably reflects the tuberculosis risks associated with overcrowding caused by rapid prison growth.

A potential criticism of the basic finding is that, given the effect of HIV on the epidemiology of tuberculosis, and the high prevalence of HIV among prisoners(15) and in particular among injecting drug users, our results are not due to incarceration per se, but rather confounded by rising HIV-IDU levels. In Model 2, we add the log of the number of HIV cases reported. HIV enters as a significant predictor of tuberculosis incidence; for every one percentage point increase in reported HIV cases, tuberculosis increases by 0.09%. The results for sentencing rates' effect on tuberculosis incidence are attenuated ($\beta = 0.27$), but remain robust. This suggests that HIV-IDU may account for an important part of the adverse effects of incarceration on tuberculosis, but not all of it.

One further possibility is that poverty rates may relate to both incarceration and tuberculosis, and as a result have confounded the observed relationship between incarceration and tuberculosis. We explored this possibility using a range of variables that capture poverty levels from the World Bank's World Development Indicators. In fact, we found that incarceration rates were negatively associated with all of the variables examined. For example, the percentage of the population living under US $1 ($R = -0.09$, $p=0.41$) and US$2 ($R =-0.21$, $p=0.06$). To the extent that these poverty measures were significantly correlated with log tuberculosis incidence, prevalence or mortality rates (US $1per day, $R =0.39$, $p<0.01$; US $2 per day, $R = 0.47$, $p<0.01$), not adjusting for poverty would render our results conservative. When we included these variables in our models, the coefficient on sentencing rates adjusted for poverty rates was slightly increased (fixed effects: $\beta=0.30$, $p<0.05$; pooled cross-sectional: 0.52, $p<0.001$) as compared to using the same sample without poverty rates, although because of missing poverty data the confidence intervals widened. The poverty measures were not significantly associated with tuberculosis outcomes once the other controls were taken into account.We also analyzed the role of expanding DOTS coverage and improving DOTS success rates, although there are high levels of missing data in these as provided by the WHO. The effect of both factors was not significant in regressions explaining tuberculosis incidence, although DOTS coverage was associated with lower log tuberculosis incidence. Pearson correlation coefficients were $r = -0.15$, $p=0.07$ for treatment success and $r = -0.31$, $p<0.01$ for population coverage. However, the sample size for the analysis falls to n=123 and n=89, respectively, when including these two factors, suggesting that further data could be collected to analyze the role of these variables. Supporting Information Tables 4-14 present a broad set of robustness checks used in the course of our analysis, including a variety of model diagnostics and outlier tests, incremental inclusion of our controls as well as corrections for additional socio-economic, health system, and demographic variables, and estimation using alternative functional forms. All of our results were consistent with our basic finding.

Cross-Sectional MDR TB Results

Comparative longitudinal data are unavailable for MDR TB. Thus the MDR tuberculosis analysis is cross-sectional, using the most recent data for each country.

Since the sample size for the MDR TB analysis is inherently smaller than that for tuberculosis incidence analysis, natural logarithms of registered crime rates were used as an indicator of imprisonment to maximize the effective sample size. While committing a crime does not imply sentencing, in our data a little over one-third of reported crimes were associated with a criminal sentence and the correlation between crime rates and sentencing was strong (Pearson $R=0.70$). Our results were replicated using sentencing rates, only the confidence intervals, as expected, were wider albeit still significant (See Supporting Information Tables 14-16). Controls were used to adjust for how the MDR

TB data was collected, the year of data collection, and whether the data are representative of the entire country; results from these analyses did not qualitatively change.

Table 3 shows the results of logistic regression models of MDR TB prevalence for untreated and treated cases of incident tuberculosis in 24 transition countries. Log registered crime rates have a significant effect on MDR prevalence among untreated tuberculosis cases (OR = 6.93, 95% CI: 1.96 to 24.44) but not for the treated tuberculosis cases. The large confidence intervals reflect high levels of uncertainty associated with the small sample size. The results are consistent with the possibility that imprisonment plays an important role in incubating MDR-TB, which subsequently spreads into the community, but that secondary resistance is primarily due to individual treatment failure.

GDP per capita had a strongly protective effect for untreated cases (OR = 0.04, 95% CI: 0.01 to 0.21) and a strong but smaller effect on treated cases (OR = 0.13, 95% CI: 0.03 to 0.57). Again, these findings indicate that the economic depression in transition countries played a role in perpetuating drug-resistant strains of tuberculosis, although the exact mechanisms are unclear. Together, the two variables, crime rates and GDP per capita, explain 53% of the between-country variation in MDR tuberculosis levels for untreated cases.

Discussion

Our results show that differences in incarceration rates among countries are strongly associated with key differences in the incidence of tuberculosis and the prevalence of its multi-drug resistant phenotype. By using within- and between-country variation, we identify that the rate of growth of the prison population, more than the overall size of the prison population, critically relates to variations in tuberculosis incidence. We also find that higher HIV prevalence exacerbates the effect of incarceration on tuberculosis incidence, strengthening the argument for a co-ordinated approach to these two diseases (28).

Despite the robustness of our findings to a broad set of social and healthcare system variables, there are several important limitations to our analysis. First, as with all cross-country analyses, the potential exists for ecological fallacies. However, as we note above, the observed associations are biologically plausible, given the numerous mechanisms by which incarceration may increase tuberculosis incidence (3, 17, 23). In future research it would be desirable to complement our ecological analyses with individual data, ideally following cohorts over time. Unfortunately, such data do not exist in any of the countries we have studied. In particular, this would allow us to examine the impact of duration of incarceration and of repeated incarceration. However, on the basis of evidence from other settings, these may have limited additional explanatory power as most people who will be infected are infected during the brief initial period of occupancy in enclosed spaces (29-32).

Second, our measure of incarceration relies upon the ability of crime-sentencing rates to capture imprisonment. Since the probability of custodial sentencing varies between countries, we use a set of dummies to control for national legislation and policies which shape how closely our proxy maps onto incarceration. Any remaining differences would register as non-differential measurement error and have the effect of diluting our results. Third, although we control for differences in surveillance between countries, there is potential for bias arising from time-varying surveillance changes within countries. It is, however, unlikely that the temporal variation in surveillance can account for the relationship between incarceration and tuberculosis net of our control variables, and the direction of the potential bias is unclear. Finally, due to high levels of tuberculosis underreporting in prisons, our findings may not adequately reflect the prominence of transmission of tuberculosis within prisons, which would understate the population-level relationship between incarceration and tuberculosis incidence and thus renders our estimates conservative.

Of the four major population tuberculosis pathways: intra-population transmission, population-to-prison transmission, intra-prison transmission, and prison-to-population transmission, our study finds that the latter three mechanisms, as measured by incarceration rates, have played a prominent role in driving overall population-level differences in tuberculosis incidence, prevalence and mortality rates. In our models prevailing population explanations, such as GDP per capita and DOTS coverage and success rates were not found to account for the observed population trends as well as did mass incarceration. These results echo findings by the WHO in 2008 that GDP per capita and DOTS are important, but incomplete, population explanations of tuberculosis rises (7).

Given that multiple circulating strains may exist in this environment (33), and strain heterogeneity can lead to increased incidence as a result of limited cross-strain immunity further amplified by the increasingly observed clonal spread of virulent M. TB subtypes (34, 35), our model produces conservative predictions about the potential amplification of TB that can occur as a result of imprisonment. MDR TB is also underdiagnosed in this region, and higher actual MDR TB rates would act on population

TB dynamics to i) increase TB mortality rates by reducing the effectiveness of treatment; ii) increase TB spread, because effective risk will be higher as a result of prolonged infectiousness and less effective treatment. This would produce a positive interaction with incarceration for increasing population-level tuberculosis rates. Characterizing the relationships between MDR TB and TB spread remains an important step for future research.

A reduction in incarceration rates is desirable for many reasons, especially in settings where prison conditions are often extremely harsh (36). This study provides a further rationale for reform, indicating that a reduction in custodial sentencing would impact favorably on the risk to the general population from tuberculosis and MDR-TB.

Periods of excessive growth of prison populations necessitate particular emphasis on controlling tuberculosis transmission. The positive news for former Soviet countries is that the growth in prison populations has slowed, and prisons are now beginning to shrink in size (Table 1). Our results offer a partial explanation of the turnaround in tuberculosis witnessed in high prevalence regions around the turn of the century that cannot be explained by DOTS, health infrastructure, poverty rates or GDP per capita alone. Nonetheless, the results also highlight the need to integrate better tuberculosis control efforts with institutions that manage prisons. Several micro-level studies have examined the effect of specific programs on the incidence of tuberculosis and MDR TB in prisons (14), but the macro-level effects of such practices, and of alternatives to incarceration, should be a subject of public health research and action.

Data and Methods

We use four sets of health data, all of which are from the World Health Organization. Tuberculosis incidence, prevalence, mortality and DOTS population coverage and treatment success data are from the WHO Global Tuberculosis Database(5); MDR TB data are from the Euro Tuberculosis Report 2007 (6); HIV case data are from the WHO/UNAIDS Global HIV database (37). Crime and sentencing rate measures are from the UNICEF TransMONEE database (38), and control variables are from the WHO European Health For All Database 2007 edition and World Bank World Development Indicators 2005 edition (26).

To our knowledge there are no direct and comparable measures of the incidence of imprisonment over time and across countries. Thus we use the rate of sentencing per 100,000 total population as an indicator of incarceration, recognizing that not all sentences will result in imprisonment. This can, however, be justified as community penalties, which do not involve custodial sentencing, such as probation or parole, have been slow to develop throughout this region (39). We cope with data monitoring and quality issues in two ways. First we use a set of dummy variables for each country, which holds time-varying effects, such as the strength of national surveillance systems or differences in national sentencing legislation, constant within nations. These variables also correct for factors that differ across countries but remain relatively fixed over time, such as past membership of the Soviet Union or proximity to Western Europe, the probability of custodial sentencing, as well as historical levels of tuberculosis (40). By using country-specific slopes, our conservative modeling approach isolates how changes within individual countries impact their own tuberculosis incidence profiles, which renders the data suitable to answer our research question.

We also considered the impacts of possible changes in detection and reporting biases over time. Such biases could skew our results only if they related to both the tuberculosis incidence data and the sentencing data in a consistent way. For example, if higher incarceration rates were associated with improved tuberculosis surveillance, then we might artifactually observe a relationship between incarceration and tuberculosis. However, the evidence from central and eastern European and former Soviet countries has established the opposite: tuberculosis reporting is known to be highly underreported in prison settings (41, 42), which means that any tuberculosis detection bias that may be associated with incarceration runs counter to our hypothesis. Similarly, if prison policies altered the reporting of sentencing over time or diagnostic systems improved tuberculosis surveillance, our results could potentially be biased, although the direction of such bias is unclear. If this were the case, we would observe a structural break in the sentencing data; yet, in our dataset we find no evidence of such breaks. Taken together, the data appear sufficiently internally valid and reliable to permit our modeling approach.

We also control for GDP per capita as a measure of overall economic development; democratization, which has been theorized to exert positive effects on health (43) and captures political change; the occurrence of military or ethnic conflict, which has been shown to adversely impact disease surveillance (26) as well as infectious disease control (44); urbanization, which may facilitate the transmission of tuberculosis but also provide access to better healthcare services as well as proxy for overall social development; population dependency ratios, which reflects the stage of demographic transition and population age-structure; and population education levels, which captures the stock of human capital.

Thus, we specify the following log-log regression model:

$$Log\ Tuberculosis_{it} = \alpha + \beta_1 PRI_{it} + \beta_2 GDP_{it} + \beta_3 DEM_{it} + \beta_4 WAR_{it} + \beta_5 URBAN_{it} + \beta_6 DEP_{it} + \beta_7 EDUC_{it} + \mu_i + \varepsilon_{it}$$

Here i is country and t is year. PRI is the measure of mass incarceration, logged to adjust for positive skew; GDP is logged per capita GDP in constant US$ 2000; DEM is a widely used index of democratization from the Freedom House political indicators which combines measures of civil liberties and political freedoms (25); WAR is a dummy variable for whether a country experienced military or ethnic conflict; URBAN is the percentage of population living in urban settings; EDUC is the percentage of the population with tertiary education; and μ is a set of dummy variables which control for country-specific effects. Supporting Information Table 1 further describes all of the variables and presents summary statistics.

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Tables and Figures

Table 1. Best and Worst Tuberculosis Performers in Postcommunist Countries, 1991 to 2005

Transition Country	**Indicator**	**Year**			
		1991	1996	2001	2005
Best Performers *Slovakia, Slovenia, Macedonia, Croatia, Poland*	Tuberculosis Incidence (per 100,000 population)	52.0	45.8	31.6	25.8
	Tuberculosis Mortality (per 100,000 population)	8.6	7.4	4.8	4.0
	DOTS Population coverage (%)	0.0	40.0	52.2	85.0
	DOTS Treatment success (%)	0.0	80.0	83.5	85.3*
	Incarceration Rates (per 100,000 population)	539.3	471.8	433.6	459.8**
Worst Performers *Russia, Moldova, Estonia, Uzbekistan, Latvia*	Tuberculosis Incidence (per 100,000)	42.8	77.6	100.4	92.4
	Tuberculosis Mortality (per 100,000)	6.6	11.8	15.6	13.6
	DOTS Population coverage (%)	0.0	20.4	49.6	82.4
	DOTS Treatment success rates (%)	0.0	63.0	67.5	66.3*
	Incarceration Rates (per 100,000 population)	277.9	523.1	742.3	647.2**

Note: * - latest available data are from 2004; ** - latest available data are from 2002. Best and worst performing countries are based upon greatest and lowest proportional changes in tuberculosis incidence and are limited by the availability of data. Tuberculosis and DOTS data are from the World Health Organization Global Tuberculosis Database 2007. Incarceration rates are from the UNICEF TransMONEE Database 2005. Missing values for DOTS population coverage and treatment success in 1991 were coded as zero. All data are further described in Web Appendix 1.

Table 2. Impact of Incarceration on Log Tuberculosis Incidence Rates in Transition Countries, 1991-2002

Covariates	Model 1	Model 2
Log Incarceration Rate	0.34** (0.12)	0.27* (0.10)
Log GDP per capita	-0.38** (0.11)	-0.28** (0.09)
Heritage Foundation Democracy Index	0.00 (0.03)	0.00 (0.01)
Military Conflict	-0.22* (0.08)	-0.05 (0.08)
Percentage of Population Urban	-0.10* (0.04)	-0.09** (0.02)
Population Dependency Ratio	-0.04** (0.01)	0.00 (0.01)
Percentage of Population with Tertiary Education	-0.00 (0.00)	-0.00 (0.00)
Log HIV cases	–	0.09** (0.01)
Number of Country-Years	211	193
Number of Countries	19	18
R^2	0.88	0.91

Note: Constant estimated but not reported; Robust standard errors clustered by country to reflect non-independence of sampling and robustness to heteroskedasticity and serial correlation in parentheses. Models include dummy variables for each country. Tuberculosis data are from the World Health Organization Global Tuberculosis Database 2007. Incarceration data are from the UNICEF TransMONEE Database 2005 edition. Data are further described in Web Appendix 1. Estimation sample includes Armenia, Azerbaijan, Belarus, Bulgaria, Croatia, Czech Republic, Estonia, Georgia, Hungary Latvia, Lithuania, Macedonia, Moldova, Poland, Romania, Russia, Slovakia, Slovenia, and Uzbekistan. When including HIV prevalence in Model 2, Uzbekistan drops out of the model because UNAIDS/WHO data are not available. Web appendices 2a and 2b present tuberculosis and sentencing rate data. Web appendix 4 presents mini-plot-pairs for each country. Web appendices 5-7 presents a series of sample, specification and functional form robustness checks.

* = p<0.05, ** = p<0.01 (two-tailed tests).

Table 3. Impact of Economic Growth and Incarceration Rates on Drug-Resistant Tuberculosis in Transition Countries

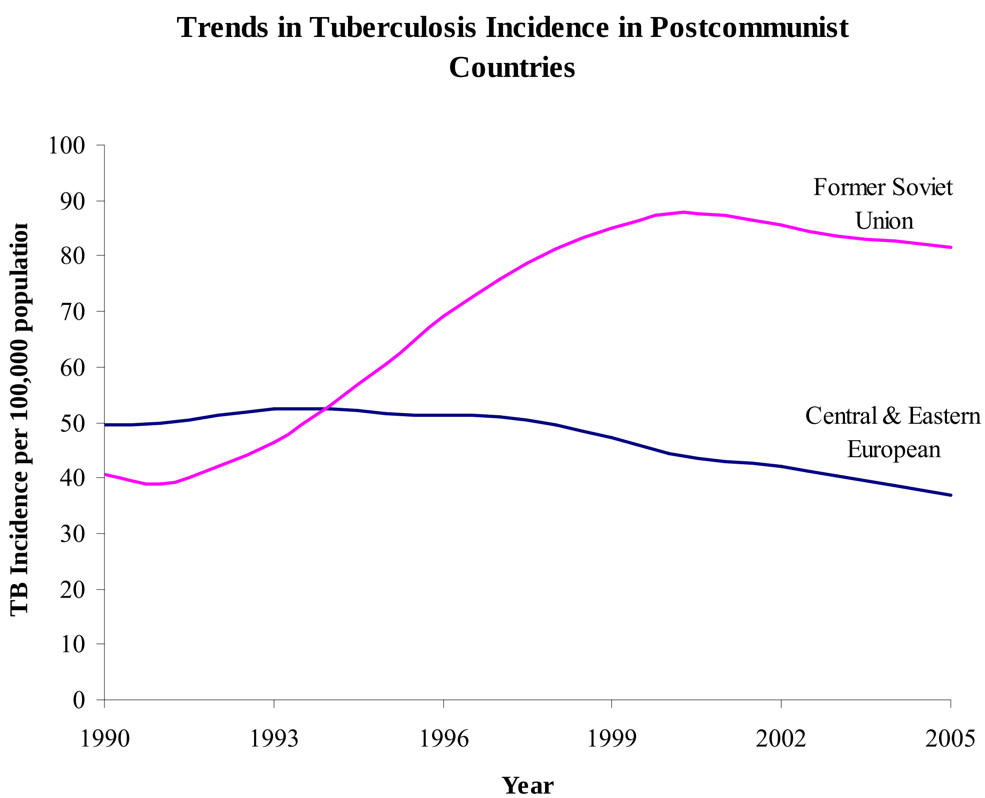
Covariates	Cases Untreated		Cases Treated	
	Odds Ratio	P-value (two-tailed)	Odds Ratio	P-value (two-tailed)
Log GDP per Capita	0.04 (0.01 to 0.21)	<0.01	0.13 (0.03 to 0.57)	<0.01
Log Incarceration Rates	6.93 (1.96 to 24.44)	<0.01	2.91 (0.92 to 9.19)	0.16
Number of Countries	24		24	
R^2	0.53		0.25	

Note: Logistic regression models also control for whether the MDR data is representative of the entire country and the year of MDR data survey. R^2 value presented is based on a linear regression model using only the two main covariates; 95% CI in parentheses. Models are also robust to the effect of urbanization, population education levels, population dependency ratios, and membership in the Former Soviet Union. MDR-Tuberculosis data are the most recently available data taken from EURO TB 2007 report. Incarceration rates are from the UNICEF TransMONEE 2005 database using registered crime rates, although results are consistent when using log sentencing rates. Countries included in the sample are Armenia, Azerbaijan, Belarus, Bulgaria, Croatia, Czech Republic, Estonia, Georgia, Hungary, Kazakhstan, Kyrgyzstan, Latvia, Lithuania, Macedonia, Moldova, Poland, Romania, Russia, Slovakia, Slovenia, Tajikistan, Turkmenistan, Ukraine, Uzbekistan. Web Appendices 14-16 describe all data, present linear regression models and provide additional robustness tests.

Figure 1. Source: World Health Organization Global Tuberculosis Database 2007. Former Soviet Union (FSU) countries include Armenia, Azerbaijan, Belarus, Estonia, Georgia, Kazakhstan, Kyrgyzstan, Latvia, Lithuania, Moldova, Russia, Turkmenistan, Ukraine, Uzbekistan; Central & Eastern European, or non-FSU, countries include Albania, Bosnia, Bulgaria, Croatia, Czech Republic, Hungary, Macedonia, Poland, Romania, Slovakia and Slovenia

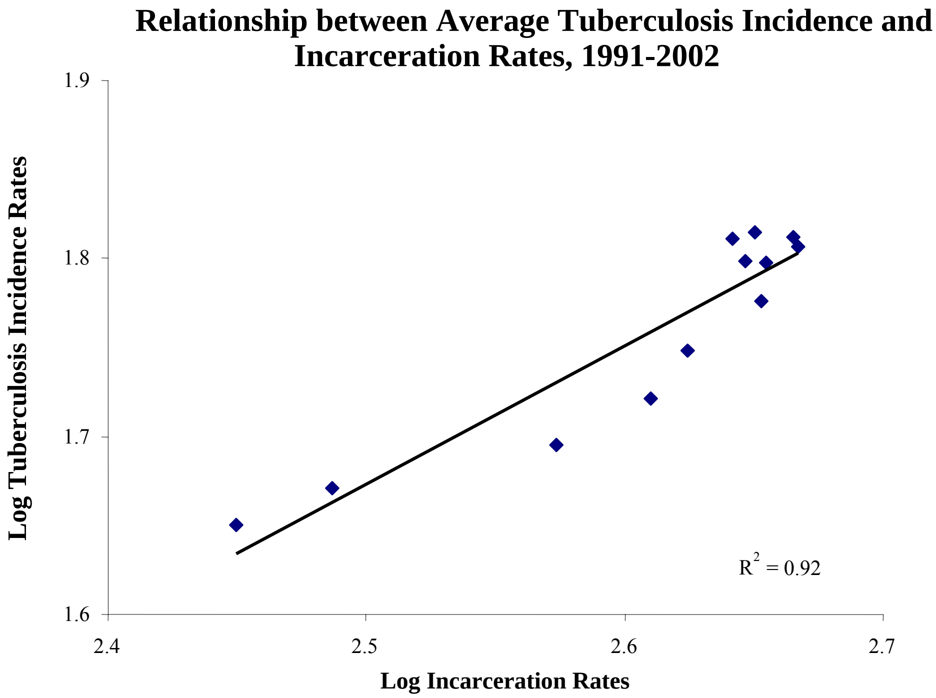
Figure 2. Source: Tuberculosis incidence data are from the World Health Organization Global Tuberculosis Database 2007. Incarceration rates are assessed using sentencing data from UNICEF TransMonee Database 2005 edition.

Figure 1. Trends in Tuberculosis Incidence in Postcommunist Countries, 1990 to 2005



Source: World Health Organization Global Tuberculosis Database 2007. Former Soviet Union (FSU) countries include Armenia, Azerbaijan, Belarus, Estonia, Georgia, Kazakhstan, Kyrgyzstan, Latvia, Lithuania, Moldova, Russia, Turkmenistan, Ukraine, Uzbekistan; Central & Eastern European, or non-FSU, countries include Albania, Bosnia, Bulgaria, Croatia, Czech Republic, Hungary, Macedonia, Poland, Romania, Slovakia and Slovenia

Figure 2. Relationship between Average Tuberculosis Incidence and Incarceration Rates, 1991-2002



Source: Tuberculosis incidence data are from the World Health Organization Global Tuberculosis Database 2007. Incarceration rates are assessed using sentencing data from UNICEF TransMonee Database 2005 edition.

Supporting Information

Supporting Information Table of Contents

Supporting Information 16. MDR TB Dataset

Supporting Information 17. Comparison of Sentencing Rate Data to Available Incarceration Rate Data, Selected Countries

Supporting Information 1. Variable definitions and summary statistics

Variable	Definition	Obs	Mean	Std. Dev.	Min	Max	Source
Log Tuberculosis Incidence Rates	Logarithm of all forms of Tuberculosis Incidence Rates per 100000	336	1.70	0.23	1.00	2.16	World Health Organization Global Tuberculosis Database 2007
Log Tuberculosis Prevalence Rates	Logarithm of all forms of Tuberculosis Prevalence Rates per 100000	336	4.24	0.59	2.40	5.36	World Health Organization Global Tuberculosis Database 2007
Log Tuberculosis Mortality Rates	Logarithm of all forms of Tuberculosis Mortality Rates per 100000	336	1.99	0.59	0.00	3.14	World Health Organization Global Tuberculosis Database 2007
HIV Cases	Reported HIV cases in current year	310	1001.59	7114.92	0.00	88253.00	WHO/UNAIDS Global HIV/AIDS Database
AIDS Cases	Reported AIDS cases in current year	311	45.14	163.84	0.00	1772.00	WHO/UNAIDS Global HIV/AIDS Database
Log HIV Cases	Logarithm of new reported HIV cases in current year	267	3.52	2.19	0.00	11.39	WHO/UNAIDS Global HIV/AIDS Database
Log HIV Prevalence	Logarithm of reported HIV cases divided by population size	241	-7.38	1.65	-11.22	-2.23	UNICEF Transmonee Monitoring Eastern Europe Database 2005 Edition
Log AIDS Cases	Logarithm of reported AIDS cases in current year	257	2.21	1.60	0.00	7.48	WHO/UNAIDS Global HIV/AIDS Database
DOTS Treatment Success	Percentage of DOTS treatment successful	143	75.67	12.57	0.00	98.00	World Health Organization Global Tuberculosis Database
DOTS Population Coverage	Percentage of population covered by DOTS programs; missing data for DOTS programs were coded as 0.	215	53.63	44.65	0.00	100.00	World Health Organization Global Tuberculosis Database
Education	Percentage of population with tertiary education	313	23.38	12.05	2.60	69.30	World Bank World Development Indicators 2005 Edition
Democratization	Inverted sum of civil liberties (originally 1-highest, 7-lowest) and political freedoms indices (originally 1-highest, 7-lowest), for a scale from 2-lowest to 14-highest.	340	8.74	3.48	2.00	14.00	Freedom House Indicators
Log per capita GDP	Logarithm of gross domestic product per capita in constant US$ 2000	340	3.16	0.42	2.18	4.13	World Bank World Development Indicators 2005 Edition

Military Conflict	Binary indicator for occurrence of an ethnic or military conflict	340	0.07	0.25	0.00	1.00	World Bank World Development Indicators 2005
Dependency Ratio	Population dependency ratio (Youth + Elderly/Total Population), in percent	340	53.41	10.50	39.01	88.33	World Bank World Development Indicators 2005 Edition
Urbanization Rate	Percentage of Population living in urban settings	340	56.63	12.46	24.82	75.20	World Bank World Development Indicators 2005 Edition
Sentencing Rate	Total number of sentences per 100,000 population	263	407.26	201.12	61.00	981.70	UNICEF Transmonee Monitoring Eastern Europe Database 2005 Edition
Log Sentencing Rate	Logarithm of previous variable	263	5.86	0.58	4.11	6.89	UNICEF Transmonee Monitoring Eastern Europe Database 2005 Edition
Registered Crime Rate	Total number of registered crimes per 100,000 population	305	1497.60	1177.43	139.20	5850.30	UNICEF Transmonee Monitoring Eastern Europe Database 2005 Edition
Log Crime Rate	Logarithm of previous variable	305	6.95	0.93	4.94	8.67	UNICEF Transmonee Monitoring Eastern Europe Database 2005 Edition
Poverty Rate, $1 per day	Percentage of the population living under US $1 per day	96	4.54	5.60	2.00	32.24	World Bank World Development Indicators 2005 Edition
Poverty Rate, $2 per day	Percentage of the population living under US $2 per day	96	17.23	17.51	2.00	74.30	World Bank World Development Indicators 2005 Edition
Cases Treated	Percentage of cases of incident previously treated tuberculosis with MDR	25	24.59	18.40	3.60	63.20	WHO EURO TB 2007 Report
Cases Untreated	Percentage of cases of incident previously treated tuberculosis with MDR	27	6.03	5.98	0.00	20.20	WHO EURO TB 2007 Report

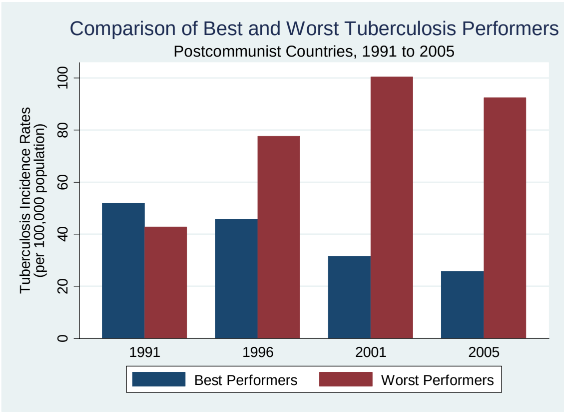
Supporting Information 2a. Full Panel Descriptives of Incarceration Rates per 100,000 population

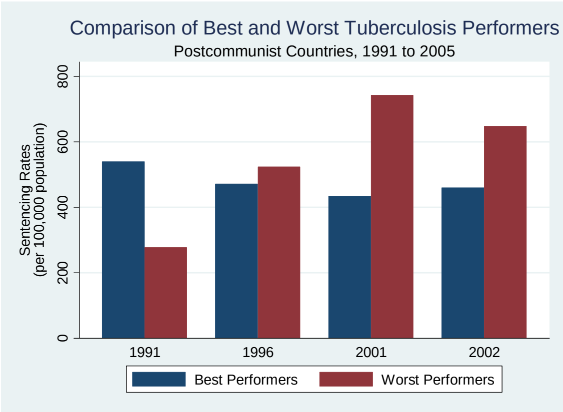
Full Panel Descriptives of Incarceration Rates per 100,000 population												
Country	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Armenia	122.1	135.7	172	188.2	166.7	179.2	187.1	169.6	172	178.5	144.5	150.1
Azerbaijan		95.9	143.9	160.5	180.9	165.1	161.2	203.9	196.6	181.5	168.8	173.6
Belarus	321.9	359.1	465	522.2	577	609.6	571.7	592.9	596.7	570.5	505	540.3
Bulgaria	124.7	114.4	76.3	102.6	127.5	178.9	239.3	293.2	280.2	334.9	329.7	318.7
Croatia	664.5	519.4	590	574.8	474.5	562.3	521.7	658.1	629.7	621.7	614.7	656.4
Czech Republic	271.3	300.7	340.3	502.5	532.2	562	580.1	525.4	608.7	615.4	587.9	637.9
Estonia	253.2	328.5	419.9	497.5	557.3	601.2	646.9	596.4	638.7	749.2	826.7	803.1
Georgia	122	61	130	154	114.2	150.4	141.9	129.6	151.8	164.9	187.5	196.9
Hungary	632.8	747.2	719.1	757.2	830.2	807.8	855.9	947.6	939.5	932.5	935.2	981.7
Kazkhstan	345.7	403.9	533.1	558.3	587.8	546.1	564.9	387.4	444.2	524	477.3	436.4
Kyrgyzstan	199.3	242.4	332.3	317.2	385.9	378.4	417.3	387.6	365	412.6	358.9	344.2
Latvia	278.1	348	440.1	448.1	394.2	424.4	525	537.4	538.1	534.7	538.4	539.4
Lithuania	246.1	353.4	442.6	478.4	505.5	471.5	506.3	550.4	558.2	590.9	600.8	573.4
Macedonia		421.5	434.6	424.5	452.4	373.3	274.3	351.8	382.7	366.9	335.6	351.2
Moldova	274.8	272.6	305.3	350.3	336.5	312.9	348.8	376.8	400.5	438.7		
Poland		528	562	624	710	733						
Romania	264.7	303.3	365.7	421.4	448.4	459.9	496.3	471.9	389.7	336	370	375.8
Russia	400.6	446	534.6	625.1	701.1	753.9	689.7	730.9	838.2	815.2	861.7	598.7
Slovakia			482	475.9	481.9	492.1	416.2	415.9	399.4	414.1	429.6	448.1
Slovenia	414	381.6	345	316.1	174	198.2	250.5	289.1	291.6	317	354.5	383.3
Tajikistan	114	81.2	109.6	129.2	112.9			118.3	122.7	142	134	121.9
Turkmenistan	192.1	193.1										
Ukraine	209.8	222.1	294.4	338.6	415.2	476.1	471.4	464.7	447.6	468.9	531.1	404.5
Uzbekistan	182.6	193.9										

Supporting Information 2b. Full Panel Descriptives of Log Tuberculosis Incidence Rates per 100,000 population

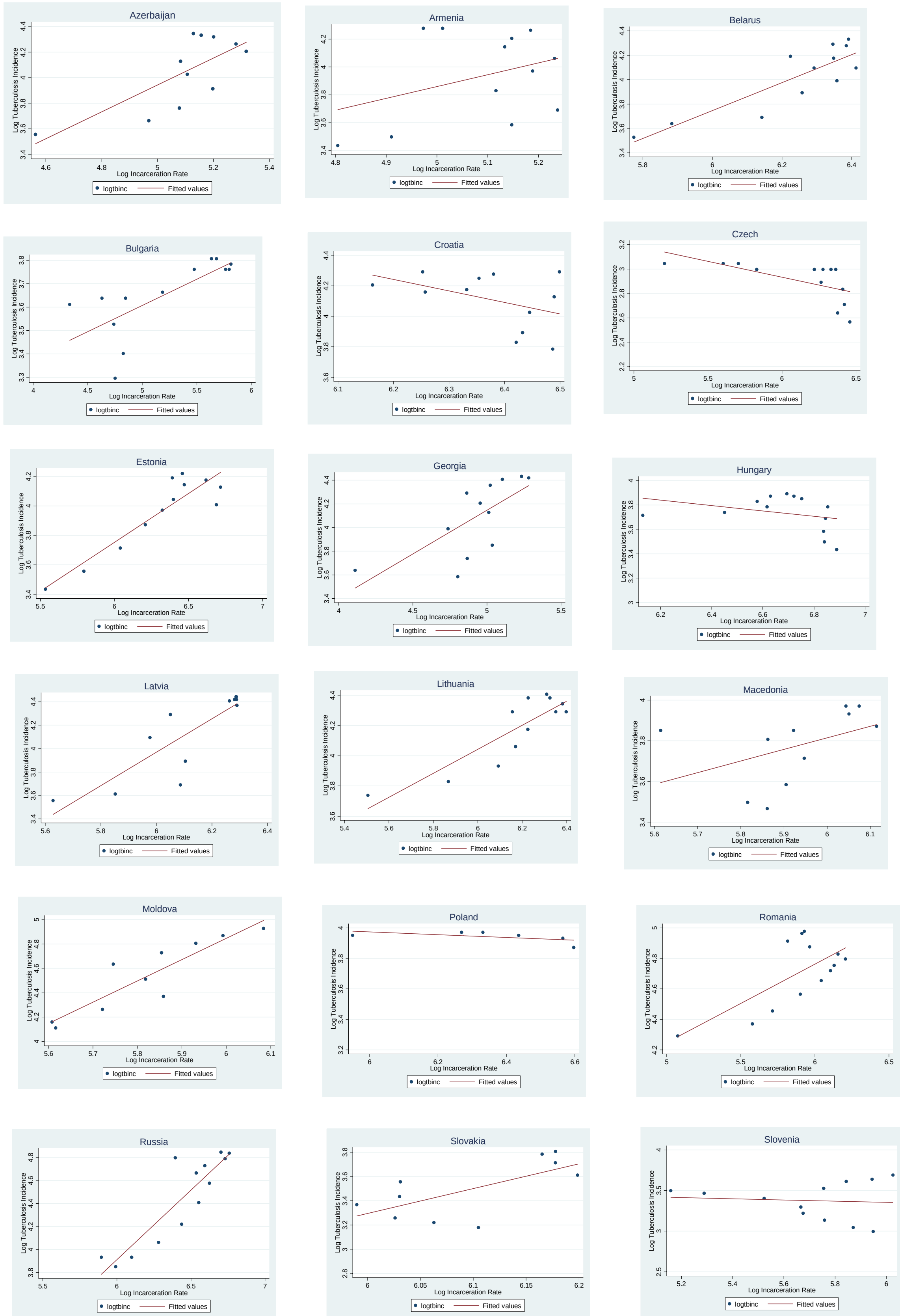
Full Panel Descriptives of Log Tuberculosis Incidence Rates per 100,000 population												
Country	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Albania	3.18	3.22	3.26	3.26	3.30	3.30	3.33	3.33	3.30	3.22	3.14	3.14
Armenia	3.43	3.50	3.58	3.69	3.83	3.97	4.06	4.14	4.20	4.26	4.28	4.28
Azerbaijan	3.50	3.56	3.66	3.76	3.91	4.03	4.13	4.20	4.26	4.32	4.34	4.33
Belarus	3.53	3.64	3.69	3.89	3.99	4.09	4.17	4.28	4.33	4.29	4.19	4.09
Bosnia	4.53	4.53	4.52	4.49	4.43	4.42	4.39	4.37	4.26	4.14	4.06	4.03
Bulgaria	3.40	3.53	3.61	3.64	3.64	3.66	3.76	3.81	3.81	3.78	3.76	3.76
Croatia	4.29	4.29	4.28	4.25	4.20	4.17	4.16	4.13	4.03	3.89	3.83	3.78
Czech Republic	3.04	3.04	3.00	3.00	3.00	3.00	3.00	2.89	2.83	2.71	2.64	2.56
Estonia	3.43	3.56	3.71	3.87	3.97	4.04	4.14	4.19	4.22	4.17	4.13	4.01
Georgia	3.58	3.64	3.74	3.85	3.99	4.13	4.20	4.29	4.36	4.41	4.43	4.42
Hungary	3.74	3.78	3.83	3.87	3.87	3.89	3.85	3.78	3.69	3.58	3.50	3.43
Latvia	3.56	3.61	3.69	3.89	4.09	4.29	4.41	4.44	4.44	4.42	4.42	4.37
Lithuania	3.74	3.83	3.93	4.06	4.17	4.29	4.38	4.41	4.38	4.34	4.29	4.29
Macedonia	3.97	3.97	3.97	3.93	3.87	3.85	3.85	3.81	3.71	3.58	3.50	3.47
Moldova	4.11	4.16	4.26	4.37	4.51	4.63	4.73	4.80	4.87	4.93	4.94	4.94
Poland	3.95	3.97	3.97	3.95	3.93	3.87	3.81	3.74	3.64	3.56	3.50	3.47
Romania	4.37	4.45	4.56	4.65	4.72	4.75	4.80	4.83	4.88	4.91	4.96	4.98
Russia	3.85	3.93	4.06	4.22	4.41	4.57	4.66	4.73	4.79	4.84	4.84	4.80
Slovakia	3.74	3.78	3.81	3.78	3.71	3.61	3.56	3.43	3.37	3.26	3.22	3.18
Slovenia	3.69	3.64	3.61	3.53	3.50	3.47	3.40	3.30	3.22	3.14	3.04	3.00
Uzbekistan	3.69	3.76	3.83	3.87	3.93	4.06	4.14	4.26	4.33	4.43	4.51	4.56

Supporting Information 3. Best and Worst Tuberculosis Performers: Alternative to Table 2 using Bar Graphs





Supporting Information Figure 4. Unadjusted mini-plot-pairs of Incarceration Rates and Log Tuberculosis Incidence Growth, by country



What this figure nicely presents is that only in countries where incarceration rates were increasing was there an adverse relationship between incarceration and tuberculosis incidence rates. This strongly supports our basic finding as to why the best performers on tuberculosis such as the Czech Republic and Croatia fared so well, whereas countries with the greatest increases like Latvia, Estonia and Russia had some of the steepest relationships between incarceration and tuberculosis incidence.

Supporting Information 5. Ten Worst Log Tuberculosis Incidence Rates, Postcommunist Countries 1991-2005

A reviewer suggested that "*Russia is the only high burden TB incidence country in the region and "swamps" the date overall*." Further, this reviewer suggested that "*Any biases (and these are significant) will tend to invalidate much of the quantification data."* Neither of these assertions is correct. According to the WHO data for Eastern Europe and former Soviet countries, the ten greatest TB incidence records are found in Moldova and Romania in the following years:

Rank	Country	Year	Log TB Incidence
1	Moldova	2003	4.983607
2	Romania	2002	4.976734
3	Romania	2001	4.962845
4	Romania	2001	4.941642
5	Moldova	2002	4.941642
6	Moldova	2004	4.941642
8	Moldova	2003	4.934474
9	Moldova	2000	4.927254
10	Moldova	2004	4.927254

Supporting Information 6. Sample Regression Decomposition

In our basic model (Table 2), we found each 1% increase in incarceration rates increased tuberculosis incidence by 0.34%; each 1% increase in GDP per capita decreased tuberculosis incidence by 0.38%. This suggests that a doubling of GDP would be needed to offset the tuberculosis harms of a doubling of incarceration rates. We here decompose our regression for Estonia (pointed out R5) by calculating Δ% TB Incidence and Δ% GDP change. We then multiply these by our β-coefficients to assess how much these variable contributed to the changes observed.

Country	Year	Log GDP per Capita	Log Sentencing Rate	Log Tuberculosis Incidence
Estonia	1991	8.00	5.53	3.43
Estonia	1992	7.83	5.79	3.56
Estonia	1993	7.81	6.04	3.71
Estonia	1994	7.85	6.21	3.87
Estonia	1995	7.95	6.32	3.97
Estonia	1996	8.03	6.40	4.04
Estonia	1997	8.10	6.47	4.14
Estonia	1998	8.24	6.39	4.19
Estonia	1999	8.24	6.46	4.22
Estonia	2000	8.23	6.62	4.17
Estonia	2001	8.32	6.72	4.13
Estonia	2002	8.47	6.69	4.01

First we note that the correspondence between log sentencing rates and log tuberculosis incidence is much closer than that observed between log GDP and log tuberculosis incidence. For example, 1994-1995, GDP increases and TB incidence goes up (opposite from the average trend), whereas sentencing rate increases while TB incidence goes up.

Let us now make the decomposition calculation specified above. GDP increased by 3% from 1991 to 1996; Sentencing rates went up 87%, and overall, log tuberculosis incidence jumped by 61%. By our regressions GDP's effect is 3*0.38, which corresponds to an improvement of 1.14%; sentencing rates on the other hand went up 87%, which corresponds to an worsening of 31% -- over half of the observed effect. When we replicated this process for all of the transition countries, we found that GDP was a much less *epidemiologically significant* variable even though it was *statistically significant.*

Supporting Information 7. Alternative Serial Correlation Models.

In the article, we note that we present "robust standard errors which were clustered by country to reflect non-independence of sampling and serial correlation. Serial correlation does not affect consistency of the estimates, only the standard errors (Wooldridge 2002).

Another strategy used is to estimate the autocorrelation directly and to then difference models based on this estimated correlation coefficient. We proceed here using Prais-Winsten regression to estimate a first-order AR(1) model with panel corrected standard errors using STATA's module xtpcse with options co(ar) and pair (for pairwise selection) with panel-corrected standard errors. These same results were also replicated using modules xtregar and xtabond2 with a finite sample bias correction.

Table 1. AR(1) Regression Models

Covariates	Model 1	Model 2
Log Incarceration Rate	0.18*** (0.05)	0.19*** (0.05)
Log GDP per capita	-0.21*** (0.06)	-0.20*** (0.05)
Heritage Foundation Democracy Index	0.01 (0.01)	-0.00 (0.01)
Military Conflict	-0.13*** (0.03)	-0.15*** (0.03)
Percentage of Population Urban	-0.09*** (0.02)	-0.09*** (0.02)
Population Dependency Ratio	-0.03*** (0.01)	-0.01 (0.01)
Percentage of Population with Tertiary Education	-0.00 (0.00)	-0.00 (0.00)
Log HIV prevalence	—	0.04*** (0.01)
Number of Obs.	211	193
Number of Countries	19	18
R^2	0.96	0.97

Note: Constant estimated but not reported; Robust panel-corrected standard errors in parentheses. Models include dummy variables for each country. Tuberculosis data are from the World Health Organization Global Tuberculosis Database 2007. Sample includes Armenia, Azerbaijan, Belarus, Bulgaria, Croatia, Czech Republic, Estonia, Georgia, Hungary Latvia, Lithuania, Macedonia, Moldova, Poland, Romania, Russia, Slovakia, Slovenia, and Uzbekistan. When including HIV prevalence, Uzbekistan drops out of the model because data are not available.
* = p<0.05, ** = p<0.01, ***p<0.001 (two-tailed tests).

Supporting Information 8a. Outlier Tests and Robustness Checks

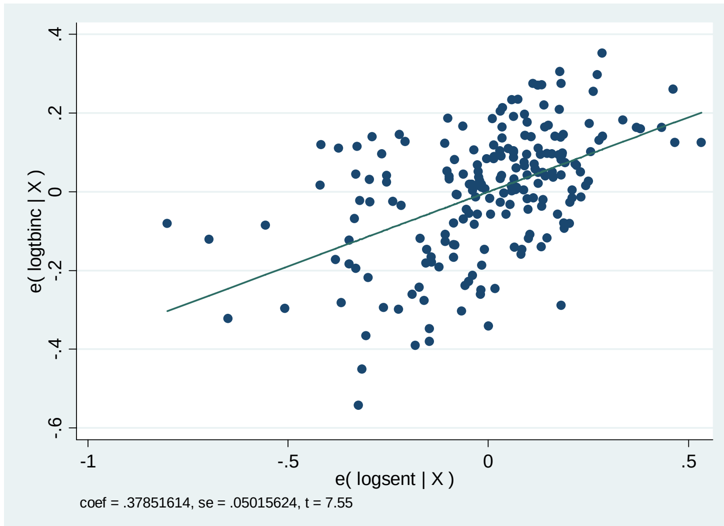
As part of our robustness checks we removed standardized residuals which were greater than 2 or less than -2 (a very liberal definition of outliers), which led us to remove 11 observations. We then re-ran our main model, which was virtually identical (although the coefficient increased on log incarceration rate to 0.38 from 0.34). We also reviewed added-variable plots of our basic model (shown below), which did not reveal significant leverage or influence points.

Covariates	Model 1	Model 2
Log Incarceration Rate	0.38***	0.34***
	(0.05)	(0.08)
Log GDP per capita	-0.36***	-0.32***
	(0.06)	(0.02)
Heritage Foundation	0.00	0.00
Democracy Index	(0.01)	(0.01)
Military Conflict	-0.17**	-0.06
	(0.06)	(0.06)
Percentage of Population	-0.10**	-0.10*
Urban	(0.02)	(0.04)
Population Dependency	-0.03***	-0.02
Ratio	(0.01)	(0.02)
Percentage of Population	0.00	-0.00
with Tertiary Education	(0.00)	(0.00)
Log HIV prevalence	—	0.05*
		(0.02)
Number of Obs.	200	193
Number of Countries	19	18
R^2	0.91	0.93

Note: Constant estimated but not reported; Robust standard errors clustered by country to reflect non-independence of country observations and serial correlation in parentheses. Models include dummy variables for each country. Tuberculosis data are from the World Health Organization Global Tuberculosis Database 2007. Sample includes Armenia, Azerbaijan, Belarus, Bulgaria, Croatia, Czech Republic, Estonia, Georgia, Hungary Latvia, Lithuania, Macedonia, Moldova, Poland, Romania, Russia, Slovakia, Slovenia, and Uzbekistan. When including HIV prevalence, Uzbekistan drops out of the model because data are not available.
* = p<0.05, ** = p<0.01 (two-tailed tests).

Supporting Information 8b. Model Diagnostics: Added-Variable Plots

Added-Variable plot, adjusted regression models



Supporting Information 9. Further Robustness checks using alternative dependent variables

All remaining analyses use xtreg module in STATA v9.2, with options fe (for fixed effect) and cluster(country) to produce standard errors robust to heteroskedasticity and autocorrelation as in the manuscript, unless otherwise specified.

Our model suggests incarceration rates matter for population health via tuberculosis outcomes. Since tuberculosis deaths, despite exhibiting alarming trends, are relatively rare events, they would not be enough to drive overall population health trends. If our results were confounded, sentencing rates would have a significant effect on life expectancy levels.

The results of such a model provide a negative check on our findings. Using the same specification of our models as before, we find that sentencing rates have no effect on life expectancy, although the direction of the finding is correct. This further supports the robustness of our findings. Similar results are observed using crime rates.

Covariate	Life Expectancy at Birth
Log Incarceration Rate	-0.32 (0.42)
Log GDP per Capita	1.70 (0.52)**

Note: Models include the full set of controls: democratization, occurrence of military or ethnic conflict, population tertiary education levels, urbanization rates, and country-specific fixed effects.

Covariate	Life Expectancy at Birth
Log Crime Rate	-0.24 (0.45)
Log GDP per Capita	1.60*** (0.47)

Note: Models include the full set of controls: democratization, occurrence of military or ethnic conflict, population tertiary education levels, urbanization rates, and country-specific fixed effects.

Similarly, we found no relationship between sentencing rates and log infant mortality rates ($\beta = -0.04$, $p=0.59$), with similar findings for crime rates.

Supporting Information 10. Alternative Sample Estimation: Replication using only former Soviet Union countries

It may be possible that the Soviet incarceration system confounding our results even though we control for membership in the Soviet Union. Nonetheless, we replicate our results here using only former Soviet countries, which are indeed more homogenous. The results become even stronger.

Replication using only former Soviet Union countries

Covariates	Model 1	Model 2
Log Incarceration Rate	0.52*** (0.11)	0.48*** (0.09)
Log GDP per capita	-0.21** (0.06)	-0.23 (0.10)
Heritage Foundation Democracy Index	0.02 (0.02)	0.02 (0.02)
Military Conflict	-0.23** (0.06)	-0.15* (0.06)
Percentage of Population Urban	-0.00 (0.02)	-0.00 (0.02)
Population Dependency Ratio	-0.05*** (0.01)	-0.03* (0.01)
Percentage of Population with Tertiary Education	0.01 (0.00)	0.00 (0.00)
Log HIV prevalence	—	0.03 (0.03)
Number of Obs.	108	98
Number of Countries	10	9
R^2-within countries	0.85	0.91

Note: Constant estimated but not reported; Robust standard errors in parentheses. Models include dummy variables for each country. Tuberculosis data are from the World Health Organization Global Tuberculosis Database 2007. Sample includes Armenia, Azerbaijan, Belarus, Estonia, Georgia, Latvia, Lithuania, Moldova, Russia, Uzbekistan. When including HIV prevalence, Uzbekistan drops out of the model.
* = p<0.05, ** = p<0.01 (two-tailed tests).

Again, we believe that these results are because incarceration rates were rising in these settings as opposed to other areas.

Supporting Information 11. Model Specification and Functional Form Robustness Tests

In the Table below we provide a stepwise introduction of controls as well as a shift from using the full variation (within + between) to the fixed effects models which exploit within variation (as in the figures shown above).

In Model 3, incarceration and GDP explain 40% of the variation in tuberculosis incidence rates. As is made clear in Table 3, our model 7, which is the one presented in the manuscript, is our most conservative estimate of the effect of incarceration on tuberculosis.

Robustness Check for Specification and Functional Form

Covariates	Model 1 Pooled OLS	Model 2 Pooled OLS	Model 3 Pooled OLS	Model 4 Pooled OLS	Model 5 Random Effects	Model 6 Fixed Effects	Model 7 Fixed Effects
Log Incarceration Rate	0.11*	—	0.50***	0.52***	0.34***	0.45**	0.34**
	(0.05)		(0.05)	(0.07)	(0.10)	(0.14)	(0.12)
Log GDP per capita	—	-0.22***	-0.44***	-0.52***	-0.42***	—	-0.38**
		(0.03)	(0.04)	(0.08)	(0.07)		(0.11)
Heritage Foundation Democracy Index	—	—	—	-0.02	0.00	—	-0.00
				(0.03)	(0.02)		(0.03)
Military Conflict	—	—	—	-0.22	-0.24*	—	-0.22*
				(0.16)	(0.10)		(0.08)
Percentage of Population Urban	—	—	—	-0.02	-0.03***	—	-0.10*
				(0.01)	(0.01)		(0.04)
Population Dependency Ratio	—	—	—	-0.03	-0.04*	—	-0.04
				(0.01)	(0.02)		(0.02)
Percentage of Population with Tertiary Education	—	—	—	0.01	0.00	—	-0.00
				(0.01)	(0.01)		(0.01)
Number of Obs.	211	211	211	211	211	211	211
Number of Countries	19	19	19	19	19	19	19
R^2	0.01	0.14	0.40	0.54	0.47	0.51	0.51

Note: Constant estimated but not reported; Robust standard errors clustered by country to reflect non-independence of sampling in parentheses. Models include dummy variables for each country. Tuberculosis data are from the World Health Organization Global Tuberculosis Database 2007. Sample includes Armenia, Azerbaijan, Belarus, Bulgaria, Croatia, Czech Republic, Estonia, Georgia, Hungary Latvia, Lithuania, Macedonia, Moldova, Poland, Romania, Russia, Slovakia, Slovenia, and Uzbekistan. When including HIV prevalence, Uzbekistan drops out of the model because data are not available.
* = p<0.05, ** = p<0.01, *** = p<0.001 (two-tailed tests).

Using a Hausman-Taylor test which compares the random effects and fixed effects models shows that we can proceed with the random effects models. That means, conditional on our observable control variables, any residual unobserved country heterogeneity – such as differences in surveillance systems – does not significantly modify our results. The Random Effects models are much more efficient because they do not include 18 additional regression model parameters, and as a result the standard errors become much tighter for the coefficient on log sentencing rates (95%: 23% to 45%). Nonetheless, in our manuscript we presented our more conservative models.

We also added a linear time trend time trend to our models, which was not significant (p=0.34) and did not affect the results. We also used log HIV cases and log AIDS cases instead of log HIV prevalence, and, since these are relative changes, the results as expected were exactly the same. As another check on our model we added log homicide rates, which was not significant (p = 0.581) and the log sentencing coefficient remained unchanged. We added controls for physicians, hospital beds and nurses per capita, public health spending, and tuberculosis immunizations, which also proxy for tuberculosis infrastructure, and results were unaffected. We added alternative poverty controls for the percentage of the population living in poverty based on national, rural and urbal poverty lines from the World Bank's World Development Indicators 2007 edition. Since many data were missing, the sample size dropped significantly although the results observed were consistent and significant with those presented in the text. The poverty measures were correlated with lower sentencing rates, although these were not significant. We weighted countries by the log of the population size and by the number of observations included in the panel; results were not significantly altered. We also removed Central Asian countries where it has been suggested that the data are misreported; the results strengthened as with the former Soviet Union sample. We also smoothed incarceration rates in STATA using tssmooth ma X, window (4 1), as well as different parameters for the smoothing operation. Results were unaffected. As seen in the description of the panel, missing data are at the tail ends of the panel which does not compromise evaluation of tuberculosis changes over time within countries.

Supporting Information 12. Alternative Dependent Variables: Replications using Log Tuberculosis Prevalence and Mortality Rate data

We also replicated our results using Log tuberculosis prevalence and mortality rate data. We would not expect significant differences since these are extremely highly correlated in our data:

Log Tuberculosis Incidence Rate	1	
Log Tuberculosis Prevalence Rate	0.96	1
Log Tuberculosis Mortality Rate	0.96	0.95

The results in the full regression models are statistically indistinguishable. The theoretical evidence suggests that rises in incidence are driving the results, and thus we present those.

Replication using Log Tuberculosis Prevalence

Covariates	Model 1	Model 2
Log Incarceration Rate	0.33**	0.27**
	(0.10)	(0.09)
Log GDP per capita	-0.42***	-0.32**
	(0.11)	(0.10)
Heritage Foundation Democracy Index	-0.00	-0.00
	(0.03)	(0.02)
Military Conflict	-0.19**	-0.04
	(0.06)	(0.07)
Percentage of Population Urban	-0.09*	-0.08
	(0.04)	(0.04)
Population Dependency Ratio	-0.03	-0.00
	(0.02)	(0.02)
Percentage of Population with Tertiary Education	-0.01	-0.01
	(0.01)	(0.01)
Log HIV prevalence	-	0.08*
		(0.03)
Number of Obs.	211	193
Number of Countries	19	18
R^2-within countries	0.45	0.54

Note: Constant estimated but not reported; Robust standard errors in parentheses. Models include dummy variables for each country. Tuberculosis data are from the World Health Organization Global Tuberculosis Database 2007. Sample includes Armenia, Azerbaijan, Belarus, Estonia, Georgia, Latvia, Lithuania, Moldova, Russia, Uzbekistan. When including HIV prevalence, Uzbekistan drops out of the model.

* = p<0.05, ** = p<0.01 (two-tailed tests).

Replication using Log Tuberculosis Mortality Rates

Covariates	Model 1	Model 2
Log Incarceration Rate	0.33**	0.27**
	(0.11)	(0.09)
Log GDP per capita	-0.35**	0.08**
	(0.11)	(0.02)
Heritage Foundation Democracy Index	-0.00	-0.26*
	(0.03)	(0.09)
Military Conflict	-0.16*	-0.00
	(0.07)	(0.02)
Percentage of Population Urban	-0.10*	-0.10*
	(0.04)	(0.04)
Population Dependency Ratio	-0.03	0.00
	(0.02)	(0.02)
Percentage of Population with Tertiary Education	0.00	-0.00
	(0.01)	(0.00)
Log HIV prevalence	—	0.08***
		(0.02)
Number of Obs.	211	193
Number of Countries	19	18
R^2-within countries	0.49	0.56

Note: Constant estimated but not reported; Robust standard errors in parentheses. Models include dummy variables for each country. Tuberculosis data are from the World Health Organization Global Tuberculosis Database 2007. Sample includes Armenia, Azerbaijan, Belarus, Estonia, Georgia, Latvia, Lithuania, Moldova, Russia, Uzbekistan. When including HIV prevalence, Uzbekistan drops out of the model.
* = p<0.05, ** = p<0.01 (two-tailed tests).

Supporting Information 13. Between effects country model and methodology

Fixed Effects

To specify the appropriate modeling approach, we first decompose the error term into an unobserved error component and a measurement error component:

(1) $\varepsilon_{it} = \alpha_i + \mu_{it}$;

By which α is the time-invariant unobservable influence and μ captures measurement error. This yields:

(2) $Log\ Tuberculosis_{it} = \gamma + \beta_1 PRI_{it} + \beta_2 GDP_{it} + \beta_3 DEM_{it} + \beta_4 WAR_{it} + \beta_5 URBAN_{it} + \beta_6 DEP_{it} + \beta_7 EDUC_{it} + \alpha_i + \mu_{it}$

The appropriate modeling strategy depends on whether the unobserved effect α_{it} is correlated with the explanatory variables over time. If the expected correlation $E[\alpha_i \mid x_{i1}, \ldots x_{iT}] = 0$, then random effects is the more efficient choice; otherwise, the fixed effects model which allows for arbitrary correlation between α_{it} and the explanatory variables is preferred.

Fixed effects is favored because it removes this heterogeneity altogether by explicitly allowing it to freely correlate with the explanatory variables (such that α can be any function of x). This allows us to consistently estimate partial effects in the presence of time-constant omitted variables. The fixed effects models are much more robust than the random effect analysis, but at the price of an inability to include time-constant covariates because they are indistinguishable from the time-constant unobserved effect α.

The fixed effects transformation, frequently referred to as the within transformation, annihilates the time-invariant components of the model:

(3) $(\text{Log TB Inc}_{it} - \overline{\text{Log TB Inc}}_i) = \beta_1(\text{INC}_{it} - \overline{\text{INC}}_i) + \beta_2(\text{GDP}_{it} - \overline{\text{GDP}}_i) + \beta_3(\text{DEP}_{it} - \overline{\text{DEP}}_i) + \beta_4(\text{URBAN}_{it} - \overline{\text{URBAN}}_i) + \beta_5(\text{EDUC}_{it} - \overline{\text{EDUC}}_i) + \beta_6(\text{WAR}_{it} - \overline{\text{WAR}}_i) + (\alpha_i - \bar{\alpha}_i) + (\mu_{it} - \bar{\mu}_i)$;

Where terms indexed only by *i* represent the mean values. The fixed effects estimator is the pooled OLS estimation of the transformed regression with time demeaning, which removes the individual specific effect α_i, provided it does not time-vary. This is also referred to as the dummy variable estimator because the results are identical to introducing a set of dummy variables for each cross sectional observation (Davidson and Mackinnon 1993).

Thus we can decompose variation into two orthogonal components

$$\nu_{full} = \nu_{within} + \nu_{between}$$

The between effects model isolates the variation in this latter term. Such a model can be specified as follows:

(4) $\overline{\text{Log TB Inc}} = \beta_1 \overline{\text{INC}}_i + \beta_2 \overline{\text{GDP}}_i + \beta_3 \overline{\text{DEP}}_i) + \beta_4 \overline{\text{URBAN}}_i + \beta_5 \overline{\text{EDUC}}_i +$
$\beta_6 \overline{\text{WAR}}_i) + \bar{\alpha}_i$

This is simply a regression of mean values of tuberculosis incidence for each country on the mean values of the associated set of covariates.

We present the results of this exercise here, and in the manuscript decompose this regression to compare the effects associated changes to parameters within countries to levels between countries.

STATA command: xtreg logtbinc lgdpc logsent $demog, i(country) be

Between Effects Country Model

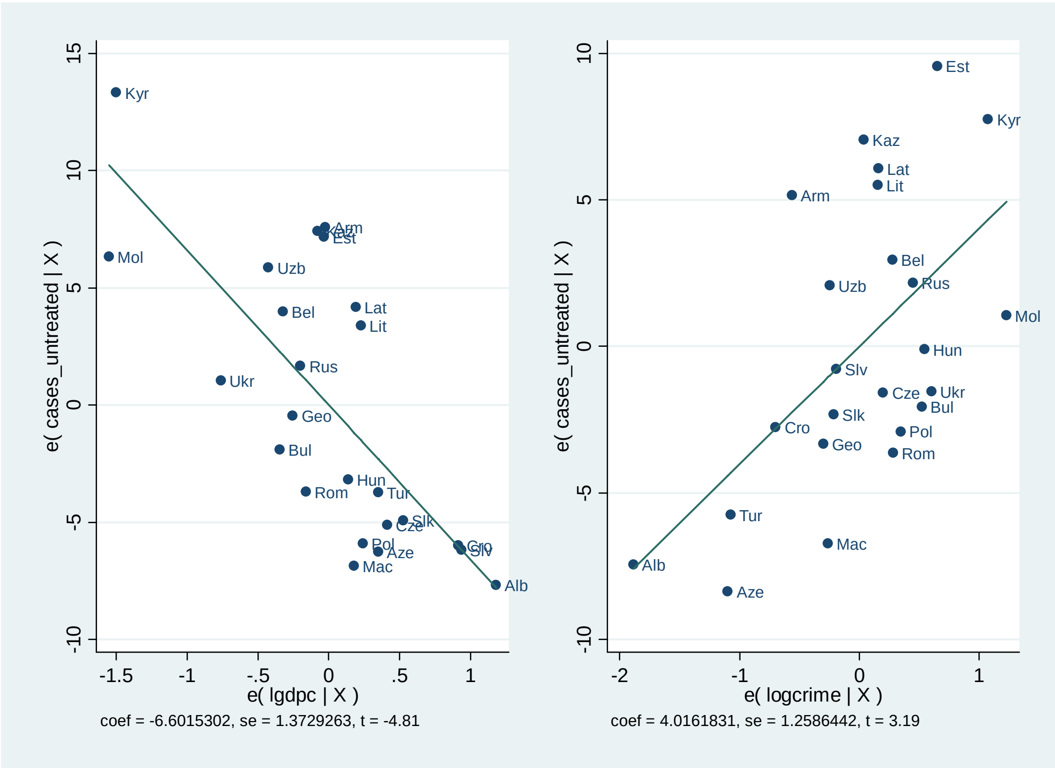
Covariates	Model 1
Log Incarceration Rate	0.73** (0.22)
Log GDP per capita	-0.65** (0.18)
Heritage Foundation Democracy Index	-0.02 (0.04)
Military Conflict	0.12 (0.65)
Percentage of Population Urban	-0.02 (0.01)
Population Dependency Ratio	-0.02 (0.02)
Percentage of Population with Tertiary Education	0.02 (0.01)
Number of Obs.	211
Number of Countries	19
R^2-between countries	0.67

Note: Constant estimated but not reported; Robust standard errors in parentheses. Models include dummy variables for each country. Tuberculosis data are from the World Health Organization Global Tuberculosis Database 2007. Sample includes Armenia, Azerbaijan, Belarus, Estonia, Georgia, Latvia, Lithuania, Moldova, Russia, Uzbekistan.
* = p<0.05, ** = p<0.01 (two-tailed tests).

Supporting Information 14. Representative Added-Variable Plots for MDR TB models, Cases Untreated

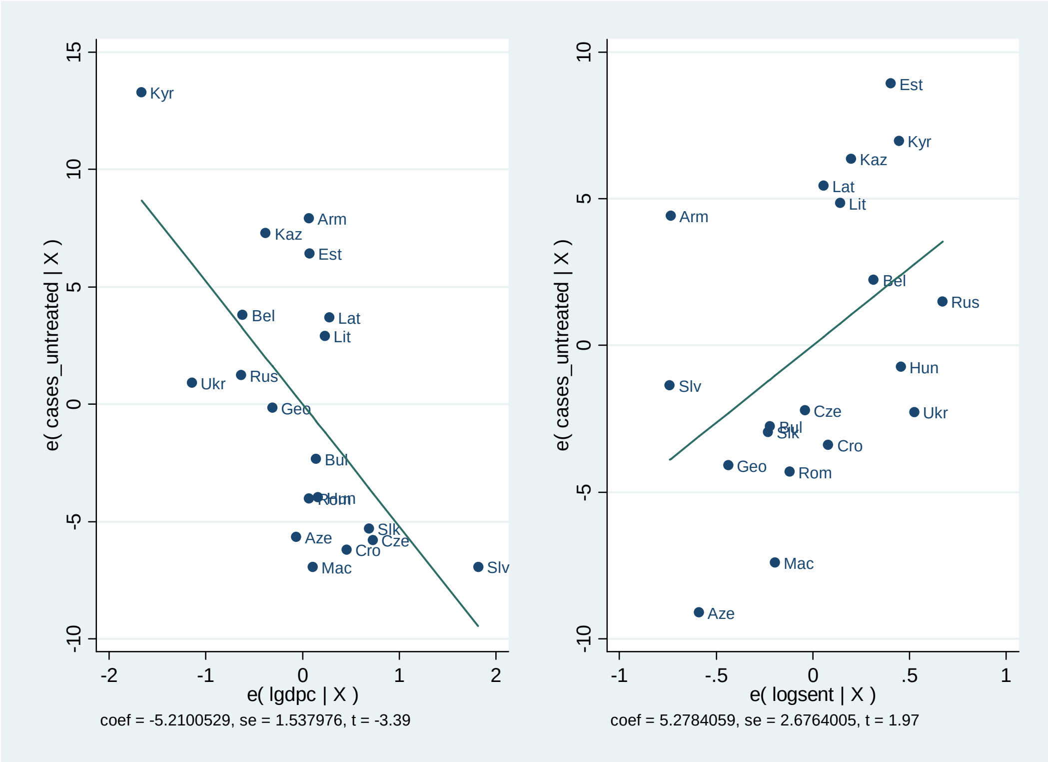
We use the Breusch-Pagan/Cook-Weisberg test for heteroskedascticity, testing the null of Constant Variance. We fail to reject the null (χ^2=0.35, p=0.56) of homoskedasticity, and thus proceed without transforming standard errors.

Figure a. Added-Variable Plot using Log-Crime Rates, Adjusted for Log GDP per Capita



Note: Estimation sample using log crime rates include Albania, Armenia, Azerbaijan, Belarus, Bulgaria, Croatia, Czech Republic, Estonia, Georgia, Hungary, Kazakhstan, Kyrgyzstan, Latvia, Lithuania, Macedonia, Moldova, Poland, Romania, Russia, Slovakia, Slovenia, Turkmenistan, Ukraine, Uzbekistan.

Figure b. Added Variable Plot Using Log-Sentencing Rates, Adjusted for Log GDP per Capita



Note: Estimation sample using log sentencing rates include Armenia, Azerbaijan, Belarus, Bulgaria, Croatia, Czech Republic, Estonia, Georgia, Hungary, Kazakhstan, Kyrgyzstan, Latvia, Lithuania, Macedonia, Romania, Russia, Slovakia, Slovenia, Turkmenistan, Ukraine, Uzbekistan. Countries Albania, Moldova, Poland, Turkmenistan and Uzbekistan are dropped because sentencing data are unavailable for the observed period.

As shown in the figures, the slopes are statistically indistinguishable from each other. Since we have comparative data for 24 countries registered crime rates, we present the log crime rate data as our proxy for these models.

As shown in Figure b, the p-value for log sentencing rates is 0.066, which is marginally insignificant, as expected from reducing the power.

Supporting Information 15. MDR TB Model Robustness Checks

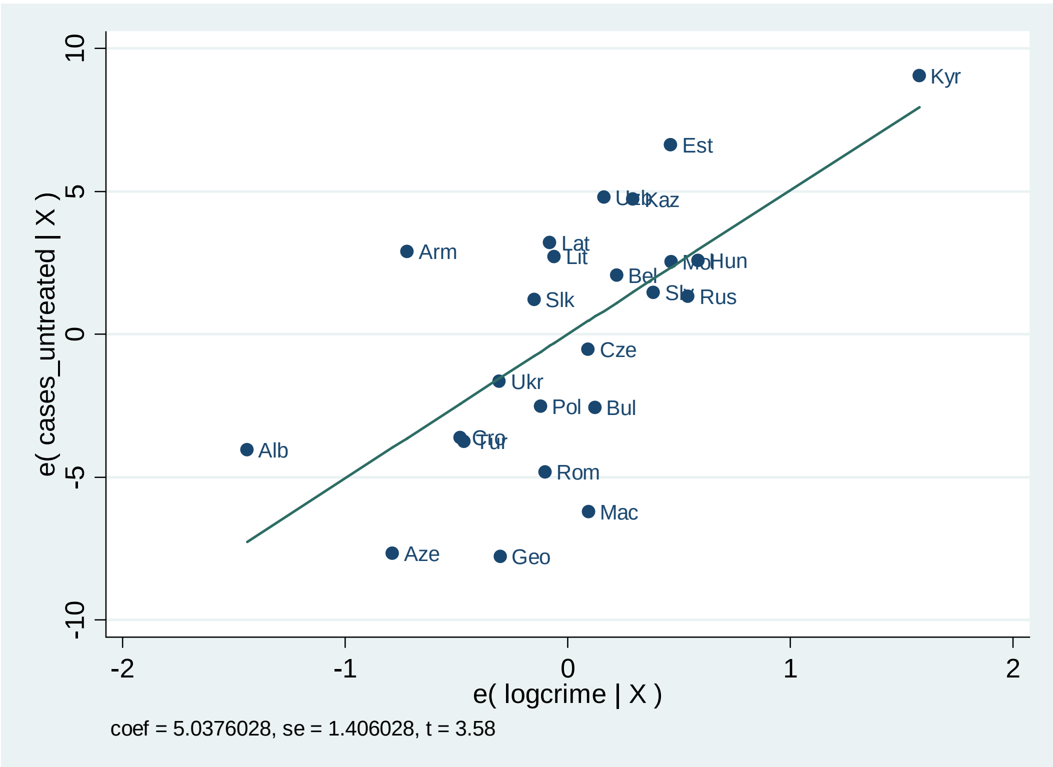
We also present a model with a broader set of controls here using a linear regression model as opposed to the logistic model as a robustness check:

$$MDR_i = \alpha + \beta_1 PRI_i + \beta_2 GDP_i + \beta_3 DEM_i + \beta_4 WAR_i + \beta_5 URBAN_i + \beta_6 YR_i + \beta_7 REP_i + \beta_8 T1_i + \beta_9 T2_i + \beta_{10} T3_i + \varepsilon_{it}$$

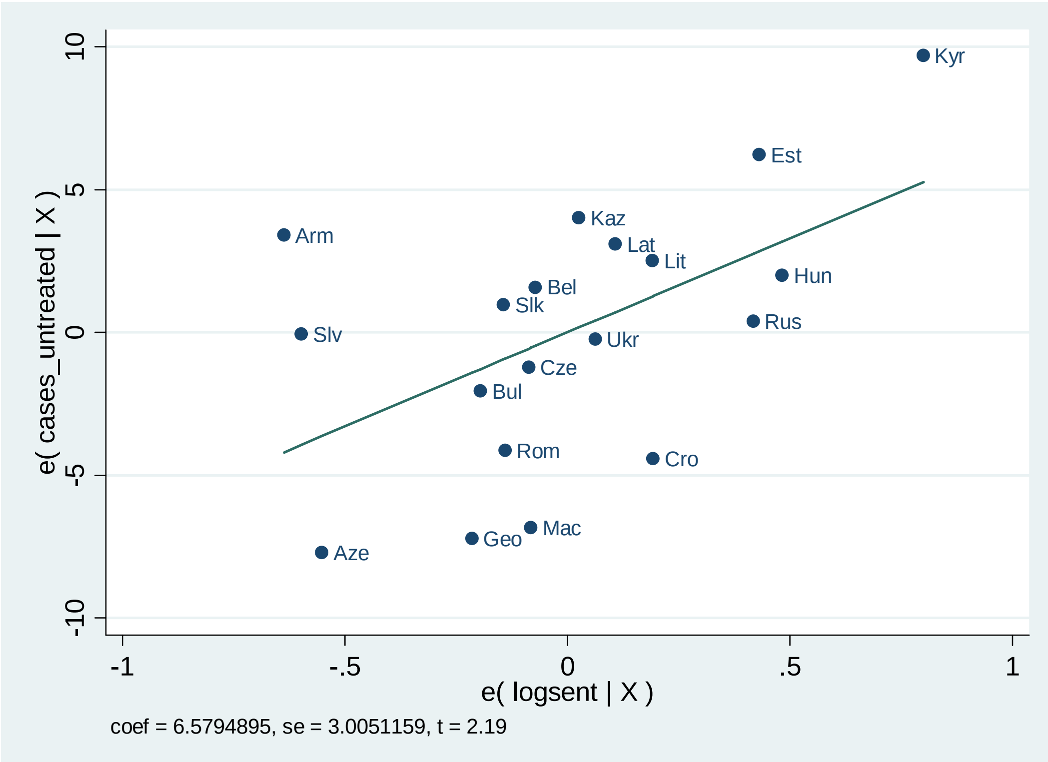
The only difference here is that YR controls for which year the data were taken from and REP controls for whether the data were representative of the entire country. T1-T3 is a set of dummies for each source of data used. These variables control for potential detection biases. MDR is the percentage of cases (either treated or untreated) which are multi-drug resistant.

Based on a parsimonious form of this model, we generate the following adjusted plot for log crime rates and log sentencing rates (Model 3, tables below)

Figure c. Added-variable plot using log crime rates, from model 3 in table below



And for log sentencing rates, which drops 5 more countries, Albania, Moldova, Poland, Turkmenistan and Uzbekistan, Figure d. Added-variable plot using log sentencing rates, from model 3 in table below



Robustness Checks for MDR TB Models, Crime Rates				
Dependent Variable: Percentage of MDR in Never Treated Cases of Tuberculosis Incidence				
Covariates	Model 1	Model 2	Model 3	Model 4
Log Crime Rate	4.02**	3.87*	5.04**	4.07*
	(1.26)	(1.34)	(1.41)	(1.86)
Log GDP per capita	-6.60**	-7.96**	-7.10**	-7.01**
	(1.37)	(2.06)	(1.51)	(2.08)
Year of Data Collection	—	-0.02	1.03	0.48
		(0.60)	(0.55)	(0.60)
Dummy for Representative of Entire Country	—	3.81	4.10*	4.29
		(2.12)	(1.96)	(2.48)
Dummy for Case-Linked data source	—	1.00	—	0.56
		(3.67)		(3.56)
Dummy for Survey data source	—	-2.77	—	-3.40
		(2.53)		(2.44)
Heritage Foundation Democracy Index	—	—	-0.90	-0.53
			(0.44)	(0.50)
Percentage of Population Urban	—	—	0.09	0.21
			(0.10)	(0.12)
Percentage of Population with Tertiary Education	—	—	—	0.07
				(0.11)
Population Dependency Ratio	—	—	—	0.39
				(0.24)
Number of Obs.	24	24	24	24
Number of Countries	24	24	24	24
R^2	0.53	0.63	0.68	0.78

Note: Representative is assessed as whether drug susceptibility testing results are for a nationwide sample of TB cases; Year is year of data collection, ranging from 1999 to 2005; Type is the source of data: case-linked, survey, or a network of labs Neither education nor dependency ratios were significant; in the set of 24 countries, there was no occurrence of war in the current period, and thus this variable was dropped. Albania, Armenia, Azerbaijan, Belarus, Bulgaria, Croatia, Czech Republic, Estonia, Georgia, Hungary, Kazakhstan, Kyrgyzstan, Latvia, Lithuania, Macedonia, Moldova, Poland, Romania, Russia, Slovakia, Slovenia, Turkmenistan, Ukraine, Uzbekistan

Robustness Checks for MDR TB Models, Sentencing Rates			
Dependent Variable: Percentage of MDR in Never Treated Cases of Tuberculosis Incidence			
Covariates	Model 1	Model 2	Model 3
Log Sentencing Rate	5.28 (2.68)	8.62** (2.76)	6.58* (3.01)
Log GDP per capita	-5.21** (1.54)	-5.39** (2.11)	-6.44* (2.38)
Year of Data Collection	—	1.36 (0.78)	1.16 (0.88)
Dummy for Representative of Entire Country	—	5.12* (2.19)	4.56 (2.58)
Dummy for Case-Linked data source	—	2.26 (3.46)	—
Dummy for Survey data source	—	-2.63 (2.35)	—
Heritage Foundation Democracy Index	—	—	0.51 (0.66)
Percentage of Population Urban	—	—	0.14 (0.15)
Number of Obs.	19	19	19
Number of Countries	19	19	19
R^2	0.42	0.68	0.70

Note: Representativeness is assessed as whether drug susceptibility testing results are for a nationwide sample of TB cases; Year is year of data collection, ranging from 1999 to 2005; Type is the source of data: case-linked, survey, or a network of labs Neither education nor dependency ratios were significant; in the set of 19 countries, there was no occurrence of war, and thus this variable was dropped. Countries include Armenia, Azerbaijan, Belarus, Bulgaria, Croatia, Czech Republic, Estonia, Georgia, Hungary, Kazakhstan, Kyrgyzstan, Latvia, Lithuania, Macedonia, Romania, Russia, Slovakia, Slovenia, Ukraine

The interpretation for these models is that each 100% increase in the log sentencing rate is associated with a 5.3% to 8.6% increase in the percentage of MDR TB in untreated cases of tuberculosis. Given that in the worst performers incarceration rates increased by nearly three-fold, this is a substantial association.

Supporting Information 16. MDR TB Dataset

MDR TB Dataset						
Country	Code	Year	Source of Data	Representative	Cases Untreated	Cases Treated
Albania	Alb	2005	0.00	0.00	0.00	8.30
Armenia	Arm	2005	2.00	0.00	14.90	41.80
Azerbaijan	Aze	2003	2.00	0.00	1.30	n/a
Belarus	Bel	2000	2.00	0.00	10.70	n/a
Bosnia	Bos	2005	2.00	1.00	0.40	6.60
Bulgaria	Bul	2005	2.00	0.00	4.60	3.60
Croatia	Cro	2005	0.00	1.00	0.70	5.10
Czech	Cze	2005	0.00	0.00	1.10	29.40
Estonia	Est	2005	0.00	1.00	13.30	52.10
Georgia	Geo	2005	1.00	1.00	6.80	27.40
Hungary	Hun	2005	0.00	0.00	2.90	14.80
Kazakhstan	Kaz	2001	2.00	1.00	14.20	56.40
Kyrgyzstan	Kyr	2005	2.00	0.00	20.20	63.20
Latvia	Lat	2005	0.00	1.00	10.60	35.70
Lithuania	Lit	2005	0.00	1.00	9.80	47.60
Macedonia	Mac	2005	0.00	0.00	0.00	21.10
Moldova	Mol	2002	2.00	0.00	13.10	24.00
Montenegro	Mon	2005	2.00	1.00	0.00	14.30
Poland	Pol	2001	1.00	1.00	0.30	8.20
Romania	Rom	2003	1.00	1.00	2.90	10.70
Russia	Rus	2002	1.00	0.00	8.12	43.00
Serbia	Ser	2005	0.00	0.00	0.40	4.10
Slovakia	Slk	2005	0.00	0.00	1.60	7.10
Slovenia	Slv	2005	0.00	1.00	0.00	3.60
Turkmenistan	Tur	2001	1.00	0.00	3.80	18.40
Ukraine	Ukr	1999	2.00	0.00	7.80	28.00
Uzbekistan	Uzb	2001	1.00	0.00	13.20	40.20

Note: Source of data defined as 0 – case-linked; 1 – is survey data; 2 – is from laboratory data, and stratified into three dummy variables for the analysis. Data are from the WHO EURO TB 2007 report.

Supporting Information 17. Comparison of Sentencing Rate of Data to Available Incarceration Rate Data, Selected Countries

Country	Year Sentencing Data /Actual Data Observed	Sentencing Rate	Actual Rate
Russia	1993/3	534.6	558
Russia	2002/5	598.7	532
Belarus	2002/3	540.3	532
Ukraine	2002/3	404.5	416
Georgia	2002/3	196.9	165
Armenia	2002/3	150.1	92
Azerbaijan	2002/3	173.6	198

Note: Actual incarceration rates are taken from Mauer, Marc. *Part 1. Americans Behind Bars: The International Use of Incarceration, 1992-93*. The Sentencing Project; 1994; Walmsey, M. *World Prison Population List.* International Centre for Prison Studies: King's College London.