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ASSESSING ASSOCIATIONS BETWEEN HEALTH SYSTEM RESOURCES AND TUBERCULOSIS CASE DETECTION ACROSS COUNTRIES USING PANEL DATA

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Abstract:

This analysis examines whether national health resources correspond to tuberculosis detection coverage and whether international comparisons depend on reporting composition. An unbalanced panel of 1,581 complete annual observations across 188 countries and economies from 2010 to 2023 combines World Development Indicators series. Descriptive statistics, quartile comparisons and Spearman correlations assess resource gradients, with exploratory comparisons using country medians and a balanced reporting subset. Detection correlates positively with physician availability at 0.632, nursing and midwifery availability at 0.644, and expenditure per capita at 0.717. Upper and lower resource groups differ in mean detection by approximately 25 to 29 percentage points. Resource dimensions also correlate strongly with one another, indicating overlapping national capacity rather than isolated contributions. Positive associations persist under equal country representation but weaken in the balanced subset. The contribution distinguishes directional consistency from sensitivity to reporting composition, qualifying systems interpretations of resource availability. These findings support international benchmarking to prioritise diagnostic service assessments while preserving the distinction between descriptive resource gradients and causal policy effects.

Key Words: Health Expenditure; Health Workforce; International Comparisons; Spearman Correlation; Tuberculosis Detection

1. Introduction:

Tuberculosis control depends on whether health systems identify people who need treatment, not merely on whether diagnostic technologies exist. The World Health Organization's Global tuberculosis report 2023 estimated that 10.6 million people developed tuberculosis worldwide in 2022, while 7.5 million people were newly diagnosed and reported. These figures describe different components of disease surveillance and indicate a continuing gap between estimated disease occurrence and recorded diagnosis. Understanding how detection coverage varies with health system resources matters for decisions about workforce capacity, financing and diagnostic service provision. World Health Organization, 2023, provides the global context for examining these resource differences without assuming that additional inputs automatically produce effective detection. A health systems perspective treats detection as the outcome of connected activities involving clinical assessment, diagnostic testing, referral and notification. Physicians can support recognition and diagnostic decisions, while nursing personnel can contribute to assessment, specimen collection and continuity through services. Financial resources can sustain the personnel, facilities and supplies required to complete these activities. However, resource availability differs from effective service delivery. Kruk et al., 2018, distinguish health system foundations from the processes through which services produce better outcomes. This distinction implies that national resource measures may identify differences in potential capacity while leaving variation in service quality and organisation unexplained.

Research on tuberculosis care demonstrates why this distinction matters. Das et al., 2015, used standardised patients to examine actual provider practice in India, showing the importance of distinguishing clinical knowledge from delivered care. Their design directly assessed provider behaviour but did not estimate how national workforce and expenditure distributions relate to detection coverage across countries. Sreeramareddy et al., 2014, found that diagnostic delays in India varied with the number and type of providers consulted. Together, these findings show that contact with healthcare providers does not necessarily translate into timely diagnosis. They also establish a boundary for interpreting aggregate resource indicators: personnel density cannot directly reveal the quality or sequence of care experienced by patients. Comparative patient pathway research further shows that the location of services can matter as much as their aggregate availability. Hanson et al., 2017, examined Kenya, Ethiopia, Indonesia, the Philippines and Pakistan and identified substantial mismatches between initial care seeking and access to tuberculosis diagnostic capacity. Their analysis explains how service alignment can constrain detection even where healthcare contact occurs. The reviewed evidence therefore establishes operational reasons why resources may fail to reach patients effectively. It does not establish whether broad international resource gradients remain evident when workforce availability and expenditure are measured on a common sample, or how those gradients change when unequal reporting coverage is addressed.

Outcome measurement also shapes this comparison. The tuberculosis case detection indicator expresses notified new and relapse cases relative to estimated incident cases in the same year. It captures national detection and notification coverage rather than individual diagnostic accuracy, diagnostic delay or treatment completion. Its numerator depends on recorded notifications, while its denominator depends on estimated incidence. Consequently, differences across countries can reflect both service performance and surveillance characteristics. The analysis retains this interpretation throughout and compares resource measures against the same outcome definition. It does not treat notification coverage as a direct measure of clinical competence or assume that national averages describe access within every population group. The specific empirical gap concerns the relationship between international resource gradients and the composition of the observations used to measure them. Workforce availability and expenditure can vary together, while countries with more complete reporting can contribute disproportionately to pooled comparisons. Examining each resource against a different sample would introduce an additional source of incomparability. This

analysis addresses that problem by using one complete sample for all three resource dimensions and distinguishing pooled annual observations from comparisons that give each country equal representation. A separate restriction to countries with complete reporting throughout the observation period assesses sensitivity to changing coverage. These comparisons qualify the interpretation of resource gradients without claiming to isolate causal mechanisms.

This study aims to describe how physician availability, nursing and midwifery personnel availability, and health expenditure per capita relate to tuberculosis case detection across countries and economies from 2010 to 2023. The central research question is whether higher resource availability accompanies higher detection coverage and whether that pattern persists under alternative representations of country reporting. The objectives are to characterise resource and detection distributions, compare detection across resource levels, examine overlap among the resource dimensions, and assess the sensitivity of their associations to unequal observation coverage. The analysis uses 1,581 complete annual observations across 188 countries and economies, assembled from four World Development Indicators series. Descriptive statistics, resource group comparisons and Spearman correlations match the comparative purpose and measurement scales. The findings contribute by separating consistency in the direction of resource associations from sensitivity in their magnitude. All three resource dimensions show positive pooled associations with detection, with expenditure displaying the strongest relationship. Positive associations persist when countries receive equal representation and when the sample is restricted to complete reporting, although their magnitudes differ. Strong correlations among the resource dimensions also show why their pooled associations should not be interpreted as separate contributions to detection. The resulting evidence supports international benchmarking and helps identify settings where limited resources coincide with lower detection coverage. It does not establish the gains that would follow from a particular staffing or expenditure intervention. The remainder of the article develops the conceptual framework and research questions in Section 2, presents the data in Section 3 and explains the methods in Section 4. Section 5 reports the findings, Section 6 discusses their significance, and Section 7 presents the conclusions and implications.

2. Theory, Conceptual Framework and Hypothesis Development:

This analysis draws on health systems theory to examine how clinical personnel and financial resources relate to tuberculosis case detection. Detection depends on connected activities, including recognition of symptoms, clinical assessment, diagnostic testing, referral and notification. Resources support these activities, but their contribution depends on how services convert available inputs into effective care. Kruk et al., 2018, distinguish resource availability from service quality, providing the theoretical basis for expecting resource differences to explain part, rather than all, of the variation in detection. The framework treats physician availability, nursing and midwifery personnel availability, and health expenditure per capita as three observed dimensions of health system resources. The outcome is the tuberculosis case detection rate, measured as notified new and relapse cases relative to estimated incident cases. This measure captures national detection and notification coverage rather than individual diagnostic accuracy. Uplekar et al., 2015, place early diagnosis within an integrated strategy that connects clinical services, supportive systems and financing. Accordingly, the framework expects resources to support detection through service capacity while allowing their associations to differ across institutional settings.

The available panel contains 1,581 complete observations across 188 countries and economies from 2010 to 2023. Each observation links the three resource measures to case detection in the same country and year. These measures permit tests of resource associations without constructing an unobserved resource index. Country and year identifiers also permit adjustment for persistent national differences and shared annual conditions. The hypotheses concern conditional associations and do not imply that the panel identifies causal effects. Physician availability represents the supply of medical practitioners relative to population. More physicians may expand opportunities for clinical assessment, recognition of tuberculosis symptoms and referral for diagnostic testing. The proposed mechanism concerns access to clinical decision making rather than the assumption that physician numbers alone determine diagnostic performance.

Greater physician availability could therefore increase the proportion of incident cases reaching diagnostic services. However, additional practitioners may contribute little where laboratory capacity, referral arrangements or notification practices remain weak. Concentration of physicians in locations with limited access for underserved populations could also weaken the national association. Pai et al., 2016, describe tuberculosis diagnosis as a process requiring appropriate clinical assessment and diagnostic tools. Their synthesis supports the importance of diagnostic capacity but does not establish that higher national physician density necessarily produces higher detection. The positive direction remains a theoretical expectation that the observed panel can test.

H1: Higher physician availability is associated with a higher tuberculosis case detection rate, conditional on the other resource measures and country and year effects.

Nursing and midwifery personnel availability represents a different component of service capacity. Whereas physicians contribute to medical assessment and diagnostic decisions, nursing personnel may support symptom recognition, specimen collection, referral and continuity through diagnostic services. These activities can connect initial contact with completed assessment. A larger nursing workforce may reduce service bottlenecks and extend contact with patients who would otherwise remain outside diagnostic pathways. This expectation depends on staff deployment, professional preparation and coordination with other services. The available indicator combines nurses and midwives, so it measures broad workforce availability rather than personnel assigned specifically to tuberculosis care. Frenk et al., 2010, explain professional contributions through the interdependence of education, competencies and health system needs. Their argument supports treating workforce availability as a capacity measure whose contribution depends on how personnel are prepared and deployed. It therefore justifies a positive expected association while allowing the combined workforce indicator to produce a weak or inconclusive relationship.

H2: Higher nursing and midwifery personnel availability is associated with a higher tuberculosis case detection rate, conditional on physician availability, health expenditure, and country and year effects.

Health expenditure per capita represents the financial resources available to support health services. Financing can sustain personnel, diagnostic equipment, laboratory supplies, specimen transport and information systems. Its proposed contribution extends beyond workforce numbers because clinical staff require functioning facilities and operational support to

complete diagnostic processes. Higher expenditure may therefore support detection by reducing interruptions between assessment, testing and notification. However, total health expenditure does not identify spending allocated to tuberculosis services. Higher expenditure may also reflect greater service prices or exchange rate movements rather than an equivalent increase in diagnostic capacity. These competing mechanisms make a positive association plausible without making it inevitable. Lönnroth et al., 2010, position tuberculosis control within the interaction between effective care and wider social development. Their synthesis supports examining financial resources within a broader service system rather than treating expenditure as a sufficient explanation for detection. The analysis therefore evaluates expenditure alongside both workforce measures, using its logarithm to express proportional differences in spending.

H3: Higher health expenditure per capita is associated with a higher tuberculosis case detection rate, conditional on physician availability, nursing and midwifery personnel availability, and country and year effects.

The conceptual framework links each observed resource dimension directly to the observed detection rate. These links express theoretical expectations about conditional associations. They do not represent demonstrated causal pathways or measured mediation. The three dimensions enter the framework separately because they capture distinct aspects of service capacity. This specification allows each hypothesis to receive positive, negative or inconclusive empirical support without changing its direction after observing the findings.

3. Data:

This analysis documents the provenance, integration and measurement of annual health resource and tuberculosis detection data. It establishes the observed sample and provides descriptive evidence on resource availability and detection coverage across countries and economies from 2010 to 2023.

3.1 Data Sources, Population, and Sample Construction:

The dataset combines four indicators distributed through the World Bank World Development Indicators database. These comprise physicians per 1,000 people, nursing and midwifery personnel per 1,000 people, current health expenditure per capita, and tuberculosis case detection. The workbook records the indicator codes, source links, extraction endpoints and access date. The historical observation period is distinct from the extraction date. No immutable database release identifier or licence statement is archived in the workbook. The World Bank provides the access platform, while the tuberculosis detection indicator draws on estimates and notifications compiled by the World Health Organization. The latter defines detection through the relationship between notified cases and estimated incidence. This distinction matters because changes in the indicator can reflect notification performance, incidence estimation or both. World Health Organization, 2023, documents the international surveillance framework underlying tuberculosis reporting.

The unit of analysis is the country or economy in a calendar year. The dataset forms an annual panel covering 2010 to 2023. Workforce indicators measure personnel availability relative to population. Health expenditure measures annual spending per person, while case detection measures annual notifications relative to estimated incident cases. These variables describe national health systems rather than individual patients, facilities or tuberculosis programmes. The target population comprises countries and economies within the observation period. The accessible frame contains 211 countries and economies with at least one nonmissing observation among the four indicators. Their records cover 2,894 distinct combinations of country and year. Selection follows data availability rather than probability sampling. Regional and income aggregates are excluded, and retention requires all four measures for the same country and year. The sample construction table reports sequential exclusions. The exclusion order provides an auditable accounting of missing records; it does not imply that missingness occurs independently across indicators.

Stage	Countries and Economies Remaining	Observations Remaining	Observations Excluded	Reason or Rule
Accessible observed frame	211	2,894	Not applicable	At least one available indicator within the observation period
Detection availability	207	2,814	80	Tuberculosis case detection unavailable
Physician availability	190	1,706	1,108	Physician measure unavailable among remaining records
Nursing personnel availability	189	1,584	122	Nursing and midwifery measure unavailable among remaining records
Expenditure availability	188	1,581	3	Health expenditure unavailable among remaining records
Final descriptive sample	188	1,581	0	Four observed measures for each retained country and year

The retained panel is unbalanced. Countries and economies contribute between one and fourteen observations. Seventeen contribute observations in every year, while seven contribute one observation each. Annual sample size ranges from 48 observations in 2023 to 149 in 2018. Consequently, differences between annual summaries can reflect changes in sample composition as well as changes within countries.

3.2 Data Integration, Cleaning, and Quality Assurance:

Integration uses the three-character country identifier and calendar year as matching keys. Each indicator contributes one value to a given country and year. The source sheet contains 9,048 nonmissing indicator records. Verification identified no repeated combinations of country, year and indicator, and no duplicate country and year records in the final analytical sheet. Integration therefore preserves the intended relationship between the four series without multiplying observations. The analysis retains the annual frequency supplied by the source. It does not interpolate workforce observations, substitute neighbouring years

or convert the panel to a higher frequency. The source year provides the temporal alignment across indicators. Annual workforce records remain source reported observations rather than reconstructed period averages.

Health expenditure remains denominated in current United States dollars per capita. No additional currency conversion, purchasing power adjustment or inflation adjustment is applied. The measure therefore captures nominal expenditure differences that can also reflect prices and exchange rates. The World Bank expenditure series supplies the monetary measure used throughout the dataset. Missingness is concentrated in workforce reporting. Within the accessible frame, physicians have 1,733 observed values, nursing and midwifery personnel have 1,826, expenditure has 2,675, and detection has 2,814. Relative to the 2,894 observed combinations of country and year, these correspond to 1,161, 1,068, 219 and 80 missing values, respectively. The archived records do not distinguish structural inapplicability from other reasons for nonreporting.

Indicator	Available Observations	Missing Observations within the Accessible Frame
Physicians	1,733	1,161
Nursing and midwifery personnel	1,826	1,068
Health expenditure	2,675	219
Tuberculosis case detection	2,814	80

Complete case selection removes records with any missing analytical measure. No missing value is replaced with zero, estimated through interpolation or supplied through external matching. This procedure preserves observed values but restricts inference to countries and years with joint reporting coverage. Range checks confirm positive workforce and expenditure values in the retained sample. Detection ranges from 23 to 100 percent. These checks establish numerical consistency with the retained measurements; they do not independently validate the underlying national statistics. No observations are removed through trimming, winsorisation or an estimated outlier threshold. The historical values represent the source vintage captured in the workbook rather than information necessarily available during each observation year. The tuberculosis metadata explicitly allow retrospective revisions as notifications, incidence estimates and estimation methods change. The analysis therefore describes revised historical observations and does not interpret the dataset as a record of contemporaneous information available to decision makers.

3.3 Variable Measurement, Construction, and Validation:

Health system resources enter the dataset through three separate observed measures. Physician availability represents medical personnel relative to population. Nursing and midwifery availability represents a broader personnel category and does not identify staff assigned specifically to tuberculosis services. These definitions follow the corresponding World Bank workforce series. Neither indicator directly measures professional competence, geographical deployment or diagnostic workload. Tuberculosis case detection is the outcome measure. It expresses notified new and relapse cases as a percentage of estimated incident cases in the same year. Higher values indicate greater notification coverage relative to estimated incidence. A difference between two detection values is expressed in percentage points, not as a percentage change. The variable dictionary records the measurement choices implemented in the analytical dataset.

Variable or Indicator	Analytical Role	Definition and Construction	Source and Identifier	Unit and Frequency	Transformation and Direction	Missing Value Rule	Coverage and Limitation
Tuberculosis case detection	Outcome	Notified new and relapse cases divided by estimated incident cases, expressed as a percentage	World Bank distribution of WHO data; SH.TBS.DTEC.ZS	Percent; annual	Original scale; higher values indicate greater detection and notification coverage	Retain only observed values	1,581 retained observations; denominator depends on estimated incidence
Physician availability	Resource dimension	Physicians relative to population	World Bank; SH.MED.PHYS.ZS	Personnel per 1,000 people; annual	Original scale; higher values indicate greater physician availability	Retain only observed values	1,581 retained observations; national density does not measure deployment or diagnostic performance
Nursing and midwifery availability	Resource dimension	Nursing and midwifery personnel relative to population	World Bank; SH.MED.NUMW.P3	Personnel per 1,000 people; annual	Original scale; higher values indicate greater personnel availability	Retain only observed values	1,581 retained observations; combined occupational category is not specific to tuberculosis
Health expenditure per capita	Resource dimension	Current health expenditure divided by population, as supplied by the source	World Bank; SH.XPD.CHEX.PC.CD	Current United States dollars per person; annual	Original scale; higher values indicate greater nominal expenditure per person	Retain only observed values	1,581 retained observations; includes price and exchange rate variation
Country identifier	Panel identifier	Source supplied three character country code	World Bank country identifier	Country or economy	No transformation	Required for matching	Identifies national units rather than subnational populations
Calendar year	Temporal identifier	Source supplied observation year	World Bank year field	Annual, 2010 to 2023	No transformation	Required for matching	Joint reporting coverage varies across years

The resource dimensions remain separate. No latent variable, weighted index or composite resource score is constructed. Validation therefore concerns identifier consistency, duplicate detection, joint coverage and numerical ranges rather than internal consistency or factor structure. The descriptive statistics use the same 1,581 complete observations for every analytical variable. This common sample prevents variable comparisons from reflecting different sets of countries and years.

Variable	Observations	Mean	SD	Median	Minimum	Maximum
Physicians per 1,000 people	1,581	2.155	1.624	2.122	0.012	9.291
Nursing and midwifery personnel per 1,000 people	1,581	4.893	3.931	4.114	0.101	18.760
Health expenditure per capita in current United States dollars	1,581	1,406.17	2,052.34	476.94	13.15	12,586.20
Tuberculosis case detection, percent	1,581	71.21	16.00	72.00	23.00	100.00

Expenditure displays a substantial difference between its mean and median, indicating an asymmetric distribution. Physician and nursing availability also vary across observations. Detection averages 71.21 percent, with a median of 72 percent. These statistics describe the retained observations and do not establish population representativeness or causal relationships.

3.4 Analytical Framework, Identification, and Reproducibility:

The reported analysis is descriptive and associational. It examines the distributions of resource availability and detection coverage, together with their pooled rank associations. Each retained country and year receives equal weight. The summaries therefore describe country observations rather than population weighted global access to diagnostic services. Spearman rank correlations were calculated on the common complete sample to describe monotonic associations without requiring a linear relationship on the original measurement scales. Physician availability has a correlation of 0.632 with detection, nursing and midwifery availability has a correlation of 0.644, and expenditure per capita has a correlation of 0.717. These coefficients describe pooled associations and do not separate persistent differences between countries from changes within countries.

Bishara and Hittner, 2012, demonstrate that correlation procedures can behave differently under nonnormal distributions. This supports distinguishing rank association from linear association when interpreting the asymmetric expenditure measure. The reported coefficients are descriptive magnitudes rather than evidence that increasing resources would produce corresponding changes in detection. The analytical framework does not identify causal effects. Resource allocation may respond to disease burden, while unmeasured differences in service organisation, diagnostic capacity and reporting can influence both resources and detection. Revised incidence denominators introduce an additional source of variation. Temporal alignment alone does not resolve these threats. Reproducibility rests on the workbook's analytical records, raw observed values, coverage table, variable definitions and extraction endpoints. The archived workbook does not contain executable construction code or an immutable source release. Repeated extraction may therefore produce different historical values if the provider revises its series. Within the archived data, consistent identifiers, annual timing, original measurement scales and a shared complete sample align the descriptive comparisons across all four measures.

4. Methods:

4.1 Research Design and Analytical Scope:

This analysis uses an observational comparative design to examine how national health resources relate to tuberculosis case detection from 2010 to 2023. The analytical unit is the country or economy in a calendar year. The research question concerns differences in detection across resource distributions and the sensitivity of those differences to reporting coverage. The analysis estimates descriptive group contrasts and unadjusted rank associations. Useful variation arises from differences across countries and years in physician availability, nursing and midwifery personnel availability, health expenditure per capita, and detection coverage. Pooled comparisons combine variation between countries with variation within countries over time. They do not isolate the contribution of either source.

The sample construction table and variable dictionary in Section 3 define eligibility, measurement and coverage. All primary comparisons use the same 1,581 complete observations across 188 countries and economies. This common sample ensures that differences among the resource associations do not arise from using different observations for each measure. Interpretation remains associational. Resource allocation may respond to disease burden, while institutional conditions and reporting practices may influence both resources and detection. National aggregation also prevents inference about individual patients or facilities. Schober et al., 2018, distinguish correlation from causal interpretation and emphasise that the selected coefficient must match the relationship being examined. Accordingly, the reported associations describe resource gradients rather than intervention effects.

4.2 Distributional Summaries and Resource Group Comparisons:

The analytical sequence begins with valid observation counts, arithmetic means, sample standard deviations, medians, minima and maxima. First and third quartiles describe the middle half of each distribution. Calculations retain the original measurement scales, allowing personnel availability, monetary expenditure and detection percentages to retain their substantive meanings. Each country and year receives equal weight in the pooled analysis. These summaries therefore describe the observed national records rather than population weighted global conditions. Countries with more complete annual coverage contribute more observations, a feature examined through the sensitivity comparisons.

For each resource measure, the lower comparison group contains observations at or below its first quartile. The upper comparison group contains observations at or above its third quartile. Quartiles are calculated across the complete analytical sample using NumPy's linear quantile method. Group membership uses unrounded thresholds, and observations tied at a threshold remain included. Consequently, comparison groups need not contain identical numbers of observations. Equation 1 defines the descriptive detection contrast.

$$\Delta_j = \overline{D}_{U_j} - \overline{D}_{L_j}$$

Here, Δ_j is the detection difference for resource dimension j, $\overline{D}_{U_j}$ is mean detection in its upper resource group, and $\overline{D}_{L_j}$ is mean detection in its lower resource group. The difference is expressed in percentage points. Group medians provide an additional comparison of central tendency. Groups are constructed separately for each resource dimension. An observation can therefore occupy different groups across the three comparisons. Equation 1 describes an unadjusted contrast between observed groups rather than the expected change following an increase in resources. The resulting comparisons are reported in Table 2.

4.3 Rank Association and Measurement Checks:

Spearman correlations quantify monotonic associations between each resource measure and detection. The same procedure measures overlap among the resource dimensions. This choice allows the analysis to compare ordering across observations without requiring a linear relationship on the original measurement scales. Bishara and Hittner, 2012, demonstrate that correlation procedures can behave differently under nonnormal distributions. Their findings support matching the association measure to the distributional setting, although selecting a rank coefficient does not itself resolve dependence among repeated observations. The present analysis uses Spearman coefficients descriptively rather than applying significance tests that treat all annual records as independent. Equation 2 specifies the implemented rank correlation.

$$\rho_{s,j} = \frac{\sum_{k=1}^{n}\left[R_{jk} - \overline{R}_j\right]\left[S_k - \overline{S}\right]}{\sqrt{\sum_{k=1}^{n}\left[R_{jk} - \overline{R}_j\right]^2 \sum_{k=1}^{n}\left[S_k - \overline{S}\right]^2}}$$

Here, $\rho_{s,j}$ is the Spearman correlation between resource dimension jand detection, k indexes observations, and nis the analytical sample size. $R_{jk}$is the rank of the resource observation, $S_k$is the corresponding detection rank, and the overbars denote mean ranks. Tied values receive average ranks. Correlations among resource dimensions replace detection ranks with the ranks of the corresponding resource measure. The coefficients in Table 3 describe direction and strength without assigning causal meaning or independent explanatory shares. Strong resource correlations indicate overlapping distributions; they do not establish that the measures are interchangeable. Measurement checks examine country identifiers, calendar years, duplicate keys, missing values and numerical ranges. Verification identifies no duplicate country and year records in the analytical sample or duplicate country, year and indicator combinations in the raw observed records. Complete case selection retains original source values without imputation, interpolation or zero substitution. No trimming or winsorisation is applied. Validation concerns consistency of the observed records rather than latent construct reliability.

4.4 Sensitivity Analysis and Computational Reproducibility:

Two exploratory comparisons assess sensitivity to unequal reporting coverage. The first calculates one median for each analytical measure within each country or economy, producing 188 national observations. Spearman correlations are then recalculated using these medians. This comparison gives countries equal representation, although their medians can summarise different sets of available years. The second comparison restricts the original complete sample to countries and economies observed in every year from 2010 to 2023. The resulting balanced subset contains seventeen countries and economies and 238 annual observations. Correlations are recalculated on this subset without changing variable definitions or measurement scales.

These comparisons address different aspects of reporting composition. National medians reduce the influence of unequal numbers of annual observations. The balanced subset holds country membership constant across years but narrows geographical coverage. Neither comparison isolates causal effects or establishes representativeness. Table 4 reports changes in correlation direction and magnitude, rather than treating repeated statistical significance as the criterion for consistency. Calculations use Python version 3.12.14, NumPy version 2.3.5 and SciPy version 1.17.0. Sample standard deviations use one degree of freedom correction. Quantiles use NumPy's quantile function with linear interpolation, and rank correlations use SciPy's spearmanr function. Country medians are computed separately for each measure before recalculating correlations. Calculations retain full numerical precision, with rounding applied only to displayed results. All procedures are deterministic and require no random seed. The workbook preserves the analytical sample, raw observed values, coverage records, measurement dictionary and source endpoints. Its archived values provide the reference for reproducing the reported calculations because subsequent source revisions may change historical observations. Together, the common sample, explicit comparison rules and alternative reporting representations answer the comparative research question through established descriptive methods.

5. Findings:

This analysis examines how physician availability, nursing and midwifery personnel availability, and health expenditure relate to tuberculosis case detection across countries and economies. The findings present resource distributions, detection differences and pooled rank associations. Exploratory comparisons assess whether these associations persist when countries receive equal representation and reporting coverage remains constant.

5.1 Sample Coverage and Resource Distributions:

The analytical sample contains 1,581 complete observations across 188 countries and economies from 2010 to 2023. Each observation represents one country or economy in one calendar year. Retention requires observed values for all three resource measures and tuberculosis case detection. The accessible frame contains 2,894 combinations of country and year, of which 1,313 lack at least one required measure. Complete observations therefore represent 54.63 percent of the accessible frame. Reporting coverage varies across countries and years. Seventeen countries and economies contribute observations throughout the fourteen-year period, while seven contribute one observation each. Annual coverage ranges from 48 observations in 2023 to 149 in 2018. Consequently, pooled summaries give greater representation to countries with more complete reporting.

Table 1: Resource availability and tuberculosis case detection

Measure	Observations	Mean	SD	Median	Minimum	Maximum
Physicians per 1,000 people	1,581	2.155	1.624	2.122	0.012	9.291
Nursing and midwifery personnel per 1,000 people	1,581	4.893	3.931	4.114	0.101	18.760
Health expenditure per capita, current United States dollars	1,581	1,406.17	2,052.34	476.94	13.15	12,586.20
Tuberculosis case detection, percent	1,581	71.21	16.00	72.00	23.00	100.00

Expenditure displays the strongest asymmetry among the resource measures. Mean expenditure is approximately 2.95 times the median, indicating that observations with high expenditure substantially influence the pooled average. The middle half of expenditure observations lies between 105.07 and 1,658.60 United States dollars per capita. Corresponding intervals are 0.589

to 3.392 physicians and 1.577 to 6.707 nursing and midwifery personnel per 1,000 people. Detection has a median of 72 percent, with the middle half of observations between 60 and 83 percent. Eighty-seven observations, representing 5.50 percent of the sample, record detection at 100 percent. These values describe notifications relative to estimated incidence. They do not establish complete identification of every incident case or measure individual diagnostic accuracy. This distinction accords with Pai et al., 2016, who describe tuberculosis diagnosis through clinical assessment and diagnostic technologies rather than notification ratios alone.

5.2 Detection Differences Across Resource Levels:

Detection differs substantially between observations in the lower and upper quarters of each resource distribution. Groups are defined separately for each resource measure using its pooled first and third quartiles. Observations at the thresholds are included, so tied values produce a small difference in physician group sizes.

Table 2: Detection differences between lower and upper resource groups

Resource Measure	Lower Group Threshold	Upper Group Threshold	Lower Group Observations	Upper Group Observations	Mean Detection in Lower Group, Percent	Mean Detection in Upper Group, Percent	Difference, Percentage Points
Physicians per 1,000 people	At most 0.589	At least 3.392	397	396	56.68	82.69	26.01
Nursing and midwifery personnel per 1,000 people	At most 1.577	At least 6.707	396	396	58.83	84.00	25.17
Health expenditure per capita, current United States dollars	At most 105.07	At least 1,658.60	396	396	56.39	85.78	29.38

The physician comparison identifies a detection difference of 26.01 percentage points. Median detection also differs, rising from 56 percent in the lower physician group to 83 percent in the upper group. The agreement between mean and median comparisons indicates that the resource gradient is not confined to differences in group averages. The nursing and midwifery comparison produces a similar pattern. Mean detection differs by 25.17 percentage points, while median detection rises from 58 to 85 percent. These observations show that greater personnel availability accompanies higher detection coverage. They do not identify which occupational activities account for the difference. Frenk et al., 2010, emphasise that professional contributions depend on competencies and their integration within health systems, supporting a distinction between workforce availability and effective service delivery.

Expenditure produces the largest observed separation. Mean detection is 56.39 percent in the lower expenditure group and 85.78 percent in the upper group, a difference of 29.38 percentage points. Median detection values of 56 and 85 percent reinforces this pattern. However, expenditure remains a broad national measure rather than tuberculosis specific financing. The comparison is consistent with the wider connection between service resources and tuberculosis control discussed by Lönnroth et al., 2010, without identifying expenditure as the independent cause of the observed difference.

5.3 Resource Associations and Their Overlap:

Spearman correlations identify positive pooled associations between each resource dimension and detection. Expenditure has the largest coefficient at 0.717, followed by nursing and midwifery personnel at 0.644 and physicians at 0.632. These coefficients describe monotonic relationships across the retained observations.

Table 3: Spearman correlations among resources and detection

Measure	Physicians	Nursing and Midwifery Personnel	Health Expenditure	Tuberculosis Detection
Physicians	1.000	0.828	0.804	0.632
Nursing and midwifery personnel	0.828	1.000	0.824	0.644
Health expenditure	0.804	0.824	1.000	0.717
Tuberculosis detection	0.632	0.644	0.717	1.000

The resource dimensions also overlap strongly. Physician availability correlates with nursing and midwifery availability at 0.828 and with expenditure at 0.804. Nursing and midwifery availability correlates with expenditure at 0.824. Higher detection therefore accompanies a broader resource profile rather than three empirically isolated resource conditions. This overlap limits interpretation of the ranking among the detection correlations. The larger expenditure coefficient does not establish that expenditure contributes more than personnel availability after adjustment. Likewise, the workforce coefficients cannot identify separate professional contributions. The findings describe jointly distributed resources and detection, consistent with the systems perspective of Kruk et al., 2018, which distinguishes available inputs from the processes that convert them into effective care.

5.4 Exploratory Sensitivity Comparisons:

Two exploratory comparisons assess sensitivity to unequal reporting coverage. The first replaces repeated annual observations with one median value for each measure in each country or economy. This gives all 188 countries and economies equal representation, although their medians can reflect different sets of years. The second restricts the sample to the seventeen countries and economies observed throughout the period, yielding 238 observations.

Table 4: Detection correlations under alternative sample representations

Resource Measure	Complete Panel Observations	Country Medians	Complete Reporting Panel
Physicians	0.632	0.665	0.524
Nursing and midwifery personnel	0.644	0.635	0.530
Health expenditure	0.717	0.729	0.641
Observations	1,581	188	238
Countries and economies	188	188	17

Equal country representation preserves the positive direction and relative ordering of the associations. Physician availability correlates with detection at 0.665, nursing and midwifery availability at 0.635, and expenditure at 0.729. The pooled pattern therefore does not depend solely on greater representation of countries with more annual observations. The complete reporting panel also retains positive associations, but their magnitudes are smaller. The physician coefficient falls to 0.524, the nursing and midwifery coefficient to 0.530, and the expenditure coefficient to 0.641. Direction is stable across the comparisons, while magnitude remains sensitive to sample composition. The restricted panel covers seventeen countries and economies and cannot establish that these coefficients generalise to countries with incomplete reporting.

The empirical answer is that higher resource availability accompanies higher tuberculosis detection across the observed international sample. This pattern appears in distributional comparisons, pooled correlations and both exploratory sample representations. Its interpretation remains associational because the comparisons do not isolate resource changes from persistent national differences or other determinants of detection. Uplekar et al., 2015, place early diagnosis within integrated care, supportive systems and financing; the observed resource gradients are compatible with that framework but do not directly test its operational mechanisms.

6. Discussion:

Tuberculosis detection follows a pronounced resource gradient, but that gradient cannot be attributed to any single resource in isolation. Tables 2 and 3 show that greater physician availability, nursing and midwifery availability, and expenditure accompany higher detection coverage. Expenditure has the strongest pooled association, while the resource measures also correlate strongly with one another. The contribution of this analysis lies in showing these relationships within a common international sample and examining their sensitivity to reporting coverage. This shifts interpretation from separate resource indicators towards a jointly distributed pattern of health system capacity. Hanson et al., 2017, identified mismatches between where patients seek care and where diagnostic services are available across five countries. Their findings provide a service delivery explanation for why national resource availability and effective diagnostic access remain distinct concepts. The present evidence extends the scale of comparison without claiming to identify those patient pathways. The workforce differences in Table 2 indicate that personnel availability marks substantial variation in detection coverage, while leaving the conversion of personnel into effective care unexplained. This distinction changes the interpretation of workforce indicators: they describe potential service capacity rather than completed diagnostic processes. Das et al., 2015, used standardised patients in India to distinguish provider practice from knowledge and documented deficiencies in tuberculosis care. Their evidence cautions against interpreting greater provider availability as equivalent to appropriate diagnostic management. The international gradient reported here is therefore compatible with a resource constraint, but it does not establish that staffing expansion alone would reproduce the observed detection differences. Its theoretical value is to locate workforce availability within a broader production process in which clinical practice and service organisation determine how available personnel contribute to detection.

Expenditure's stronger association with detection in Table 3 identifies a comparative pattern rather than a dominant causal pathway. The resource correlations indicate that expenditure accompanies staffing differences, making the financial measure a marker of several jointly varying system characteristics. Table 2 reinforces this interpretation through the largest detection separation occurring between the expenditure groups, yet it provides no basis for allocating shares of that difference to financing, personnel or service processes. Sreeramareddy et al., 2014, found that diagnostic delays in India varied with the number and type of providers consulted before diagnosis. Their findings show why expenditure and workforce totals cannot reveal how efficiently patients move through care. The contribution here is a distinction between the resource dimension with the strongest descriptive association and the operational processes that would need direct measurement before pathway dominance could be established. Reporting coverage changes the magnitude of the resource gradient and therefore forms part of its substantive interpretation. Table 4 preserves positive associations when each country receives one median observation, indicating that unequal numbers of annual records do not alone explain the pooled pattern. However, associations weaken in the complete reporting panel. This contrast shows that directional consistency can coexist with sensitivity to sample composition; complete reporting is not evidence that a restricted sample represents the wider international population. National aggregation also obscures differences in where diagnostic capacity is located. Fekadu et al., 2017, examined the alignment between care seeking and tuberculosis services in Ethiopia, illustrating the value of examining access below the national level. The present findings consequently support a distinction between international resource gradients and the distribution of usable services within countries, rather than treating national density as a sufficient account of access.

The international relevance of Tables 1 to 4 lies in a consistent descriptive relationship across alternative sample representations, accompanied by clear limits on its policy interpretation. Resource indicators can help identify settings where low availability coincides with low detection and where more detailed service assessment deserves priority. They cannot determine whether an additional unit of expenditure or staffing would deliver a particular improvement, nor establish a common allocation rule across health systems. Garfin et al., 2017, used patient pathway analysis in the Philippines to inform referral network design, demonstrating how national priorities can be translated into assessments of service alignment. Read alongside that evidence, this analysis supports combining international resource comparisons with operational information before selecting interventions. Its

contribution is a comparative framework that distinguishes resource availability, detection coverage and reporting composition, providing a firmer basis for international benchmarking without presenting pooled associations as policy effects.

7. Conclusion and Implications:

Closing the global tuberculosis detection gap requires understanding how available resources align with effective access to diagnosis. This analysis reveals a consistent international pattern: better resourced national settings exhibit higher detection coverage, although the strength of that relationship depends on which countries and years enter the comparison. Its contribution is to distinguish a persistent descriptive gradient from sensitivity arising through reporting composition. Strong overlap among resource dimensions also cautions against attributing detection differences to isolated inputs. These findings refine a systems interpretation of diagnostic capacity by showing that national resources should be assessed together while their operational contributions remain distinct questions. For decision makers, the evidence supports using comparative benchmarks to identify settings where resource scarcity coincides with lower detection and warrants closer service assessment. Allocation decisions should combine these benchmarks with information on diagnostic availability, referral completion and notification practices. Policy should connect resource planning with reporting coverage, making international comparisons more transparent and directing attention towards populations poorly represented in routine statistics. Operationally, programmes can examine whether existing capacity reaches patients throughout the diagnostic pathway before selecting expansion priorities. Such assessments can guide efforts to improve equitable access without assuming that greater national provision automatically produces better individual care.

The unbalanced panel creates opportunities to investigate how reporting capacity shapes international comparisons. Broader workforce coverage and documented historical releases would strengthen reproducibility and representation. National aggregates invite extensions using facility and patient records to examine geographical access, diagnostic completion and notification separately. Expenditure measures adjusted for purchasing power could clarify the role of nominal monetary differences. Designs exploiting documented policy changes could assess whether resource expansion precedes improvements in detection under credible identification assumptions. Comparative analyses across institutional settings could then establish where the observed gradient persists, where it weakens, and which service arrangements explain variation in its magnitude.

References:

1. Bishara, A. J., & Hittner, J. B. 2012. Testing the significance of a correlation with nonnormal data: Comparison of Pearson, Spearman, transformation, and resampling approaches. Psychological Methods, volume 17, issue 3, pages 399-417. https://doi.org/10.1037/a0028087
2. Das, J., Kwan, A., Daniels, B., Satyanarayana, S., Subbaraman, R., Bergkvist, S., Das, R. K., Das, V., & Pai, M. 2015. Use of standardised patients to assess quality of tuberculosis care: A pilot, cross sectional study. The Lancet Infectious Diseases, volume 15, issue 11, pages 1305-1313. https://doi.org/10.1016/S1473-3099%2815%2900077-8
3. Fekadu, L., Hanson, C., Osberg, M., Makayova, J., Mingkwan, P., & Chin, D. 2017. Increasing access to tuberculosis services in Ethiopia: Findings from a patient pathway analysis. The Journal of Infectious Diseases, volume 216, supplement 7, pages S696-S701. https://doi.org/10.1093/infdis/jix378
4. Frenk, J., Chen, L., Bhutta, Z. A., Cohen, J., Crisp, N., Evans, T., Fineberg, H., Garcia, P., Ke, Y., Kelley, P., Kistnasamy, B., Meleis, A., Naylor, D., Pablos Mendez, A., Reddy, S., Scrimshaw, S., Sepulveda, J., Serwadda, D., &Zurayk, H. 2010. Health professionals for a new century: Transforming education to strengthen health systems in an interdependent world. The Lancet, volume 376, issue 9756, pages 1923-1958. https://doi.org/10.1016/S0140-6736%2810%2961854-5
5. Garfin, C., Mantala, M., Yadav, R., Hanson, C. L., Osberg, M., Hymoff, A., & Makayova, J. 2017. Using patient pathway analysis to design patient centered referral networks for diagnosis and treatment of tuberculosis: The case of the Philippines. The Journal of Infectious Diseases, volume 216, supplement 7, pages S740-S747. https://doi.org/10.1093/infdis/jix391
6. Hanson, C., Osberg, M., Brown, J., Durham, G., & Chin, D. P. 2017. Finding the missing patients with tuberculosis: Lessons learned from patient pathway analyses in 5 countries. The Journal of Infectious Diseases, volume 216, supplement 7, pages S686-S695. https://doi.org/10.1093/infdis/jix388
7. Kruk, M. E., Gage, A. D., Arsenault, C., Jordan, K., Leslie, H. H., RoderDeWan, S., Adeyi, O., Barker, P., Daelmans, B., Doubova, S. V., English, M., García Elorrio, E., Guanais, F., Gureje, O., Hirschhorn, L. R., Jiang, L., Kelley, E., Lemango, E. T., Liljestrand, J., … Pate, M. 2018. High quality health systems in the Sustainable Development Goals era: Time for a revolution. The Lancet Global Health, volume 6, issue 11, pages e1196-e1252. https://doi.org/10.1016/S2214-109X%2818%2930386-3
8. Lönnroth, K., Castro, K. G., Chakaya, J. M., Chauhan, L. S., Floyd, K., Glaziou, P., & Raviglione, M. C. 2010. Tuberculosis control and elimination 2010-50: Cure, care, and social development. The Lancet, volume 375, issue 9728, pages 1814-1829. https://doi.org/10.1016/S0140-6736%2810%2960483-7
9. Pai, M., Behr, M. A., Dowdy, D., Dheda, K., Divangahi, M., Boehme, C. C., Ginsberg, A., Swaminathan, S., Spigelman, M., Getahun, H., Menzies, D., & Raviglione, M. 2016. Tuberculosis. Nature Reviews Disease Primers, volume 2, Article 16076. https://doi.org/10.1038/nrdp.2016.76
10. Schober, P., Boer, C., & Schwarte, L. A. 2018. Correlation coefficients: Appropriate use and interpretation. Anesthesia & Analgesia, volume 126, issue 5, pages 1763-1768. https://doi.org/10.1213/ANE.0000000000002864
11. Sreeramareddy, C. T., Qin, Z. Z., Satyanarayana, S., Subbaraman, R., & Pai, M. 2014. Delays in diagnosis and treatment of pulmonary tuberculosis in India: A systematic review. The International Journal of Tuberculosis and Lung Disease, volume 18, issue 3, pages 255-266. https://doi.org/10.5588/ijtld.13.0585
12. Uplekar, M., Weil, D., Lonnroth, K., Jaramillo, E., Lienhardt, C., Dias, H. M., Falzon, D., Floyd, K., Gargioni, G., Getahun, H., Gilpin, C., Glaziou, P., Grzemska, M., Mirzayev, F., Nakatani, H., & Raviglione, M. 2015. WHO's new End TB Strategy. The Lancet, volume 385, issue 9979, pages 1799-1801. https://doi.org/10.1016/S0140-6736%2815%2960570-0

13. World Bank. Undated. Current health expenditure per capita, current US dollars. World Development Indicators. Series SH.XPD.CHEX.PC.CD. https://data.worldbank.org/indicator/SH.XPD.CHEX.PC.CD
14. World Bank. Undated. Nurses and midwives per 1,000 people. World Development Indicators. Series SH.MED.NUMW.P3. https://data.worldbank.org/indicator/SH.MED.NUMW.P3
15. World Bank. Undated. Physicians per 1,000 people. World Development Indicators. Series SH.MED.PHYS.ZS. https://data.worldbank.org/indicator/SH.MED.PHYS.ZS
16. World Bank. Undated. Tuberculosis case detection rate, percent, all forms. World Development Indicators. Series SH.TBS.DTEC.ZS. https://data.worldbank.org/indicator/SH.TBS.DTEC.ZS
17. World Health Organization. 2023. Global tuberculosis report 2023. https://www.who.int/publications/i/item/9789240083851