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Vaccination Convergence in Italian Regions: a comparative statics analysis *

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Abstract

This study examines regional convergence in childhood vaccination coverage across Italy from 2000 to 2021, focusing on the interaction between socioeconomic development and public health policy. Using regional data from the Italian Ministry of Health and the Global Data Lab, vaccination rates for key antigens (POL3, DTP3, EpB3) were analyzed through multivariate mixture models linking coverage to the Human Development Index (HDI). Results reveal a marked convergence: southern regions with historically lower HDI and vaccination levels have progressively aligned with the national average, driven largely by legislative reforms—particularly Law 119/2017, which reintroduced and expanded mandatory immunization. However, persistent outliers, such as the Province of Bolzano, highlight the influence of cultural and linguistic factors beyond socioeconomic determinants. The findings underscore that sustained national coordination, coupled with region-specific communication and trust-building strategies, is essential to achieving equitable vaccination coverage and long-term public health cohesion.

Keywords: Vaccination coverage; Regional convergence; Health policy; Italy; Human Development Index (HDI)

JEL Classification: I12, I38.

1 Introduction

Childhood vaccination coverage is a crucial indicator of the performance of national health systems and the effectiveness of National Vaccination Plans [1]. Vaccines are widely recognized as one of the most effective public health interventions, significantly reducing the burden of infectious diseases. Their ability to prevent severe clinical outcomes for individuals and curb the spread of pathogens within communities is well established [2, 3]. From 2000 to 2019, it is estimated that global vaccination programs averted 37 million deaths [4]. The World Health Organization (WHO) attributes childhood vaccination as a primary driver in reducing under-5 mortality, which has fallen by more than 50 % since 1990 [5]. Their ability to prevent severe clinical outcomes for individuals and curb the spread of pathogens within communities is well established [2, 3]. Moreover, vaccination plays a key role in combating antimicrobial resistance by preventing infections and thereby reducing the need for antibiotics [6, 7]. This is critical as antibiotic misuse is a leading factor in developing drug-resistant strains of bacteria. A literature review revealed that immunization programs have been shown to reduce antibiotic use by 5 to 10% in randomized controlled trials and by as much as 64% in observational studies [8].This highlights vaccination as an essential tool in the global fight against antibiotic resistance, a growing public health threat [9].

Vaccinations have long been recognized as one of the most effective tools in public health, preventing the spread of infectious diseases, reducing mortality rates, and minimizing healthcare costs. Country-specific studies, such as those conducted in France, have demonstrated the importance of completing

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the full vaccination cycle to eradicate diseases on a national scale [10]. Additionally, evidence from Rwanda highlights how comprehensive immunization campaigns have dramatically reduced the incidence of vaccine-preventable diseases like polio and measles, contributing to significant improvements in child health outcomes [11]. The benefits of vaccination are evident not only on a global scale but also within specific regions, where case studies highlight its impact on community health. For instance, Italy's regions have served as valuable case studies for understanding vaccination's role in public health. In particular, regions like Veneto, Emilia-Romagna, and Tuscany have provided critical insights through their differing approaches to vaccination policies and their outcomes in public health.

In Veneto, the temporary cessation of mandatory vaccinations in 2007 created a unique opportunity to study the effects of voluntary vaccination policies on disease prevalence. Initially, vaccination rates remained relatively high; however, a gradual decline was soon observed, leading to localized outbreaks of preventable diseases like measles, mumps, and rubella. This scenario underscored the critical role of mandates in maintaining community immunity and preventing outbreaks, as vaccination rates alone are insufficient without policies supporting them. The rise in measles cases specifically served as a public health warning, prompting Veneto to reconsider its stance on mandatory vaccinations as a public health safeguard [12, 13].

In contrast, regions that continued to uphold mandatory vaccination policies, such as Emilia-Romagna, demonstrated a strong correlation between policy enforcement and high immunization coverage. Following the national vaccination law of 2017, which reintroduced mandatory vaccinations for key childhood vaccines, Emilia-Romagna reported a stabilization in vaccination coverage and fewer disease outbreaks compared to regions with voluntary policies. This consistency emphasizes the role of legislative support in achieving and maintaining herd immunity, especially as vaccine hesitancy grows worldwide [14, 15].

Tuscany provides an additional example of how proactive vaccination campaigns, even within a framework of mandatory policies, can further improve public health outcomes. In this region, targeted educational campaigns focusing on the benefits and safety of vaccines have contributed to higher-than-average vaccination rates. The region's success has been attributed to policy enforcement and public trust fostered through outreach and communication efforts that emphasize the role of vaccines in protecting both individual and community health [14].

Italy's varied regional approaches and experiences illustrate that the benefits of vaccination extend beyond individual protection to encompass community-wide health stability. Case studies from these regions reveal that vaccination policies must balance public health mandates with effective communication and education to counter vaccine hesitancy. Overall, the Italian regional data reinforce the evidence that high vaccination coverage, backed by policy support and community trust, is essential for preventing outbreaks and ensuring long-term public health security.

These regional comparisons within Italy underscore the importance of high vaccination rates in achieving herd immunity and preventing outbreaks. Moreover, they demonstrate how different policy approaches can influence public health outcomes, reinforcing the necessity of vaccines not only as individual health interventions but as essential components of community protection.

In this context, this work tries to provide an overview of the different paths of vaccination at the regional level in Italy. In particular, it will be possible to assess whether Italian regions have converged over time to higher level of vaccination coverage. The work proceed with Section 2 in which follows a history of the legislative framework in Italy for voluntary and mandatory vaccination. Sections 3 and 4 present the data and the methodology employed for the analysis. Results will be discusses in Section 5 and will be commented in Section 6. Ultimately,in Section 6.1 conclusions and policy implications will be drawn. The analysis highlighted how, despite socioeconomic differences, Italian regions have progressively converged to higher vaccination coverage for the diseases considered. However, the algorithm highlighted the case study of the Province of Bolzano, which was characterized by lower immunization coverage, despite higher development. This work highlights that achieving and maintaining higher vaccination levels requires a unified strategy that involves all stakeholders. This is more valid when dealing with communities characterized by different cultures and language barriers.

2 Italian Legislative Framework for voluntary and mandatory vaccination

Italy's legislative framework for vaccination reflects a complex evolution between mandatory and voluntary approaches, shaped by regional autonomy, vaccine hesitancy, and epidemiological threats. Historically, the country introduced compulsory immunization early: diphtheria (Law No. 891/1939), tetanus (No. 292/1963), polio (No. 51/1966), and hepatitis B (No. 165/1991). However, the 2001 constitutional reform (Law No. 3/2001) devolved most health competencies to the Regions and Autonomous Provinces, fostering policy heterogeneity and gradually eroding the national coherence of immunization programs [16].

By 2005, the State-Regions Conference enabled some regions to experiment with the suspension of mandatory vaccinations and administrative sanctions. Veneto's 2007 shift to voluntary immunization was a pivotal example, revealing initially stable but subsequently declining coverage and local outbreaks of preventable diseases [16]. This policy experimentation was further complicated by increasing vaccine hesitancy, driven by mistrust in pharmaceutical companies and institutional inconsistency. A national survey cited in ACTA Medica (2020) found that over 15% of Italian parents expressed some degree of hesitancy, particularly regarding MMR and newer vaccines like HPV [16].

To counter declining coverage—dropping below 90% for several key vaccines by 2015—the government enacted Decree-Law No. 73/2017, later converted into Law No. 119/2017, reinstating and expanding mandatory childhood vaccinations from 4 to 10. The law linked school attendance to immunization compliance, introduced fines, and mandated public health interviews with parents who were hesitant about vaccines. Notably, the reform emphasized both enforcement and persuasion, incorporating exemptions for medical contraindications and proof of immunity through serology[16].

Legal complexity also emerged around indemnification for vaccine-related adverse events. Italian Law No. 210/1992, later expanded by Laws No. 229/2005 and No. 641/1996, provided compensation not only for compulsory vaccinations but eventually for some recommended ones, further blurring the line between recommendation and mandate [16].

As emphasized by [16], although vaccines have been mandatory in Italy since the 1930s (e.g., anti-diphtheria) and 1960s (e.g., anti-tetanus, anti-polio), inconsistent enforcement, limited sanctions, and regional autonomy led to a fragmented system. The resurgence of preventable diseases and falling coverage rates in the 2010s triggered a re-centralization of authority. The 2017 reforms, together with the alignment of regional immunization calendars through the PNPV, contributed to reducing disparities. Despite these reforms, vaccination rates remained uneven across regions, prompting further centralization in the 2023 National Vaccination Plan, which reaffirmed compulsory childhood immunizations while enhancing regional flexibility for outreach and communication.

3 Data

Data on vaccination rates in Italian regions have been taken from the Ministry of Health for the period 2000-2021 for the following diseases: POL3, DTP3, Hib3. The Italian Ministry of Health provides comprehensive regional datasets on pediatric and adolescent vaccine coverage through its official portal. These datasets include annual vaccination rates by birth cohort for key antigens: POL3 (third dose of polio, a proxy for hexavalent coverage), DTP3 (diphtheria-tetanus-pertussis), EpB3 (hepatitis B). Coverage is reported at fixed ages—commonly 24, 36, and 48 months —and at school entry (5–6 years), enabling both temporal and age-cohort tracking. Data are disaggregated by Region and Autonomous Province, highlighting geographic disparities. Table 1 shows the summary of the variables analysed.

For instance, the national average POL3 coverage at 24 months was approximately 94–95%, with regions such as Sicily falling slightly below (89–90%), while most Northern regions exceed the WHO target of 95%. Similar patterns appear for DTP3 and EpB3, which typically maintain high national coverage but reveal below-95% levels in certain regions throughout 2020–2021. *9//////////////////6- Data on the socioeconomic context have been retrieved from the ISTAT Regional Statistics: GDP, GDP per capita, Employment. Data on the Human Development Index at subnational level (NUTS 2) have been retrieved from the Global Data Lab. The Human Development Index (HDI) is a composite indicator developed by the United Nations Development Programme to assess countries' average achievements

Statistic	Year	N	Mean	St. Dev.	Min	Max
GDP per capita	2000-2021	460	28,201.890	7,795.098	15,307.630	43,468.780
Employment	2000-2021	460	1,133.270	1,097.873	58.700	4,925.100
POL3	2000-2021	450	94.946	3.630	75.620	100.000
DTP3	2000-2021	447	94.035	5.105	48.000	99.600
EpB3	2000-2021	447	94.554	3.901	75.750	99.900
HDI	2000-2021	437	0.873	0.027	0.807	0.934

Table 1: Summary Statistics

in three fundamental dimensions of human development: a long and healthy life, access to knowledge, and a decent standard of living. Specifically, it integrates life expectancy at birth (health), mean and expected years of schooling (education), and gross national income per capita adjusted for purchasing power parity (economic standard of living) into a single score spanning from 0 to 1. Each component is first transformed into a normalized index. Then the geometric mean of these indices is calculated, reflecting the diminishing marginal contribution of income and ensuring balance among the dimensions. Since its inception in 1990, the HDI has shifted evaluative focus from purely economic metrics like GDP to a broader view of well-being, encouraging policymakers to examine how comparable income levels may still yield different developmental outcomes when education and health vary. While the HDI serves as a valuable summary measure, it does not capture inequality, poverty, empowerment, or environmental sustainability; thus, analysts often supplement it with additional indices—such as the IHDI, GDI, and MPI—to provide a more nuanced understanding of development. To address the often-concealing effect of national averages, the Subnational Human Development Index (SHDI) was developed by the Global Data Lab, translating the standardized HDI methodology to the regional level. SHDI is calculated by first estimating regional indicators—in education, health and income—using census and survey data (including proxies such as under-five mortality and household wealth) and then aligning these estimates to national HDI benchmarks. The three dimension indexes are aggregated via a geometric mean to produce a region-level score comparable across all areas, while ensuring consistency with the UNDP's national HDI.

This subnational decomposition covers over 1,600 regions across more than 160 countries since 1990, and reveals notable within-country inequalities: in low- and middle-income nations, regional disparities typically double overall human development inequality, while in highly developed nations they increase by roughly 12%. By illuminating "pockets" of low development previously obscured by national aggregates, the SHDI supports more nuanced SDG monitoring and policy targeting, making it a powerful complement to the national HDI framework

4 Methodology

Mixture distributional approaches (multivariate mixture densities).(See, for instance,[17] and [18] allows us to take into account the possibility of heterogeneous behaviors (unknown subpopulations may have different parameters and different dynamics over time). So that we may consider within- and across-group tendencies. Put in a simple way, we may assess how units within groups become more or less similar over time and how groups become closer or more distant to others over time.

Now, consider that we want to model the tendency of k bivariate clusters of a set of two variables $\mathbf{X}$, namely human capital and vaccination shares, without a priori definition of clusters. This is equivalent to a missing data problem and is usually solved through the EM (expectation-maximization) algorithm [19]. The density of each bivariate observation, $\mathbf{X}$i, is a weighted average of the density of each cluster. Here, N_2 is the bivariate (let's say normal Gaussian) density of vaccination shares and human capital with mean μ_s and covariance Σ_s for each cluster s, and ψ_s is the probability that observation i becitens to group s. This way, the unconditional function on the left-hand side (with a common set of ψ, μ, Σ) is a weighted average of the k different component densities on the right-hand side, according to Bayes' rule.

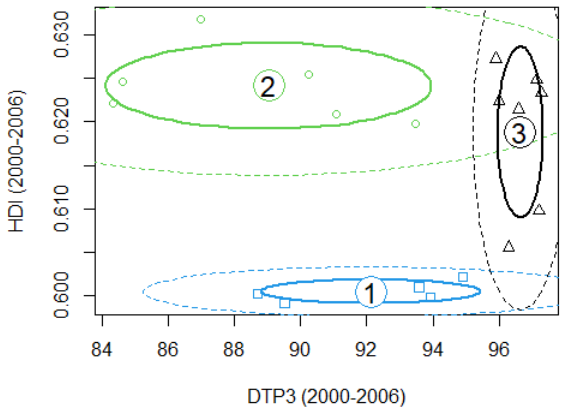
The alternate steps of density computation and parameter estimation continue until the algorithm

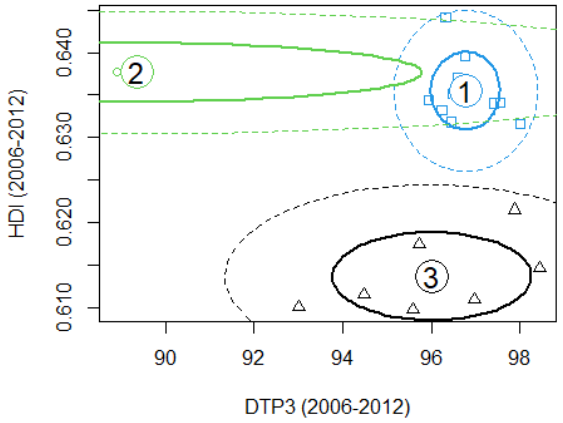
converges. Practical implementation problems include:

1. the choice of k, the number of clusters, usually determined by the Bayesian Information Criterion [20], [21];
2. the constraints about the Σ matrix, which in principle contains three parameters: volume, shape, and orientation. The most general model allows differences in all characteristics for the clusters, while the most restrictive model puts constraints to have the same volume, shape, and orientation of each cluster covariance. BIC is considered as a guide for this set of choices [20];
3. the log-likelihood convergence criterion (change in log-likelihood each iteration, according to a common rule of thumb lower than 1^{E-6});
4. the use of different sets of starting probabilities to avoid the usual problem of local optima in the mixture solution. Estimations are implemented through the R code of flexmix by [22]

5 Results

We divided the sample into three distinct periods: 2000–2006, 2006–2012, and 2012–2018. For each period, we perform a multivariate clustering analysis on vaccination coverage and socioeconomic data. By examining the composition and density of clusters over time, we aim to assess convergence trends in vaccination coverage across regions. Figure 1 shows the results for the DTP3 vaccine with HDI.





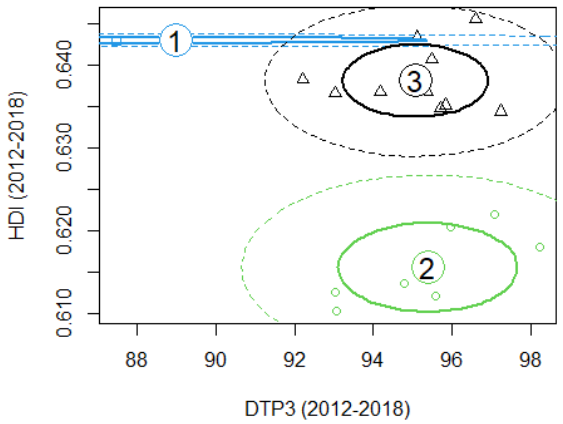


Fig 1: Results Cluster DTP3 vs. HDI

The optimal number of clusters for tuning the algorithm is 3 for all periods. The configuration of the three clusters is maintained in the three periods. However, the numerosity of cluster 1 decreases up

to one region in the period 2012-2018. In terms of composition, the clustering follows the North-South (not only) geographical distribution of the Countries. However, most of the difference is more related to the HDI levels and less to vaccination. Regions in the South show lower levels of HDI and DTP3 coverage, especially in the first two periods. The intermediate cluster is formed by mostly regions at the center-south, namely Abruzzo, Lazio, Molise, and Tuscany. Those regions have been absorbed mostly into the cluster of regions of Northern Italy. The only region left is the Autonomous Province of Bolzano, showing a relatively higher level of HDI coupled with a lower level of coverage of DTP3. The same pattern is shown for another vaccine, such as EpB3 and POL3, in Figures 2 and 3.

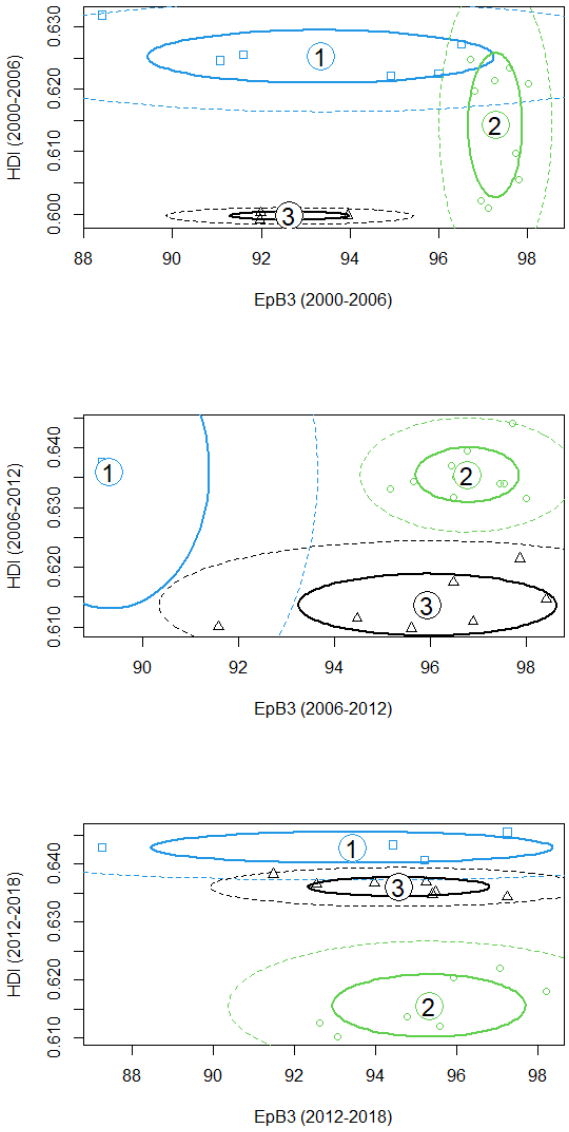


Fig 2: Results Cluster EpB3 vs. HDI

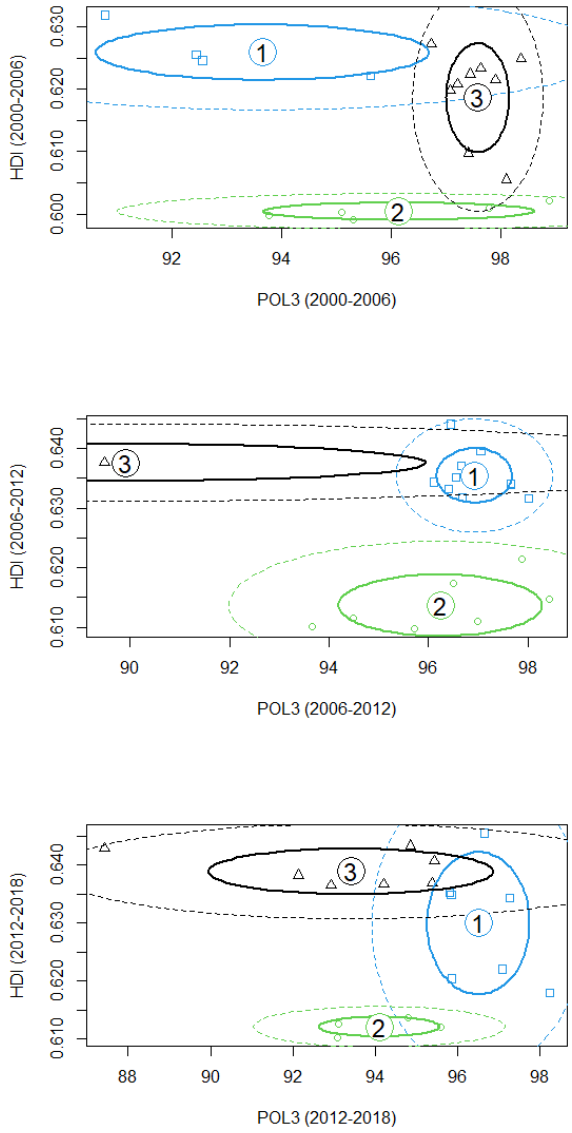


Fig 3: Results Cluster POL3 vs. HDI

6 Discussion and Conclusion

Our findings show stable cluster configurations over time but reveal strong convergence dynamics: Southern regions with low HDI and vaccination rates uptake gradually transition into higher-performing clusters, leaving only one region in the lowest cluster by 2012–2018.

These trends might be interpreted in light of Italy's robust legislative and institutional framework. Since the inception of the National Health Service (Servizio Sanitario Nazionale) in 1978, Italy has offered universal healthcare through regional Local Health Authorities (ASL), coordinated via the Ministry of Health. National Vaccination Plans (PNPV) introduced in 1999–2000, 2005–2007, and 2012–2014 systematically promoted increasing immunization coverage, expanding the schedule beyond core childhood vaccines and embedding them within a life-course framework [23].

The 2017–2019 PNPV and its enforcement through Law 119/2017 (Decree-Law 73/2017) marked a turning point by extending compulsory vaccinations from four to ten, and by imposing school-entry

restrictions and penalties for non-compliance. Early implementation of this "hard" policy was associated with sharp rises in vaccine coverage nationally [24, 25]. These nationwide reforms appear to have driven the observed convergence: regions more historically lagging in HDI and vaccination uptake caught up, reducing interregional disparities.

However, regional autonomy remains significant. The case of Bolzano—high HDI with lower DTP3 coverage—highlights that socioeconomic factors alone do not fully account for coverage levels. Instead, local institutional responses, communication strategies, and trust in public health systems likely modulate uptake [26]. For instance, some studies highlighted that there are also cultural and linguistic barriers, along with historical skepticism with the central government, that have influenced vaccination coverage in South Tyrol [27, 28, 29]

Moreover, the clustering analysis reflects the dual impact of policy and culture. Veneto's earlier 2007 suspension of mandatory vaccines, under the "nudging" approach, demonstrated the limitations of voluntary schemes, as evidenced by coverage declines that prompted the national reinstatement of compulsory immunization. The shift away from voluntary nudging toward nationwide mandates underscores the importance of legislative reinforcement to secure equitable vaccine coverage.

In sum, convergence in regional vaccination coverage appears closely tied to national policy reforms that standardized immunization requirements and reduced regional variation in vaccine delivery. Yet the persistence of outliers suggests that local trust, communication, and governance remain crucial [13]. Future policies should therefore combine national mandates with region-specific engagement strategies to sustain convergence and ensure equitable public health outcomes across all Italian regions.

6.1 Conclusions and policy implications

This study has examined regional convergence in childhood vaccination coverage in Italy in relation to socioeconomic development, using HDI as a proxy. The multivariate clustering analysis over three distinct periods (2000–2006, 2006–2012, 2012–2018) reveals a clear trend toward convergence: regions historically characterized by lower HDI and lower vaccination rates—primarily in the South—are progressively aligning with the national average, both in terms of health outcomes and development indicators.

This convergence reflects, at least in part, the cumulative effect of national vaccination policies, especially following the implementation of the National Immunization Prevention Plans (PNPV) and the 2017 extension of mandatory vaccines through Law 119/2017. These centralized measures have been critical in harmonizing vaccination standards across the country, mitigating the historical North–South divide.

From a policy perspective, several key implications emerge. While national mandates have proven effective, future strategies should maintain this universal framework while allowing for tailored interventions that account for regional socio-demographic and cultural differences [30, 31, 32]. In this context, it is important to construct a solid health communication strategy to strengthen trust of the population [33, 34]. In regions where convergence has occurred more slowly, targeted health literacy campaigns and community-level engagement may accelerate progress and sustain gains, especially in populations facing structural or educational disadvantages [35]. Improvements in HDI-related components—such as education, income, and healthcare access—appear to facilitate vaccination uptake. Policies that integrate social development with health interventions are likely to generate more sustainable improvements. Continued surveillance of regional disparities through high-resolution data and multivariate methods can guide real-time adjustments in public health strategies and allow for early identification of emerging gaps.

In conclusion, convergence in vaccination coverage across Italian regions suggests that equity in public health outcomes is an achievable goal, but it depends on sustained political commitment, regional coordination, and integration of health and social policy.

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