Modelling and Assessing Public Health Policies to Counteract Italian Measles Outbreaks

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ABSTRACT

This study aims to understand, through explanatory research, the key factors that led to the 2017 measles outbreak in Italy, the causes of the low level of immunisation and the causes of possible cyclical phenomena of measles epidemics. This topic's comprehension has required a holistic approach, merging epidemiological aspects, socioeconomic aspects (including the evolution of mistrust in vaccinations, infodemy and fake news) and health law constraints. A specific SIR System Dynamics (SD) model was built to reproduce the relevant cause-and-effect relationships between social interactions, the public institutions' behaviour and the Measles outbreaks. SD results permit the assessment of the health policies to counteract the measles outbreaks. Findings, limits and further research recommendations are briefly reported in the conclusions.

KEYWORDS: System Dynamics; Infodemic; Measles; Communicable diseases; SIR Model; Vaccination; Public Health

1 Introduction

Communicable diseases have always been an essential part of human life. Since the beginning of recorded history, epidemics have invaded populations, often causing many deaths before disappearing and possibly recurring years later, often diminishing in severity as populations developed some immunity (Brauer, 2017). Nowadays, it is common to talk about infections, micro-organisms from other continents and epidemics, and discuss prevention and systems to counteract outbreaks of infectious diseases. Infectious diseases were responsible for most of the considerable global burdens of premature death and disability until the end of the twentieth century, when that distinction passed to noncommunicable diseases (Holmes et al., 2017). However, infectious diseases, albeit in decline, remain a significant cause of death and disability-adjusted life-years worldwide, especially in low- and middle-income countries[1].

The successful diagnosis, prevention and treatment of a wide array of infectious diseases has altered the fabric of society, providing significant social, economic and political benefits (Fauci, 2001). However, recent events regarding SARS-CoV-2 (Covid-19) have shown how much the previous claims had a consistent fragility; some aspects, as the presence of new viruses deriving from natural mutations (Andersen et al., 2020), as well as the presence of other pathogens of viral and bacterial origin (Reperant and Osterhaus, 2017), show their repercussions not only towards public health in the strict sense but also social, economic and political aspects. Indeed, events related to the SARS-COV-2 pandemic have again shown global public health's precariousness and the strong correlations between public policies, health practices, and social behaviours. Social behaviours are also closely linked to habits, education, culture, and, in specific contexts, affected by fake news, causing a sort of friction in implementing best practices for health prevention (Orso et al., 2020). Furthermore, vaccination policies have often faced the tension between public health targets and individual freedom, despite overwhelming evidence supporting vaccinations' safety and benefits (Ropeik, 2013; Salmon et al., 2006). Nowadays, Vaccine hesitancy is particularly evident regarding the Covid-19 pandemic (Soares et al., 2021).

Although the diffusion of fake news and related complications are not new phenomena, the study aims to focus on their impact on the measles epidemic in Italy, trying to reproduce an SD model that represents the main dynamics related to the exponential oscillatory behaviour from 2005 to 2017, as reported in Fig.1.

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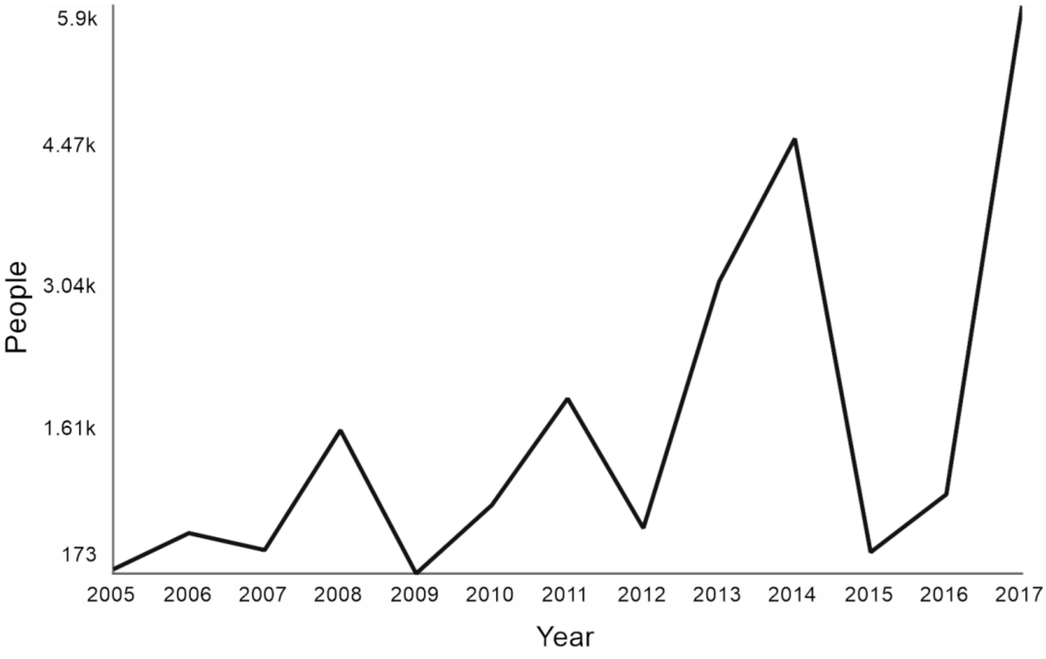
[1] https://www.who.int/news-room/fact-sheets/detail/the-top-10-causes-of-death

Fig.1 Measles – Number of Cases (Suspected and Confirmed) in Italy



Source: WHO

The topic of measles is already well known; several surveys (Filia et al., 2013) and case studies (Bechini et al., 2013) have analysed the diffusion of the measles vaccination in Italy. While global measles vaccination coverage has increased, resulting in a significant reduction in measles mortality in the world (De Vries et al., 2015, p. 1), according to the Italian healthcare system and reported in Fig. 1, in Italy, the number of infectious people dramatically increased in 2016 from 862 to 5397 (Adamo et al., 2019). Meanwhile, the trivalent MMR (measles, mumps and rubella) infant vaccination coverage decreased by 5% from 90.4% in 2013 to 85.3% in 2015 in Italy[2]. The Vaccine Confidence Project reported that while Italians did not perceive measles as a severe problem, antivaccine movements gained popularity, dangerously publicising unfounded vaccine safety concerns. A reduction of investments in prevention may have stimulated the growth of the no-vax community, which started with the fraudulent publication of Wakefield (1998), now retracted, which affirmed a correlation between the MMR vaccine and the appearance of autism and bowel diseases (The Editors of The Lancet, 2010). So far, studies report the absence of a correlation between the MMR vaccine and autism (Hviid et al., 2019). The counteraction of disinformation about vaccines by health authorities is part of the solution, but vaccines' loss of confidence goes far beyond misinformation. Communities, social environments and educational levels are a few examples of

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[2] https://www.epicentro.iss.it/vaccini/dati_Ita#morbillo

factors affecting vaccine confidence. Education and transparency are essential aspects to keep in mind when increasing vaccine confidence (Arif, 2018; Lambert & Podda, 2018). According to Tagliabue et al. (2019), vaccine education should not be limited to raising expert vaccinologists and educating the general public. Vaccine hesitancy is growing and is a significant major threat to vaccine effectiveness, as reported by the Vaccine Confidence Project[3]. In 2019, the WHO (World Health Organisation)[4] defined vaccine hesitancy as one of the planet's top ten global health threats. Besides, the mentioned project states that 14.6% of the Italian population mistrust vaccines, although more in-depth reasons can be found for vaccination hesitancy. In this context, the misuse of social media information without a filter control, endogenously defined by investments in education and culture and exogenously defined by external audits, could lead to increased vaccine hesitancy (Arif et al., 2018). Vaccine hesitancy is also reinforced when Italian regions with financial problems devote less attention and fewer resources to prevention activities (Adamo, 2016, p. 1). However, after implementing the mandatory childhood immunisation programme, coverage rose to 91.84%[5], and the number of infectious cases fell from 5404 cases in 2017 to 2682 in 2018 (Adamo et al., 2019). Although several studies have focused on the outcomes regarding vaccinated people, infectious people and deaths, socioeconomic analyses could play a critical role in fostering individual and societal governmental decisions about immunisation (Adamo et al., 2016, p. 1; Thompson & Odahowski, 2016, p. 1377).

This study aims to assess the impact of Italy's health policies to manage the measles outbreaks by using a System Dynamics approach to developing an explanatory model of the issue. In addition to including the political levers and financial constraints of Italian public spending, this model aims to ascertain the dynamic complexity, considering the coexistence of epidemiological and social aspects. Some health policy levers to counteract the measles outbreaks have been assessed through the SIR SD Model; relevant considerations about the vaccination capacity, the mandatory vaccination system, investments in health educations and eHealth have been analysed. Furthermore, the evaluation of this specific issue could improve the surveillance system that allows the control of the spread of infectious diseases and the monitoring of the secondary effects of immunisation (Levin et al., 2011).

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[3] http://www.vaccineconfidence.org/research/the-state-of-vaccine-confidence-2016/
[4] https://www.who.int/news-room/feature-stories/ten-threats-to-global-health-in-2019
[5] https://www.epicentro.iss.it/vaccini/dati_Ita#morbillo

2 Theoretical Background: Modelling dynamic complexity of infectious diseases.

Previous behavioural modelling analyses have been applied to the assessment of public health policies, linking the spread of communicable diseases with situational awareness, public attention and the community's response (Sharareh et al., 2016; Subyan et al., 2018) or analysing the factors influencing public health services provided by the national centres for disease control and prevention (Li et al., 2019). Indeed, the recent spread of increasingly advanced vaccines has highlighted the importance of mathematical modelling studies. Mathematical models are intended to help understand the observed epidemiological tendency of diseases, support and guide data collection to understand disease behaviour better and define programmes for their control. Mathematical models tend to organise population variables, such as births, deaths, recoveries, chronicity and transmission rates, to formulate mathematical algorithms that capture the essence of phenomena like the natural history of the disease and the impact of vaccinations (Gasparini, 2009). A model can also foster the decision-making process to make projections regarding essential issues, such as intervention-induced changes in disease outbreaks. Sterman (2002), regarding the use of mathematical models, emphasised the need to explain the models' hidden assumptions and biases by listening to others with respect and empathy. To use mathematical models effectively for investigating the dynamics of the spread of a pandemic, including possible control strategies, there is a need to be confident that the values used for the various parameters in the model correspond to reality. Although some parameters can be determined by previous knowledge, others must be estimated by fitting the model to the available data (Huppert & Katriel, 2013, p. 1003).

In the mathematical modelling of disease transmission, there is a trade-off between strategic or straightforward models; the latter models omit most of the details and are designed only to highlight general qualitative behaviour, detailed or tactical models, usually designed for specific situations. Detailed models are generally difficult or impossible to solve analytically, and hence their usefulness for theoretical purposes is limited, although their strategic value may be high (Brauer, 2017, p. 117).

Nowadays, a broader critical question is what information influences the population's behaviour during a disease outbreak and how to include this in a model (Manfredi & D'Onofrio, 2013). For example, this latter aspect was mainly studied during the last outbreaks of Ebola (Sharareh et al., 2016; Pruyt et al., 2015) and H1N1 Influenza (Cauchemez et al., 2011), while other studies reported the public managerial and social aspects (Fast et al., 2015; Ozawa et al., 2016).

The eradication of infectious diseases is a substantial public, political and economic commitment in healthcare, and the intensity of efforts needed to eliminate a disease cannot be sustained indefinitely (Klepac et al., 2015). Although technological growth could push policy-makers to believe they have more power based on excellent information knowledge, without a shared vision of all stakeholders and collaborative coordination, the risk of facing unexpected adverse events could increase due to information redundancy. Planning in healthcare organisations and implementing healthcare services require complex and extended intersectoral collaboration, with stakeholders often coming from diverse backgrounds and with a range of priorities and agendas. Without an understanding of the series of interconnecting systems that influence clinical care delivery, it is impossible to improve healthcare operations. Patients interact in a context where different levels operate. Environmental causes, including intense financial pressures, complex operating structures and cultures with multi-stakeholder leaderships that resist change, are commonly cited for the failure of healthcare organisations' execution. Furthermore, the lack of coordination between different departments lies in the absence of comprehension of the dynamic causality between strategic objectives and specific financial or operational outcomes.

The complexity is a significant cause of amplifying “wicked” social issues, whose sustainable fixes cannot be found in isolated and sectoral policies, such as: improving service delivery, reforming institutional systems through laws and regulations, and launching programs to change the culture and attitudes of people. Although each of these efforts might be considered as potentially helpful in responding to public needs, an implementation might not produce a set of outcomes that would ensure community resilience and endurance in the long run (Borgonovi et al., 2017, p.1).

Sometimes, it is not easily possible to understand when, where and how to deal with a social issue because some interventions may have unintended consequences and may tend to be resisted or undermined by opposing interests or as a result of limited resources or capacities. According to Morecroft (1998), Senge (1990) and Sterman (1994), the source of this limits regards the dynamic complexity as a feature of an unforecastable system due to interconnections with delays, nonlinearities and multiple feedback loops, whose dominance affects the system. Dynamically complex problems are often characterised by long delays between causes and effects and multiple goals and interests that may in some way conflict with one another. In some cases, only a longer time frame is needed to evaluate how the programmes have affected the outcomes (Bovaird, 2014) due to the delay; in other cases, it implies the need to identify trade-offs over time and across space between alternative policies (Bianchi, 2016, p. 4).

Using System Dynamics (SD) methodology (Bianchi, 2016; Forrester, 1961,1969, 1971; Sterman, 2000), it has been possible to study and manage complex dynamic phenomena[6]. In the field of population health, SD modelling has been applied since the 1970s in several fields, such as disease epidemiology, substance abuse epidemiology, patient flows in emergency and extended care, healthcare capacity and delivery and the interaction between healthcare or public health capacity and disease epidemiology (Homer & Hirsch, 2006). The use of the SD methodology could manage to overcome some healthcare issues as a steering instrument to face the wicked issues of public health (Bianchi et al., 2010; Bivona & Cosenz, 2017a, 2017b; Darabi & Hosseinichimeh, 2020, Fanta et al., 2016; Ghazvini & Shukur, 2013; Homer & Hirsch, 2006). This methodology is a rigorous modelling method that allows the building of formal computer simulations of complex systems and designing more effective organisations' policies (Sterman, 2000). Indeed, it offers the possibility of creating a safe and controlled laboratory environment, in which it is possible to simulate various policies without creating any damage in reality. This approach can support planning and control systems by identifying the best strategy; moreover, it may represent an instrument of learning and engagement (Scirè, 2018, p. 355).

According to Darabi & Hosseinichimeh (2020), most SD studies in Public Health focused on regional health modelling and disease-related modelling; however, according to them, Measles is not very popular in SD research.

3 Research Methodology: Simulation Process and Model Description

This study analyses the specific issue of measles through SD methodology, involving an empirical investigation of the phenomenon considering social, epidemiological and financial factors and overcoming the scarcity of quantitative information with the support of expert opinions. Indeed, heterogeneous sources and different disciplines have required collecting data through different methods, despite the nature of the data, the state of knowledge, and the uncertainty level. A quali-quantitative approach has been adopted, combining qualitative data from open interviews with quantitative data from statistics reports[7].

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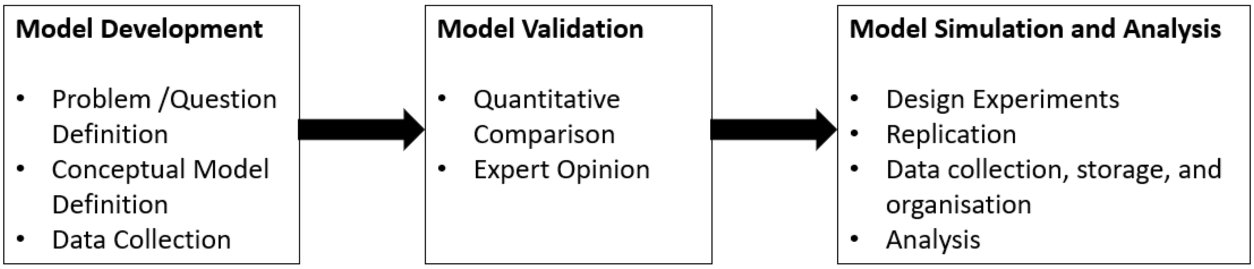
[6] The SD approach represents the system with a casual loop diagram (CLD) or with a stock and flow diagram (SFD). CLDs are simply maps showing the casual links among variables with arrows going from a cause to an effect (Sterman, 2000, p. 102). CLDs are characterised by the presence of reinforcing loops (“R” or “+”) and balancing loops (“B” or “-“). While CLDs help in understanding the dynamics of the system from a qualitative perspective, SFDs are a way to reproduce a system from a quantitative perspective (Scirè, 2018, p. 355).

[7] Mainly the reports have been collected from Istat, Eurostat, WHO and from Italian Ministry of Healthcare

According to McLaughlin and Olson's temporal-logical framework (2012, p. 262), the model was developed, as reported in Figure 2.

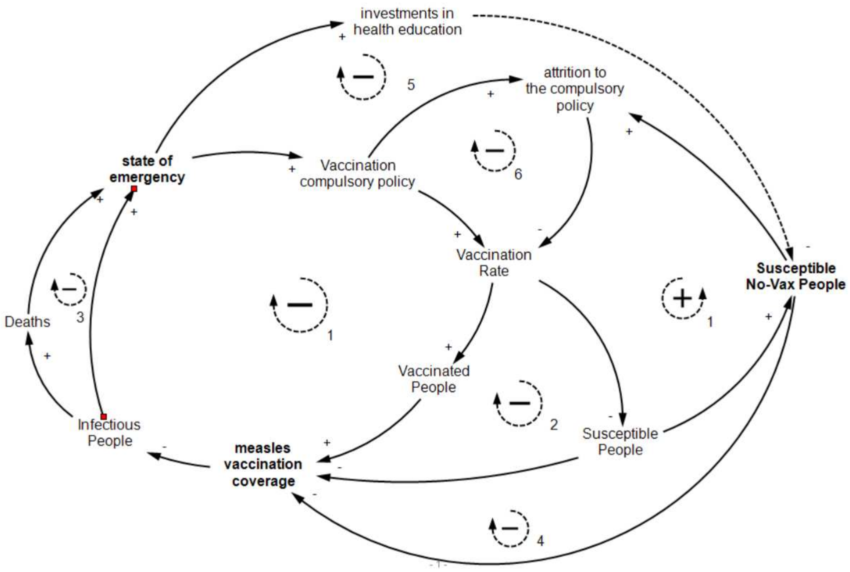
Fig. 2 Simulation Process



Source: McLaughlin and Olson, p. 262, 2012.

A preliminary conceptual CLD was built (Fig. 3) to set the hypothetical dynamics relationships through a review of the scientific literature. The main variables have tried to highlight the measles outbreaks' behaviour (Fig. 1), hypothesising an exponential oscillation behaviour with a limit to growth. The presence of reinforcing and negative loops and public policies delays represented the simulation process's starting point. Indeed, the conceptual CLD shows as an increase of Measles vaccination coverage causes a reduction of the infected cases over time, pushing the national government to reduce funding for the management of measles *prevention* in favour of other urgent diseases because of the reduction in the *state of emergency* for measles (B1). A reduction of *investments in prevention*, brings not to consider the growth of the no-vax community (B5), that started with the fraudulent publication of Wakefield (1998), now retracted, that affirmed a correlation between the MMR (measles, mumps, rubella) vaccine and the appearance of autism and bowel diseases. An increase of the *susceptible no-vax people* decreases the *measles vaccination coverage,* causing an increase of *the infectious people* and subsequently increasing the *state of emergency*. A state of emergency leads to an increase in the *investments in health education* (prevention) to counteract the growth over the time of the *susceptible no-vax people* (B5) as well as to implement more restrictive rules, as mandatory school child vaccination (B1). The policy-makers should consider a natural resistance to mandatory policies (B6) as well that they need to manage the *susceptible no-vax people* because an increase of this community affects the performance of the vaccination program (R1). The increase of the *susceptible no-vax people* reduces the *vaccination rate,* allowing *no-vax communities* to persuade *susceptible people* not yet informed adequately about vaccines.

Fig. 3 The conceptual model through a causal Loop Diagram



To collect data and validate the model, a mixed-methods approach was adopted, combining qualitative data from questionnaires submitted to public health experts with quantitative data collected from institutional websites (such as those of the WHO, the Italian Ministry of Healthcare and Eurostat).

Structured questionnaires were sent to healthcare professionals (paediatricians, general practitioners, public health experts) and healthcare sociologists[8]. Even though Guest, Bunce and Johnson (2006) propose that saturation often occurs at around 12 participants in homogeneous groups, in this specific case, the sample was smaller (7 experts in measles and public health issues); as the interviewees generally reported complete and compliant responses to what is reported by the scientific literature as well as by the National Vaccine Prevention Plan (Italian Ministry of Healthcare, 2017b)[9]. The reason for the formulation of these interviews also lies in the nature of several data, defined as "mental data" by Sterman (2000, p. 853), that are required to be extracted through interviews because they regard all the information in people's mental models, including their impressions, the stories they tell, their understanding of the system and how decisions are made. The decision to obtain the information by sending questionnaires via email and then through non-physical contact was decided due to the

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[8] The structure of the questionnaire is downloadable from this URL: https://drive.google.com/file/d/1FOuKrceHrsAVDNI2P74Y5nVeYxnHW7MA/view?usp=sharing

[9] The outcomes of the questionnaires are downloadable from this URL: https://drive.google.com/open?id=1HKPXVy-K3RI_hDpYmGjKEWotDoqmrb3s

difficulty of obtaining specific information face-to-face (due to time constraints of the interviewee and geographical constraints).

Therefore the explanatory model has included some soft variables because it aims to understand the qualitative relationships between the variables regardless of the numerical evaluation. The study intends to steer policy-makers towards a set of effective healthcare policies without offering a quantitative "magic sphere". Indeed, SD models are mathematical representations of problems and policy alternatives; it is recognised that most of the information available to the modeller is not numerical in nature, but qualitative (Luna-Reyes et al., 2003, p. 271).

The development of the SD model has required extracting several data from the WHO (World Health Organisation), Eurostat, Epicentro (the Italian website for public health) and the Vaccine Confidence Project[10]. The project has gathered data since 2012, with a reference period of 5 years; this reference period represents a satisfactory level in terms of data availability and completeness for the development of the model. *Stella Architect* of *Isee-Systems* was used to build the SD model to support decision-makers in better conceptualising the relevant system related to the investigated problem behaviour and better implementing the designed strategies to achieve a sustainable system approach in the healthcare sector.

The final model was developed following the Ministry of Health databases' statistics and the information obtained from the questionnaires and the literature. Although the model considers several assumptions because of the models' boundaries, the reference data's behaviour (Fig. 1) was partly replicated; indeed, the intention was to replicate the increasing oscillation behaviour. Furthermore, the model considers a theoretical limit to the growth of the epidemics.

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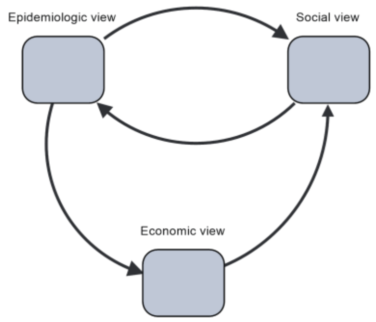
[10] https://www.vaccineconfidence.org/

Fig. 4 Interconnecting Multisectoral System Dynamics Dimensions Through Isee Stella Architect Software



The SD model (Fig. 4) includes three Stock and Flow Diagrams (the epidemiologic view, the social view and the financial view) interconnected by 120 variables, 20 stocks, 34 flows and 66 converters and 30 constants, 70 equations and 10 graphical functions[11]. Some values were defined according to the qualitative information collected from the interviews. The initial values and the parameters were estimated from the primary and secondary data collected from different research reports; in the case of the absence of quantitative data, several assumptions were made, consistent with the qualitative information collected from the literature and interviews, as the purpose of the model is to understand the dynamic relations[12]. The main assumptions are based on the value of some inputs.

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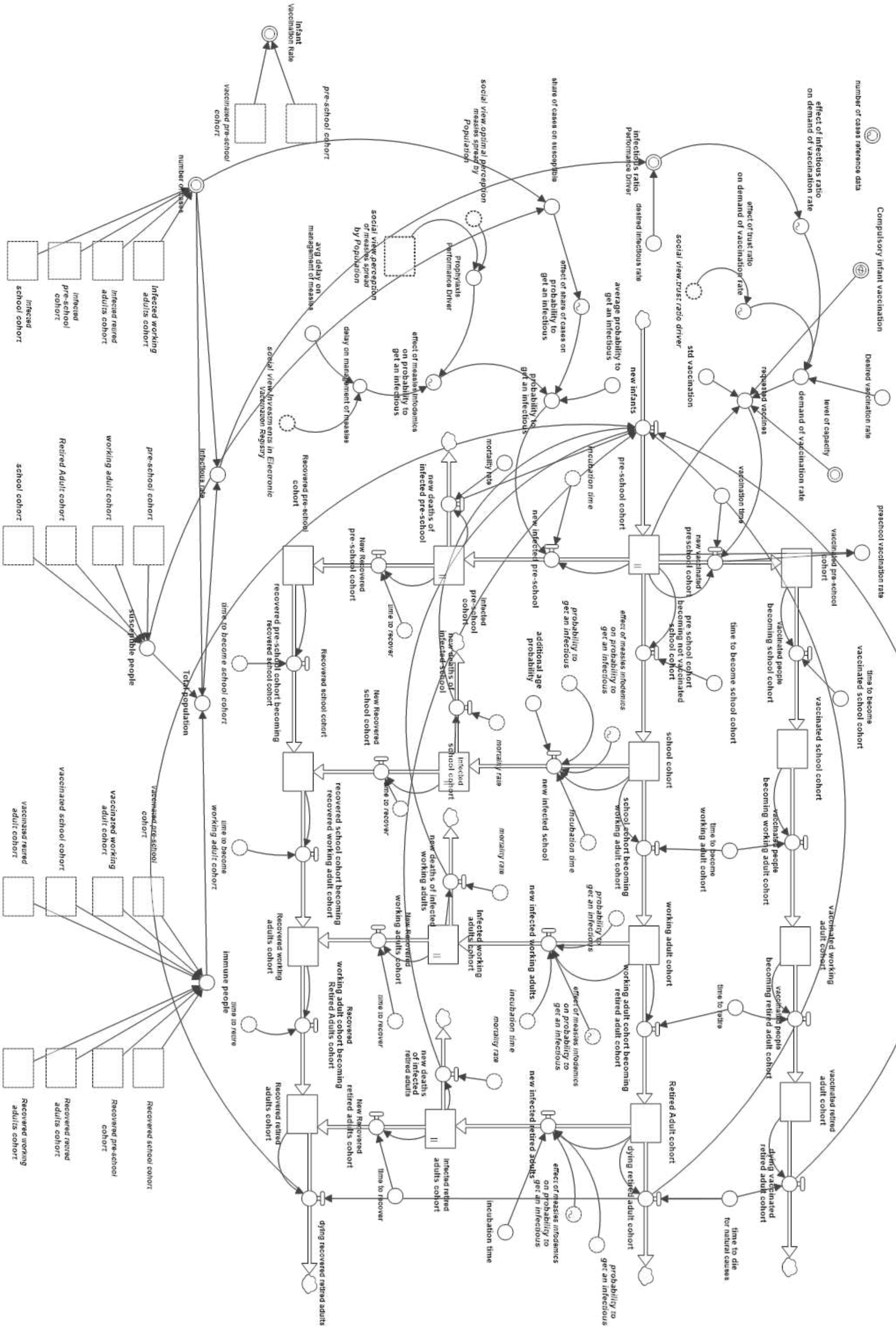
[11] The equation list is downloadable through the following URL: https://drive.google.com/file/d/1yiFDmzRKrpE2VHmHNkckUdE2MXbLhkZA/view?usp=sharing

[12] The list of the variables with their units of measure and their assumptions is downloadable through the following URL: https://drive.google.com/file/d/1r_WqNs_j3JacRRYDYt03ykocv70NhoKW/view?usp=sharing

Fig. 5 The Epidemiological View

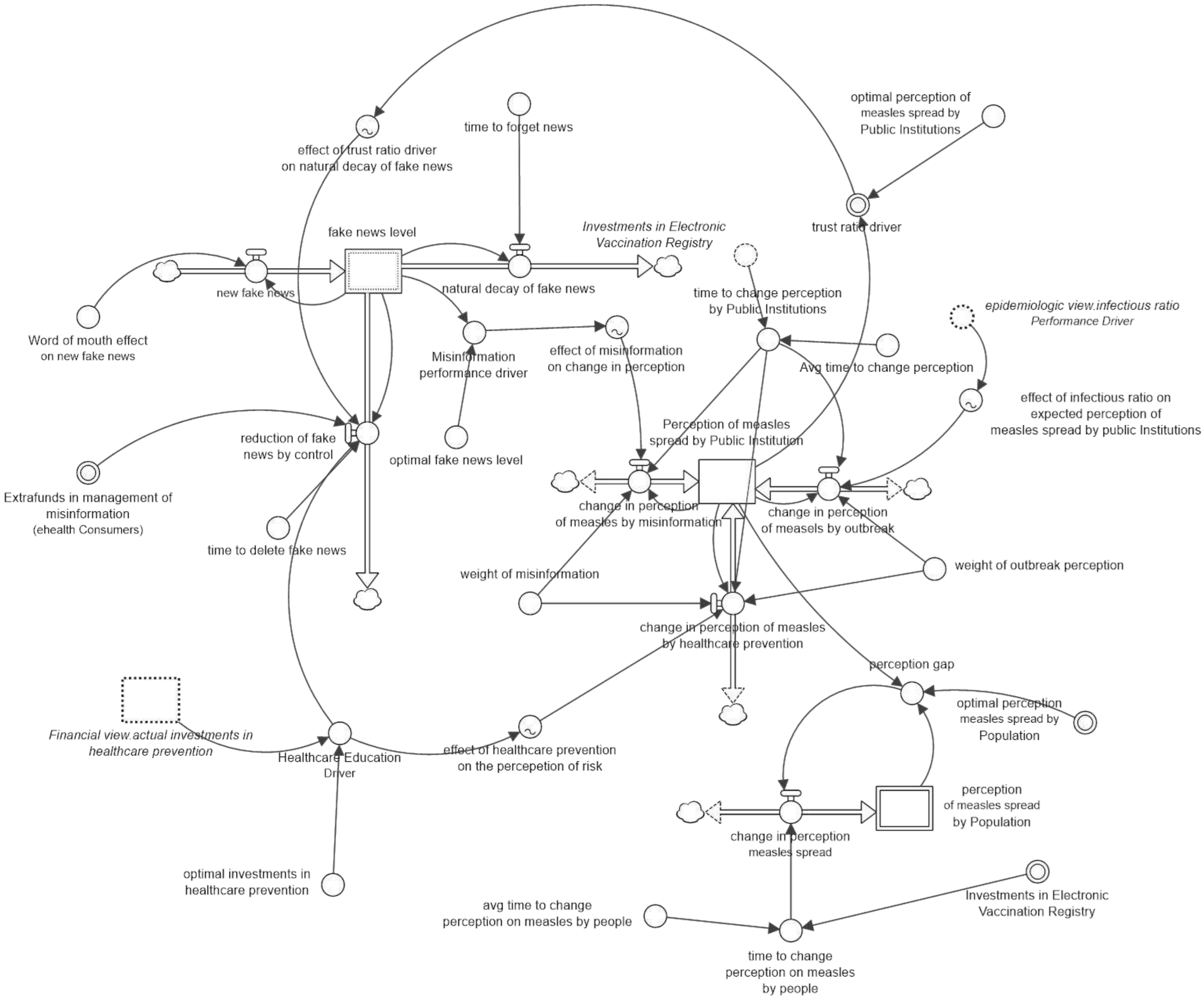


The starting point of the model of the *epidemiologic view* (Fig. 5) was to build an age-chain model where inside every age stock, a SIR (Susceptible, Infected, Recovered) model was developed (Allen et al., 1991; Chen et al., 2006; Kermack & McKendrick, 1991; Okyere-Siabouh & Adetunded, 2013; Sterman, 2000; Vynnycky & White, 2010), combined with the current implemented vaccination policies. This approach is advantageous because, with the ageing-chain model's inner structure, it is possible to understand oscillations' behaviour.

The epidemiological view was developed by making the following assumptions:

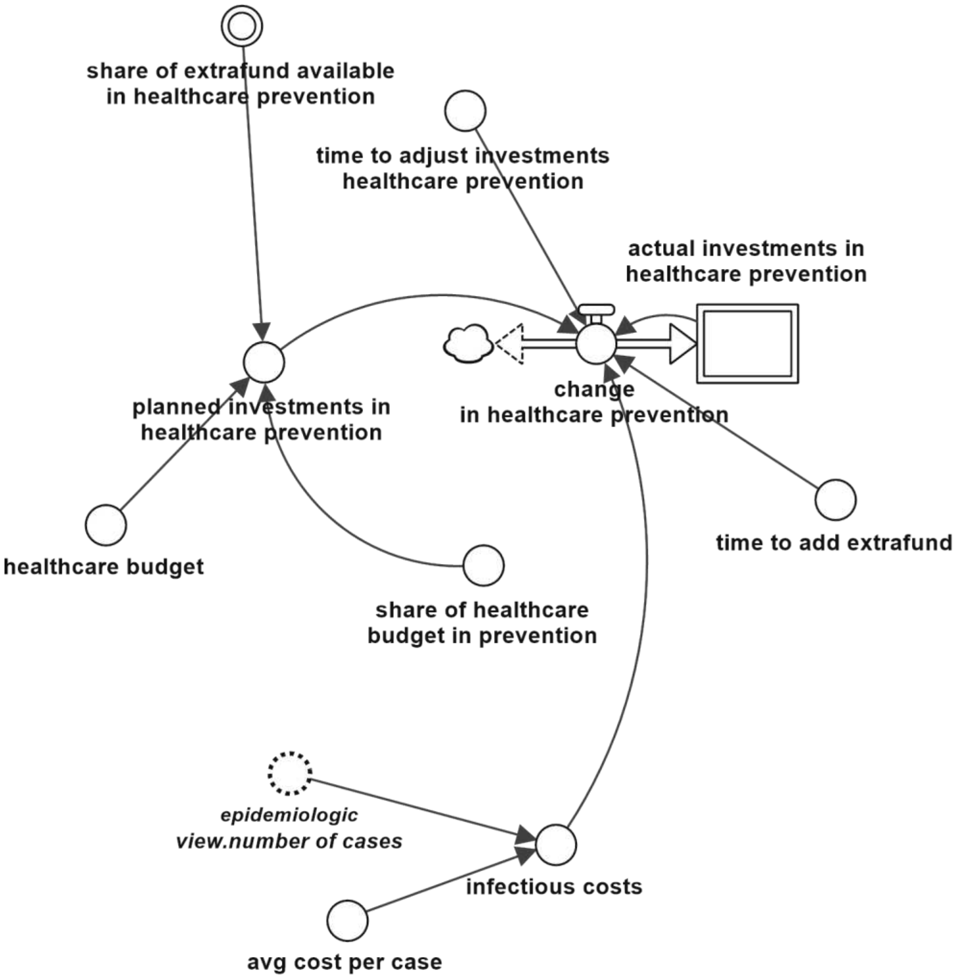
- A no-growth population, as the Italian population was almost constant during the last decade;
- Initial uniform distribution of the vaccination by age;
- A patient who survives remains immune;
- The model does not consider migration phenomena concerning both population distribution and outbreaks;
- The model considers a probability of contagion independent of age;
- The model does not contain a spatial perspective.

Fig. 6 The Social View



The *social view* (Fig. 6) of the model contains the macro-social aspects. Fake news proliferation, due to a word-of-mouth effect, is counteracted by the presence of the presumed control of misinformation and by natural decay due to the forgetting of the false information acquired. The level of fake news directly influences the level of risk perception of measles by the population and indirectly influences the policy-makers level of risk perception. Indeed, the model includes phenomena such as the spoil system as a manifestation desired by the population and health policies. As policy levers, the model includes the use of prevention and health education tools to counteract the influence of fake news to avoid the development of political-cultural divergences regarding health by the population.

Fig. 7 The Economic View



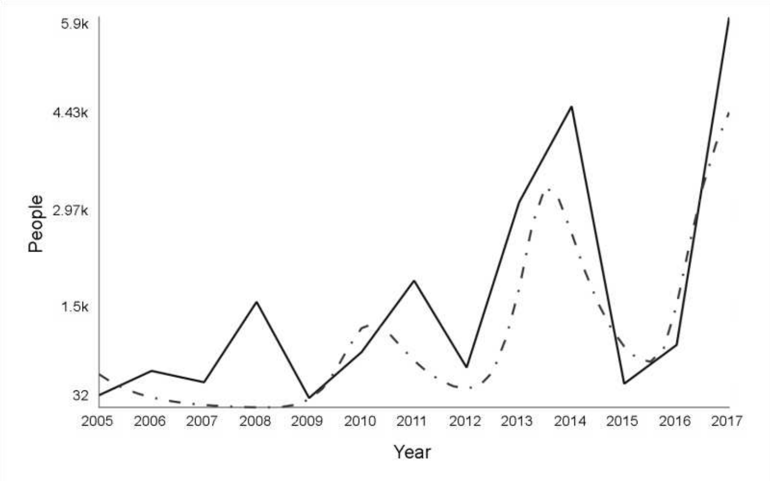
The policy levers of the investments in healthcare prevention are explained by the *Economic view* (Fig. 7); this view was built in a simplified way as this study intended to embrace different perspectives. The model assumes a fixed budget for healthcare (as the population remains constant), but health expenditure suffers a dichotomy between short-term (due to the infected cases) and medium-long-term expenditure. In this sense, healthcare spending on infection treatments is considered an emergency expenditure that can draw extra funds away from the budget of long-term prevention policies. Therefore, there is a trade-off between short-term emergency and long term investments. Indeed, an increase in the number of cases will cause an increase in the current treatments costs of the outbreaks, draining resources from investments in healthcare prevention, causing a social underestimation of the risk of measles, which may subsequently result in a reduction in the perception of the risk by policy-makers.

The model assumes a fixed budget for healthcare (as the population remains constant); however, health expenditure suffers a dichotomy between short-term (due to the infected cases) and medium-long-term expenditure. In this sense, healthcare spending on treating infections is considered an emergency expenditure that can draw extra funds away from prevention expenses. Therefore, there is a managerial delay between the expenditure needs to be prepared to manage long-term policies and emergencies. Indeed, an increase in the number of cases will cause an increase in infectious costs, draining resources from investments in healthcare prevention, therefore causing an underestimation of the risk of measles (and, for example, a more significant impact on the no-vax community). A general underestimation of the risk of measles may subsequently reduce the perception of the risk by policy-makers (for example, greater political participation by subjects wary of vaccination or more remarkable superficiality in terms of health prophylaxis in schools and hospitals).

4 Simulation Results and Discussion

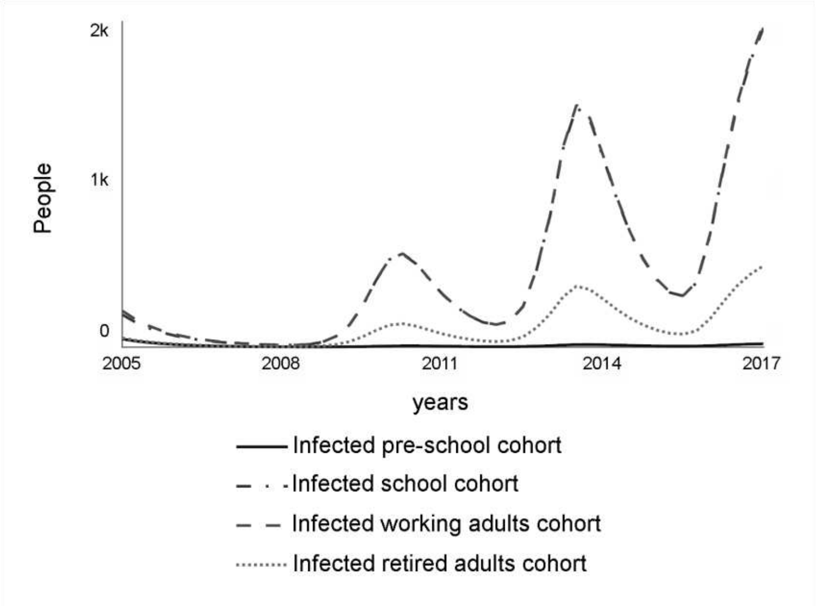
A comparison between the reference data (Italian Ministry of healthcare) and the simulated data, is reported in Figure 8. The initial values and the parameters were estimated from the primary and secondary data collected from different research reports; in the absence of quantitative data, several assumptions were made, consistent with the qualitative information collected from the literature and interviews. The main assumptions are based on the value of some inputs.

Fig. 8 Comparison Between Real Infected Cases and Simulated Infected Cases



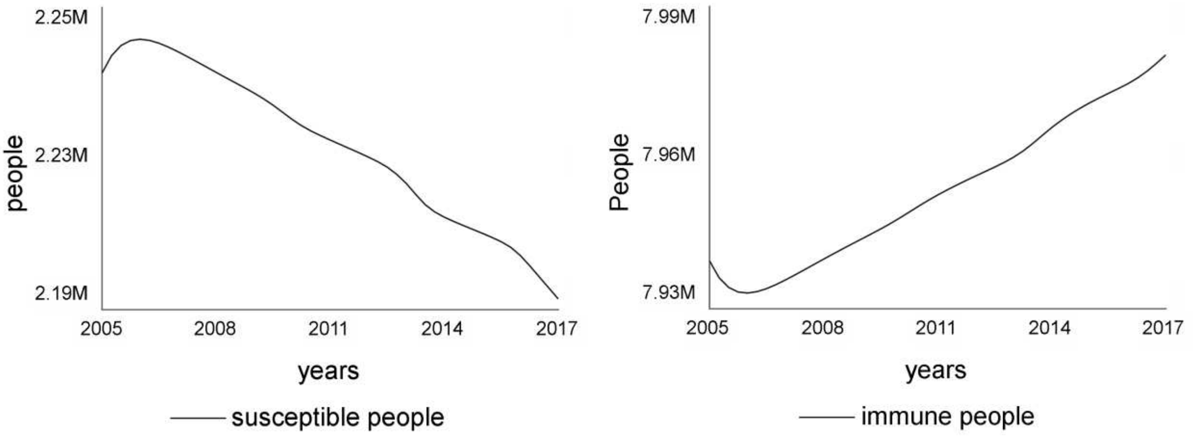
As reported by the literature (Filia et al., 2018), the simulated data evince that students and workers are the age group that suffers the most infections (Fig. 9), despite the target of mandatory vaccinations in the infant population.

Fig. 9 The Trend in Simulated Cases over Time



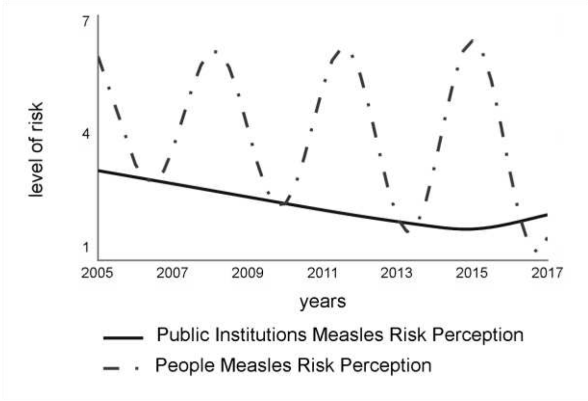
This whole model shows how the social aspects, in some cases, can have a more significant impact than the distribution of the vaccination, regardless of the classic SIR model. Indeed, the last epidemic peaks are not explained by the levels of susceptible and immune people. Figure 10 shows an increase in the immune population (a) and a decrease in the susceptible population (b), disaccording to SIR basic theory.

Fig. 10 The evolution in Susceptible and Immune People (a, b)



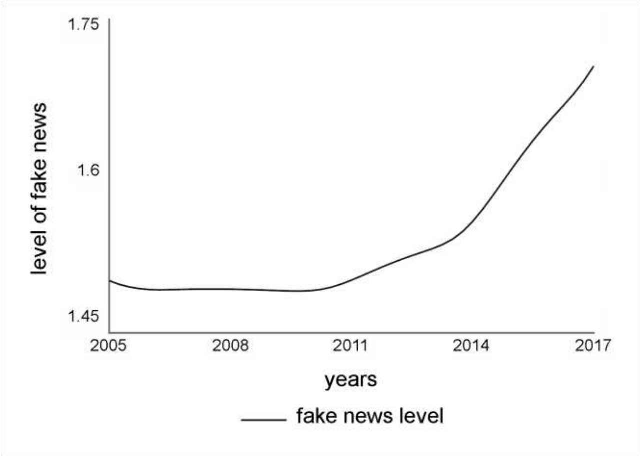
The model features an interconnection between the population and public institutions (Fig. 11); although the first influences the latter, there is an asynchrony between the two actors' perception due to delays. Furthermore, the model assumes that public institutions have a higher level of perception of measles. However, public institutions' perception is influenced by public opinions (through public participation powers, such as voting) and current conditions and scientific opinions that remain irremovable (defined by the optimal variables).

Fig. 11 Comparison of the Public Institutions' measles and People's measles perception



Public institutions tend to adapt to the vision of the community. This topic has been studied by the health communication literature and by research on health-related decision-making, indicating that in times of crisis, people, including experts, make decisions based on a mixture of feelings, experience and analytic considerations (Gesser-Edelsburg et al., 2018, p. 5).

Fig. 12 The Trend in the Spread of Fake News



As explained above, people's risk perception has an oscillatory behaviour, which is influenced by several factors, including the decreasing trend in the perception of the risk and fake news growth (Fig. 12). The proliferation of fake news may provoke more significant confusion and, therefore, greater chaos for which the population begins to have irrational behaviours that cause such fluctuations. Furthermore, the exponential growth of the oscillations in Figure 9 (since 2013) is influenced by the delay of perception and increasing fake news trends (Fig. 12).

As reported in the previously cited literature, in a low-level cultural context, the proliferation of misinformation can cause serious health concerns for the community (Lasco & Curato, 2019). In this sense, without interventions regarding the containment of fake news and the improvement of the population's level of discernment, the spread of measles may experience a worrying trend. Currently, during outbreaks (whether familiar or new), the public receives information, which is sometimes misinformation (insufficient information) or disinformation (intentionally false information). These aspects have some severe implications for health-related decision-making and public health behaviour. People often tend to reject information corrections that contradict their attitudes, share content that is consistent with their narratives while ignoring the rest and allow the inaccurate information to continue to affect their conclusions even when they bluntly admit that the information is incorrect (Gesser-Edelsburg et al., 2018, p. 5).

The model considers a rate of growth of the level of fake news that is less than proportional over time, as indicated by the Digital News Report 2018[13], which states that an increase in the diffusion of fake news causes an increase in the mistrust of free information. Moreover, the trend is nonlinear because several drivers affect the diffusion of fake news over the population.

These aspects may be of particular interest because they could explain how to intercept the moment in which attitudes and beliefs about vaccines begin to develop: indeed, in a dynamic context, it is preferable to solve problems in advance when there is still no urgent need to adhere to the vaccine proposal.

Regarding the assessment of the policy levers, the model includes the following aspects:

1. Investments in vaccination capacity,
2. Compulsory infant vaccination (partially already implemented),
3. Investments in the management of misinformation (fake news reduction),
4. Investments in eHealth (implementation of a national electronic vaccination registry).

A change in the infant vaccination capacity (Fig. 13) seems to influence the outbreaks' evolution too weak because the infantile population represents only a tiny part of the entire population. However, an increase in vaccination capacity can lead to the protection of a higher share of children (Fig. 14) and positively affect the future, creating a better demographic composition in the long run.

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[13] http://media.digitalnewsreport.org/wp-content/uploads/2018/06/digital-news-report-2018.pdf?x89475

Fig. 13 The Effects of a Change in Infant Vaccination Capacity on the Outbreaks

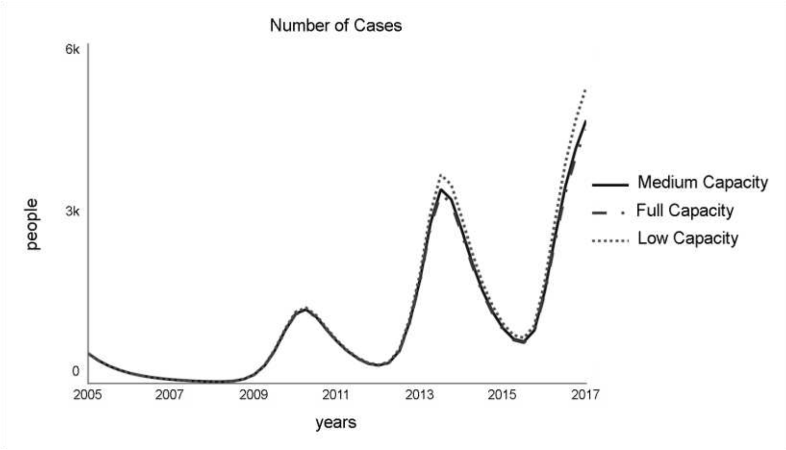
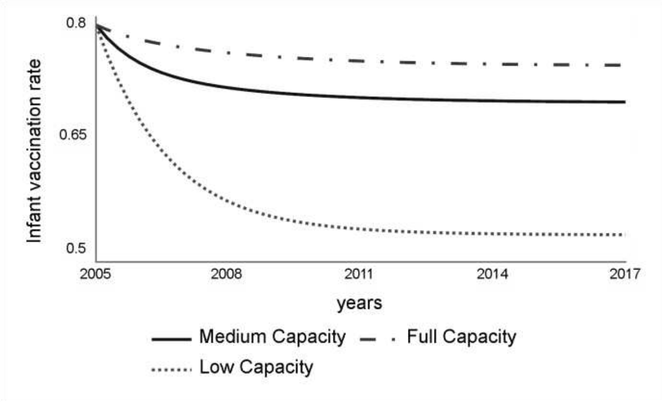


Fig. 14 The Effects of a Change in Infant Vaccination Capacity on the Infant Vaccination Rate



The Italian system does not provide mandatory vaccinations for adults (Gori et al., 2020), except in some cases for health professionals, and a flat extension is too burdensome to manage. The susceptible population appears to be minimally affected, considering that the population share with an age of two years old represents 0.05%. In this sense, a variation from 90% to 95% in the infant vaccination population will affect 0.0025% of the total vaccination population[14].

The evidence from the simulation shows only an increase in peak behaviour in the case of a reduction in infant vaccination. This simulation could provide deeper analysis for a longer horizon by changing the population's epidemiological structure. So, although it turns out to be a good practice, in the long run, having a vaccination rate that reaches herd immunity, a 10-year time horizon maybe not enough

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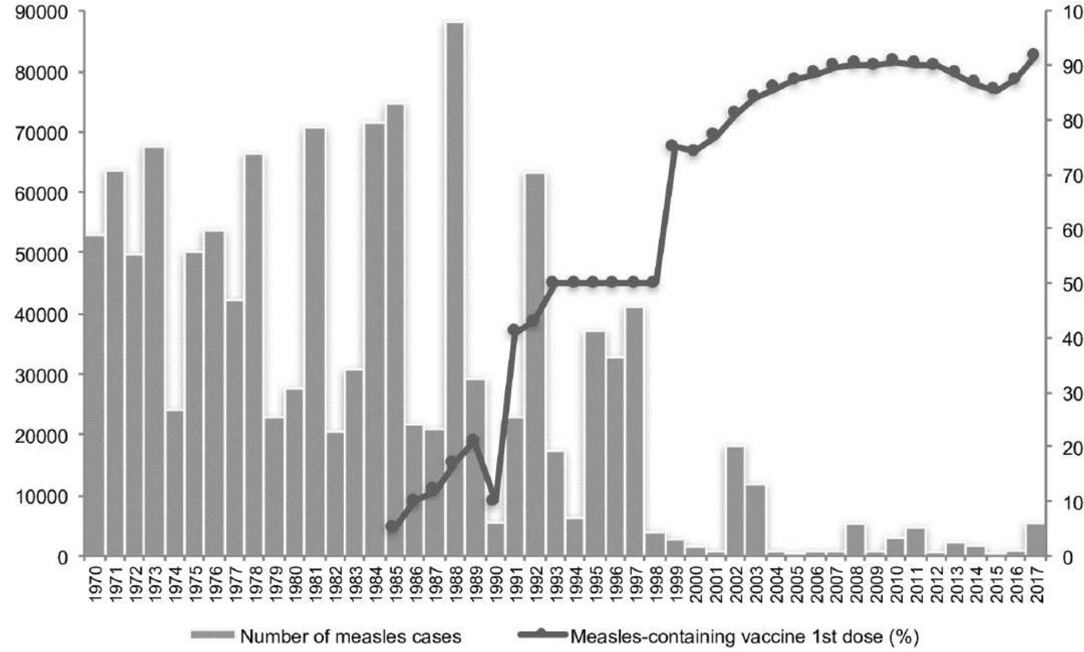
[14] http://dati.istat.it/

to eradicate the disease. Therefore, the model also suggests evaluating a vaccination for other age groups or, otherwise, assessing this policy as a very long-term one.

Indeed, as indicated by Adamo et al. (2018) in Figure 15, starting from the 1970s, the child vaccination coverage was too low. Although epidemic peaks are currently significantly lower, it is evident that the older generations have a different and deficient vaccination history.

Figure 15. Notified measles cases and child vaccination coverage in Italy. 1970 - 2017

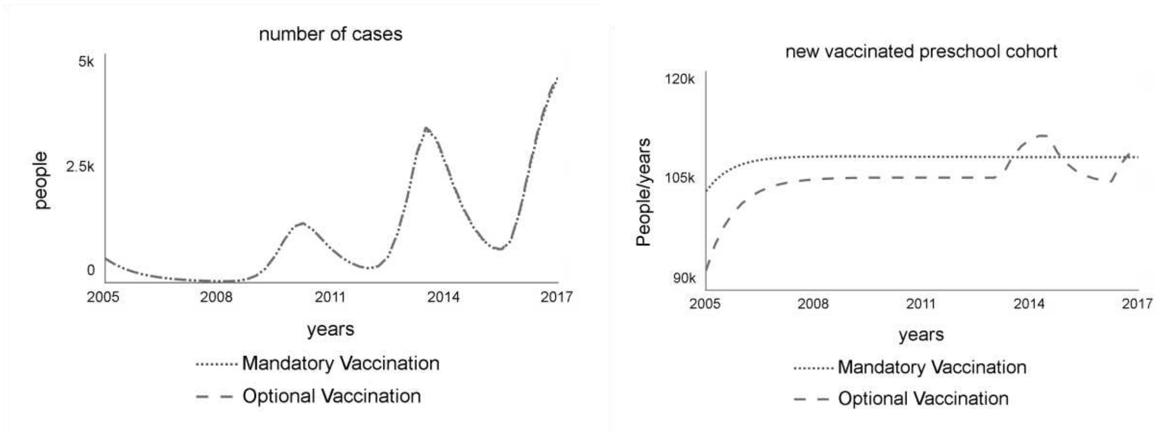


Source: (Adamo, et al., 2018)

The second policy lever, the introduction of a mandatory infant vaccination, is quite similar to the first policy (Fig. 16 a, b). Although the goal is the same (an increase in child vaccination), the method appears different. While in the first case, a logistical deficit was assumed, in this case, the introduction of a normative instrument is hypothesised to protect public health.

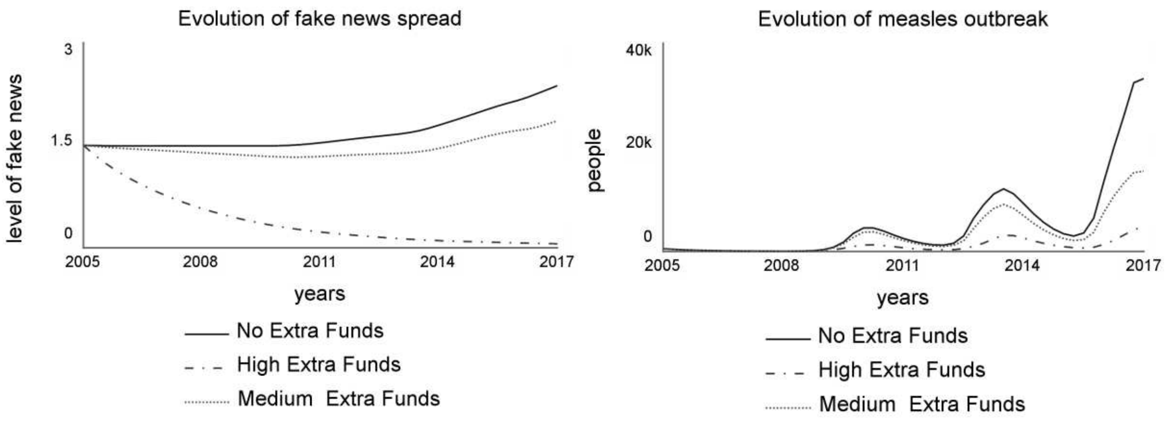
There is not much evidence of a reduction in infected cases (fig. 16.a), although there is a pretty stable increase in vaccinations over time (fig. 16.b). In the optional system, there are some peaks in outbreaks due to the emergency social state. The low impact can be explained by the low presence of infants in the age population distribution.

Fig. 16 The Introduction of a Mandatory Child Vaccination (a, b)



The third policy regards reducing health misinformation, which is achieved by introducing extra funds to reduce fake news and spread good practices (Fig. 17.a). This policy can cause an increase in health culture to contain the proliferation of fake news and, therefore, the growth of possible outbreaks. Figure 17.b shows, indeed, how the reduction of fake news has a substantial positive impact on the spread of the disease.

Fig. 17 Introduction of Extra Funds to Counteract Health Misinformation (a, b)

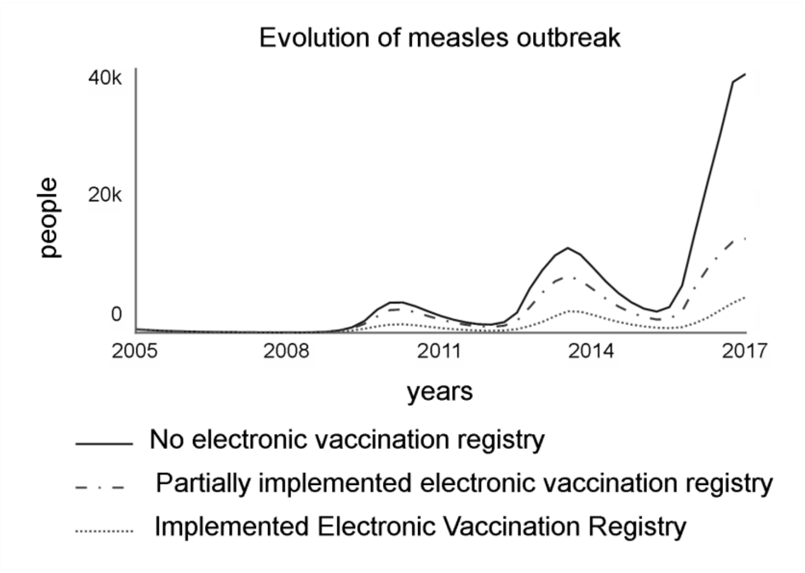


Mackey and Liang (2013) considered the dissemination of misleading or unbalanced information about the risks and benefits of medications could cause negative consequences because people may engage in the self-diagnosing and self-prescribing of their health conditions without the support of a medical professional. This behaviour may represent a form of friction for the success of any public health policies. Among other things, in a public governance context, these harmful practices can indirectly negatively influence the context of determining and applying policies.

Considering that this model wants to reproduce a micro-world to understand the central relationships (Sterman, 2000), the introduction of extra funds causes a spread of health culture to contain the proliferation of fake news and, therefore, possible growth outbreaks. The previous figure shows how the reduction of fake news has a substantial positive impact on the outbreaks.

The last policy is the introduction of an electronic vaccination registry (Fig. 18). This policy may improve the prevention, diagnosis, treatment, monitoring, and management of measles outbreaks, through an informative national system to promptly inform the infections and people not yet vaccinated. This innovation will cause a reduction in the delays in detecting outbreaks, improving the management of the prophylaxis of the infected people.

Fig. 18 The Introduction of an Electronic Vaccination Registry



According to the simulation, table 1 reports the main policy levers and their impact on the evolution of measles epidemics. Eradication initiatives require sustained public health, political, financial and individual efforts. The model, although limited by various deficits, such as the need to formulate a series of assumptions due to a lack of quantitative data, has been able to explain how, within its dynamic complexity, it is possible to analyse the evolution of measles in Italy, evaluating current policies and assuming future scenarios. Although it is not possible to be sure about the future, it is possible to highlight the benefits of implementing an electronic vaccination register and prevention policies.

Table 1 Assessing Main Policy Levers Regarding the Measles Issue in Italy

Main policy levers simulated in the model	**Effectiveness in the short run**	**Effectiveness in the long run**	**Already implemented**
Investments in Infant Vaccination capacity	LOW	MEDIUM	Partially implemented
Mandatory Infant Vaccination	LOW	HIGH	Partially implemented
Investments in the management of the misinformation (fake news reduction)	MEDIUM	HIGH	Since 2017
Investments in e-Health (implementation of a national electronic vaccination registry)	HIGH	HIGH	To be implemented

Regarding measles vaccination, the latest journalistic speculations state an instant cause-and-effect relationship (after only one year) between childhood immunisation and the outbreaks; these speculations appear somewhat dubious, according to the model. As Jansen (2003, p. 804) considered, measles' population biology depends on many factors, such as the seasonality of transmission and the population's social, spatial and age structure. Being a pathology that, unfortunately, more easily affects the older age groups and considering that the benefits of the compulsory vaccination are observed in the long run, it remains very doubtful that the correlation between the infant vaccination and the number of measles cases will have a cause-and-effect relationship in the short run.

5 Conclusions

In the public healthcare sector, it is necessary to consider all the stakeholders, mainly based on a logic of health governance; however, particular interest must be placed on decision-makers; the latter are, themselves, stakeholders, as they are representative, in most cases, of citizens' requests. This holistic view is especially true for policy-makers, who should ensure an efficient allocation of resources that meet the population's priority health needs equitably. Likewise, politicians have a moral obligation to protect citizens' health, as stated in article 32 of the Italian Constitutional Charter. However, these key actors have a filtered vision that is sometimes characterised by constraints as the party's social vision is bound to virtuous (and unfortunately, vicious) aspects produced by the community as an active part of the political process. Additionally, these constraints can derive from the vicious aspects of a highly demagogic nature. The model explained the key factors that caused the measles outbreak in 2017 and the dynamic oscillations, showing how the financial and social aspects have significant attrition on public health's effectiveness.

The model has shown that the low level of vaccination is due to a culture damaged by the spread of fake news and underestimating the problem due to a trade-off between urgent contingent problems and long-term planning needs. Undoubtedly, the introduction of a mandatory vaccine for those at risk (including people of different ages), in a demagogic cultural context, can be a health policy tool and can be helpful in the short term; this approach, however, diverges deeply from the concepts of public governance. The model, through its simulations, showed how the introduction of an electronic vaccination registry has a fundamental impact in reducing epidemics, mainly if supported by a cultural context in which information is controlled through policies that are effective at promoting health. If we think nowadays, some veracity has been shown for Covid-19 in some Countries[15].

Without analysing the weight exerted by bureaucracy, vaccination policy, which appears to be the best solution, can be ineffective: it is necessary to consider the strict hierarchical subordination within it, the obligation of its endorsement by the political manager, the complex procedures of administrative acts and controls too numerous to which it must be submitted (Magaldi, et al., 2014).

The use of a remarkably advanced information context (eHealth as information management), on the one hand, represents a solution for the acceleration of processes, but, on the other, it may generate worsening if it is not filtered and managed to improve performance. The redundancy of data and the implementation of policies that do not consider the dynamic complexity and the cultural context in which they operate, may represent a reversal achieving improvements in the quality of life. If, on the one hand, it may appear that we must consider a process by which we pass from a vision of obligations to a logic of collaboration, on the other, this passage is not at all easy, especially in terms of public health, where information asymmetries are high and can represent a cause of public failure. The transition from the compulsory vaccination regime to a regime where it is recommended must be accompanied by a particular reference to individual "responsibility" in terms of choices and behaviours (Osservatorio Nazionale sulla Salute nelle Regioni Italiane, 2015); otherwise, this process can lead to a severe disincentive to get vaccinated.

The need for detailed analytical information to obtain a truthful model also requires more significant health data computerisation developments involving different public organisations. The dynamic complexity and the overlapping of shared sectoral problems regarding the epidemics require vast data

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[15] https://www.nature.com/articles/d41586-020-03518-4

integration over temporal, geographical, and socioeconomic scales. Furthermore, a comparative analysis with another healthcare system can improve the robustness of the SD model. The comparative analysis results can provide decision-makers with new insights into a deeper understanding of the dynamics characterising the investigated phenomenon and design more robust policies to reduce the measles infection rate.

In the case of measles, it has been shown that access to electronic health information is particularly delicate and requires essential coordination from the health service in order to avoid differences of opinion between the general population and the public health system. The underestimation of fake news diffusion as the sub-violation of a future epidemic risk is a more readily understandable concept through a dynamic approach. Nowadays, the vaccine Covid-19 hesitancy is part of the issue, although it would require more in-depth analysis, including more socio-political aspects; furthermore, it would require an analysis of big techs' impact on the governance of fake news in the social networks (Massei & Di Matteo, 2019; van Dijck, 2020). However, it should be noted that while in the case of Covid-19, there is a greater degree of uncertainty about the evolution of the epidemic (vaccines, adverse events, future variants and chronic diseases caused by the Covid-19), while in the case of measles, the scientific information is sufficiently clear and complete.

An unanswered question is whether poor performance is due to a general tendency to resolve emergencies, losing a long-term perspective. Lastly, a combination of the spatial and dynamic approaches to analysing measles' case study is recommended, as it has been recently applied to the Covid-19 Pandemic (Bai, 2020); it would also help consider the territorial economic inequality (North–South divide) and the individual risk centres (such as hospitals and schools).

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