A Qualitative System Dynamics Approach to Enhance Understanding of Accelerated Vaccine Market Access and Implications for Covid-19 Vaccine Acceptance

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Abstract

Background: The COVID-19 pandemic revealed critical challenges in vaccine development, communication, managing trust, and behavioral responses. These challenges exist beyond the medical side of the pandemic, emphasizing the need of systems based insights for future health preparedness. This study adopts a systems thinking approach to explore how these interconnected factors influenced COVID-19 immunization dynamics in Belgium through a Causal Loop Diagram (CLD).

Methods: A CLD was developed to map the relationships among risk perception, Non-Pharmaceutical Interventions (NPIs), vaccine production, regulatory processes, public trust, and vaccine hesitancy. Informed by the in-depth stakeholders interviews Belgium and Europe, the model captures complex interaction and provides a system-level understanding of COVID-19 Immunization System (CIS).

Results: The CLD identifies key balancing feedback loops such as *Non-Pharmaceutical Intervention* which while temporarily reducing the transmission also reduced the social freedom. *Accelerated Vaccine Production & Supply* loop highlights how the expedited development increased vaccines availability, *Conditional Marketing Authorization* loop indicates the compression of regulatory timelines, and *EU joint procurement* loop shows improved coordination and price driven accessibility. These loops explain how accelerated vaccine development enabled early vaccination and reduced COVID-19 cases. Conversely, reinforcing loops such as *Acceleration Induced Hesitancy* show how the public perceived this acceleration and associated it with lower vaccine quality, reducing their acceptance for vaccine. Additionally, *Sensational Reporting Induced Trust Erosion* and *Conditional Authorization Communication gap* loops illustrate how misinformation and propaganda messaging reduced public trust, lowered perceived COVID-19 risk, and contributed to increased hesitancy and/or complacency. Moreover, *Premature Data Submission* and *Pressure on Regulatory Resources* loops highlight how partial trail evidence and fast-tracked authorization added pressure on regulatory resources over time. Together, these interacting loops demonstrate that the vaccine availability, patient's acceptance, trust and strain on health capacity emerge over time, hence timely communication, trust building and resourcing unfold as critical points for improving long-term vaccine uptake and pandemic preparedness.

Conclusion: The systems map underscores the value of understanding dynamic feedback in public health systems. While accelerated vaccine development was essential, it could unintentionally reduce public trust in the absence of adequate transparency and engagement. Similarly, conditional authorizations, although they shortened the regulatory timelines, gradually increased pressure on regulatory resources and risked breakdown with extended use. Therefore, transparent communication, adaptive governance, and anticipatory strategies are essential to build trust and resilience. These findings support the development of more human-centered, integrated approaches to pandemic preparedness and response.

Introduction

The COVID-19 pandemic was not only a public health emergency, but also a multi-faceted crisis that affected virtually all areas of human life. In the absence of known treatment, the rapid spread of COVID-19, forced governments to implement flurry of unprecedented Non-Pharmaceutical Interventions (NPIs) like social distancing and travel restrictions as preventive measures. Among the mitigation strategies, vaccination appeared to be the most effective measure to reduce the risk of severe COVID-19 disease. As efforts were made to contain the spread of disease, researchers pushed towards accelerated COVID-19 vaccine development. 'Accelerated' in this context refers to the unprecedented shortening of vaccine development and regulatory approvals time from typical 10-15 years to less than a year (Claessens et al., 2025; Marinus et al., 2022a). For instance, COVID-19 mRNA vaccine developed by Pfizer/BioNTech became the first vaccine to receive emergency validation from WHO in a year since the outbreak began (WHO, 2020b). WHO's Emergency Use Listing (EUL) opened the door for countries to expedite their own regulatory approval processes to import and administer the vaccine (WHO, 2020b).

While the rapid pace of COVID-19 vaccine development marked a milestone in the history of drug development, it also fueled concerns among parts of the population regarding the vaccines safety and efficacy (Al-Jighefee et al., 2021; Graña et al., 2022). In addition, vaccine attributes like booster doses, ability to protect against mutations were (are still) the questions of concerns all over the world (EMA, 2021; Mambelli et al., 2025). Therefore, analyzing the COVID-19 pandemic, specifically its vaccine development and uptake challenges, requires a comprehensive examination of not only the biological and epidemiological aspects but also the behavioral, social, and systemic factors influencing both public and government decision-making. While continuous efforts are being done and researchers are delivering breakthroughs in the treatment of Covid-19(Laporte et al., 2025), to date, such system-level research remains limited. This qualitative study aims to explore how these interconnected factors shape immunization outcomes in the Belgian context, in order to improve pandemic preparedness and response. The following literature review presents key insights from prior research, drawing from epidemiology, behavioral science, and systems thinking.

Literature Review

The scope of COVID-19 research has been expanding ever since pandemic was declared and now we have reviews and researches in the areas of disease surveillance (Nambasa et al., 2025), equitable testing (WHO, 2022), communication, enablers, political influencing (Lemor et al., 2024), challenges in vaccine development and prevention strategies (Mambelli et al., 2025), socio-economic impacts (Strelkovskii & Rovenskaya, 2021), and supply chain of vaccines (Puri et al., 2024).

Complementing biomedical and public health studies, psychological and behavioral research has also explored areas such as risk perception (Gordon et al., 2024; Rahmandad, 2022), individual risk factors, sustained motivation, mental well-being, public trust, and policy learning (Green et al., 2024; Kalk et al., 2022; Kattumana & Larson, 2025; Lemor et al., 2024; Nambasa et al., 2025; Nguyen et al., 2023; Rigoni et al., 2025; Zaki et al., 2023). These behavioral insights underscore the complexity of public engagement with vaccination campaigns and compliance with mitigation measures. Next to these epidemiological, psychological and behavioral models, System Dynamics models have also incorporated epidemiological parameters and behavioral responses, revealing how fear, fatigue, misinformation, and trust in authorities can influence the trajectory of an outbreak (Jia et al., 2022; Ozair Ahmad et al., 2021; Rahmandad, 2022; Rahmandad et al., 2021; Strelkovskii & Rovenskaya, 2021). While existing systems research has addressed vaccination and

immunization dynamics in general (Cascini et al., 2021; Decouttere et al., 2021), the application of qualitative SD methods, such as Causal Loop Diagrams (CLDs), specifically to a comprehensive COVID-19 immunization system remains limited. There are Causal Loop Diagrams (CLDs) showing examples of some key interacting components in a society that is responding to the threat of COVID-19 (Bradley et al. 2020; Rahmandad, Lim, and Sterman 2021; Jia, Li, and Fang 2022). However, there is a notable gap in exploring how risk perception, accelerating vaccine development and approvals, communication, patient preferences, vaccine acceptance and stakeholder interactions collectively shape COVID-19 immunization outcomes within a systemic framework.

This study uses qualitative system dynamics to explore how interconnected factors shape immunization outcomes within the Belgian context. First, we systematically map the perspectives of patients alongside those of key institutional stakeholders engaged in COVID-19 vaccine development and approvals in Belgium's COVID-19 immunization efforts. Second, we develop a causal loop diagram (CLD) that illustrates the structural complexity of the Belgian COVID-19 Immunization System (CIS), highlighting dynamic interconnections between the decisions made by pharmaceutical developers, regulatory agencies, health technology assessment (HTA) bodies, policy-makers, and the public preferences. Finally, this system-level perspective generates actionable insights to inform strategic pandemic preparedness and strengthen health system resilience. In doing so, the study responds to and reinforces current WHO and EU policy directives on integrated risk governance and adaptive health system planning, specifically for pandemic preparedness and response.

Methods

3.1 Study Design

We use a qualitative system dynamics modelling approach wherein the primary data collection is done to gather diverse end user's perspective via semi-structured interviews. The focus here is on the creation of Causal Loop Diagrams (CLD) via the analysis of these interviews. The analysis and processing of interview transcripts into CLDs is based on steps explained in literatures (Kim & Andersen, 2012; Bureš, 2017; Cassidy et al., 2022). To systematically elicit and integrate diverse perspectives into a consolidated CLD, we used granular level microstructure to better understand the differing opinions and reason the cause of those differing views. The step by step process is further explained in sections 3.2 and 3.3. In addition, to ensure transparency in CLD development, we followed the set of recommendations outlined by Jalali & Beaulieu (2023).

3.2 Data Collection

We use the data collected for a qualitative study (approved by the Ethics Committee Research UZ/KU Leuven, Belgium (*S65264*)) about patient preferences. This study generated insights about COVID-19 vaccine characteristics that are important according to potential vaccine recipients in Belgium. Participants were considered able to provide guidance with regard to their preferences for COVID-19 vaccination (purposive sampling). The sampling strategy was designed to ensure diversity and inclusivity, guided by the following broad selection criteria: (i) Over 18 years of age, (ii) Belgian residents and (iii) Written approval of the informed consent.

The recruited participants included population vulnerable to COVID-19, different ethnic or religious groups, the elderly, and pregnant women. Codes and characteristics of 30 participants (15 each from both Dutch and French speaking regions) thus recruited are shared in the Supplementary Material. Interviews of approximately 60 minutes were conducted using a semi-structured qualitative design. This design followed a predefined interview guide containing the

questions that were asked to participants, but depending on the participant's response, new questions could emerge through dialogue. Transcriptions were produced verbatim, ensuring accuracy for subsequent qualitative coding.

Furthermore, to include the insights from regulators, Health Technology Assessors (HTA), and pharmaceutical industry representatives, the multi-stakeholder interview (n=16) study done by Claessens et al. (2025) is referred. The inclusion of perspectives from experts and policymakers supported a holistic view of the COVID-19 immunization system. Ethical clearance for the study was obtained from Ethics Committee Research UZ/KU Leuven, Belgium (S66267).

3.3 Data Analysis

After transcription, the recordings and transcripts were pseudonymized, meaning that all names and references towards participants were removed and every participant received a unique code. A key linked the code to the name of the participant. Next, the transcripts were analyzed using a purposive text analysis method to support the development of the Causal Loop Diagram, following the approach outlined by Kim and Andersen (Kim & Andersen, 2012). This structured method is also valuable when working with textual data that were neither generated by the modeler nor originally intended for system dynamics modeling. It provides a systematic means of extracting causal relationships and constructing feedback-rich representations from qualitative sources. The method used here emphasizes thorough documentation of the interpretive process in model building, achieving a visible connection between each data segment and the causal structures generated from the data segment. The visible, traceable cohesion between causal relationships leading to model structure and its data source enhances confidence in the resulting model and its policy recommendations for users as well as modelers (Kim & Andersen, 2012). The causal relation mapping sheet (Interview data synthesis) developed during coding process is available in the Supplementary Materials.

In the context of COVID-19, people can exhibit diverse attitudes toward vaccination ranging from strong support to deep skepticism. To address the contrasting information in the data regarding certain causal relationships, we followed the approaches used by (Decouttere et al., 2021; Littlejohns et al., 2018). While Decouttere et al. treated the causal loop diagram as a template for mapping the vaccination preferences with varying spatial condition, Littlejohns et al. manually transformed the text into fragmentary microstructures, almost entirely made up of cause-effect pairs/chains and could be combined in the larger model through common variables. Although Littlejohns et al. (2018) used microstructure to validate CLDs, we used microstructures to represent the differing views with corresponding pathways in the feedback loops. A typical example of diverging views is the varying degrees of vaccine acceptance across the population, shaped by their behavioral orientation. For instance, pro vaccination individuals may not be influenced by reporting, whereas anti-vaccine individuals may become more rooted due to misinformation or perceived coercion. By considering different views we can clearly articulate differing opinions of the people, and the links that are active respective to behavior of population cohort.

3.4 CLD Construction

The majority of data was analyzed by only one coder (the first author) who was not engaged in the data collection. To mitigate the risk of bias introduction by the single coder and to ensure that the data is analyzed in the right context, all the variables and linkages were included in one CLD. Each and every causal link was then peer reviewed by Valentijn Stienen and Catherine Decouttere. The causal statements containing codes formed the basis of an initial CLD representing the interview data which can be traced in the documentation of the model. The quotations were added to each causal link of the CLD developed using Stella Architect software. Once the comprehensive CLD was developed including all of the data, it was then simplified

for comprehensibility using endogenization, encapsulation and order-oriented reduction analysis (Bureš, 2017). Figure (1a &1b) illustrates the process step by step.
Loops were labeled either reinforcing (R) or balancing (B) based on the signs of causal links. In a reinforcing feedback loop, an increase (or decrease) in one variable feeds through effects in other variables represented in the loop, and through those mechanisms ends up increasing (or decreasing) the initial variable even more. Meanwhile in a balancing loop, an increase (or decrease) in one variable produces feedback effects which decrease (or increase) the starting variable. In other words, reinforcing loops cause changes in the same direction, while balancing loops cause changes in the opposite direction as the initial. The iterative versions of CLD are available in the 'CLD Versions' section in Supplementary Material.

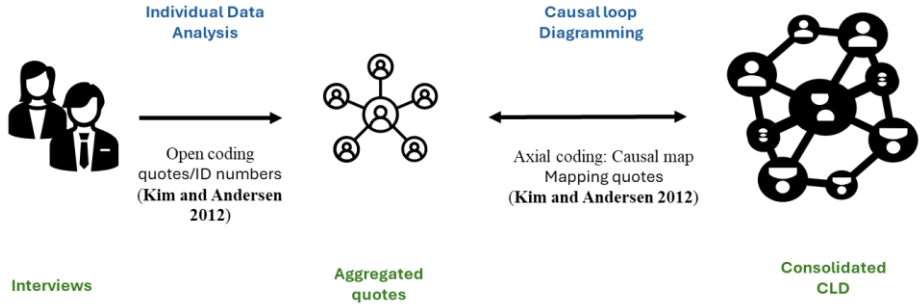


Figure 1a: Stage I - Steps and methods followed during consolidated CLD development.

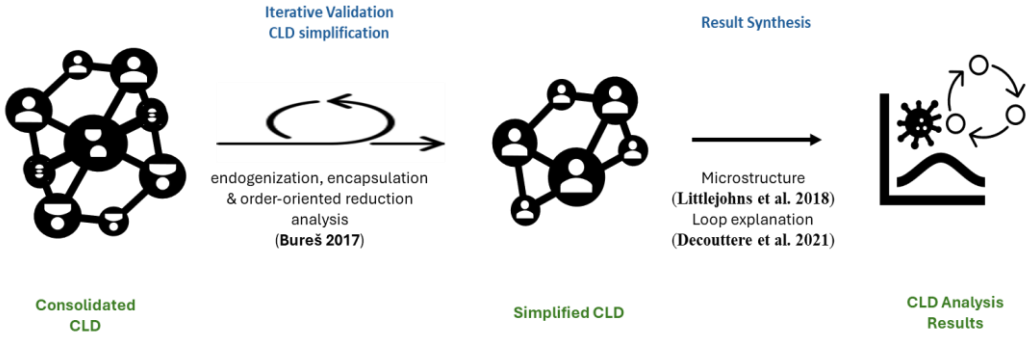


Figure 1b: Stage II - Steps and methods followed during CLD simplification and result synthesis.

Results

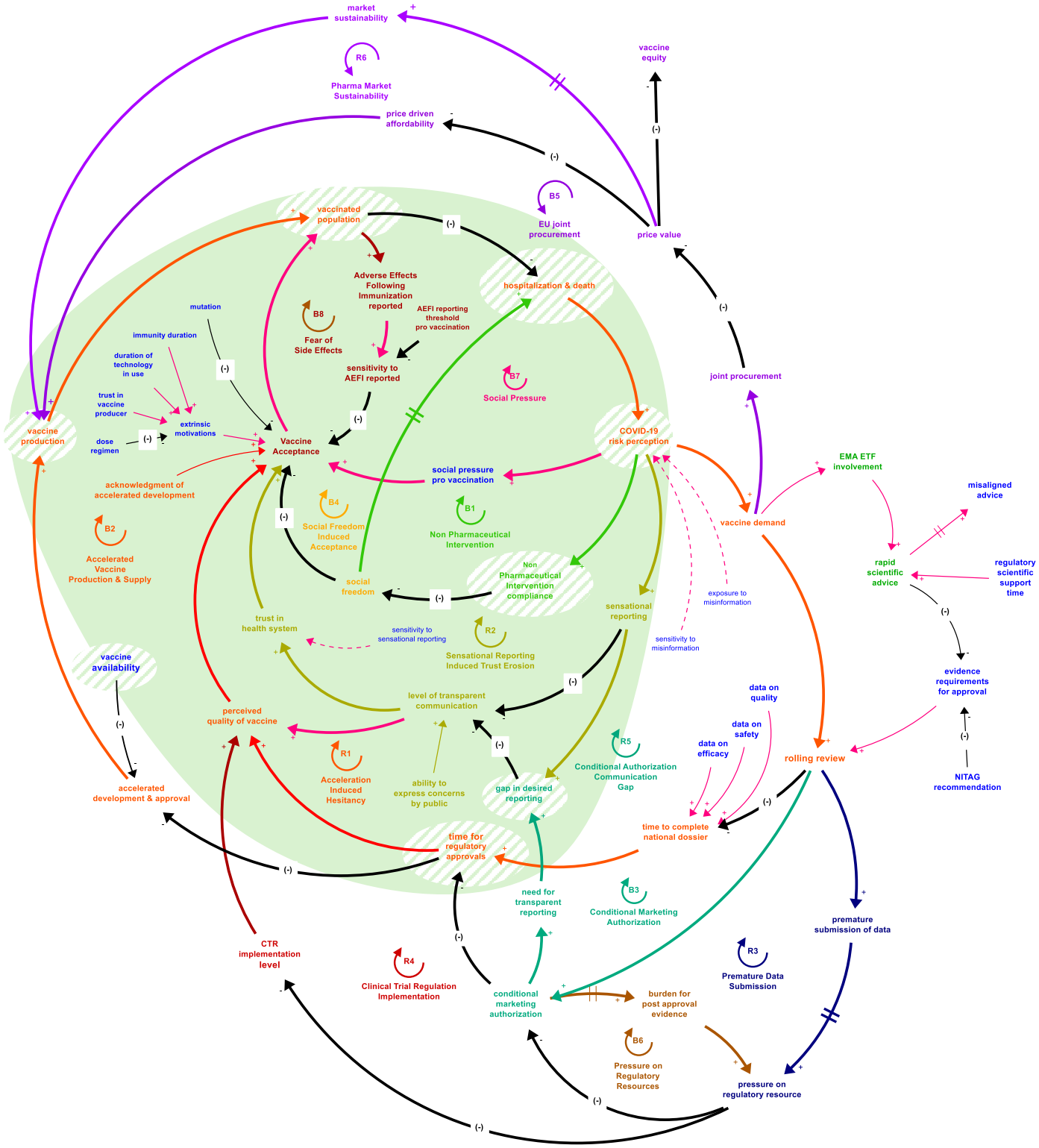
This section presents the consolidated Causal Loop Diagram (CLD), shown in Figure 2, which was developed based on interview data including perspectives from all the relevant stakeholders. This system's map contains key causal relationships and feedback loops, reflecting the complexity and divergence of stakeholder perspectives. As a result, integrating diverse viewpoints was essential to support convergence. Several iterations were required to produce a simplified version of the broader CLD. Through this iterative process, we identified eight balancing and six reinforcing interlinked loops. Additionally, to capture the nuanced nature of vaccination behavior and the heterogeneity within the population, variations of the CLD reflecting different stakeholder perspectives are presented within the respective loops using microstructure loop diagram.

Balancing Feedback Loops:

B1 - Non-Pharmaceutical Intervention
B2 - Accelerated Vaccine Production & Supply
B3 - Conditional Marketing Authorization
B4 - Social Freedom Induced Acceptance

B5 - EU Joint Procurement
B6 - Pressure on Regulatory Resources
B7 - Social Pressure
B8 – Fear of Side Effects
Reinforcing Feedback Loops:
R1 - Acceleration Induced Hesitancy
R2 - Sensational Reporting Induced Trust Erosion
R3 - Premature Data Submission
R4 - Clinical Trial Regulation Implementation
R5 - Conditional Authorization Communication Gap
R6 - Pharma Market Sustainability

In the consolidated CLD below, the area highlighted (in light green) represents the CLD developed based on patient (end-users) perspectives while the rest of the diagram represents the views from the industry experts, regulators, and policy makers. The area with striped pattern represents the factors mentioned by both patients and policymakers. For instance, '*COVID-19 risk perception*' is a common factor related by both patients and policymakers.
In the diagram, the positive sign ("+") at the arrowhead of a causal link signifies that the cause and effect variables move in the same direction, while a negative sign ("-") means that the two variables move in opposite direction over time. The dashed link represents the factors illustrating the causes of the differing opinions among the population, more explanations are provided in the microstructure CLD. A double pipeline line symbol (||) on causal links denotes a relative delay. The reinforcing loop (R) or balancing loop (B) are color coded for easy distinction and reference.
Software: Stella® Architect (version 4.1.1) from Isee Systems®



247 **Figure 2**: Consolidated Causal Loop Diagram (CLD).

248 The subsequent section offers a detailed explanation of each loop, highlighting the underlying
249 dynamics and stakeholder perspectives they represent.

Feedback Loops : COVID-19 CLD

B1 – Non-Pharmaceutical Intervention

This loop represents how COVID-19 risk perception leads to non-pharmaceutical control measures. As the COVID-19 cases increased, the risk perception increased prompting government to implement Non-Pharmaceutical Interventions (NPI) like use of facemasks, social distancing, and restricted travel to control the spread of infection. These interventions, although, assumed to reduce the number of COVID-19 cases, also decreased the social freedom. The term 'social freedom' in this context refers to the form of liberty which allows individuals to travel/move, interact, and participate in normal social activities.

Talking about restrictions imposed during COVID-19, one participant (F6) said, "*..things that are also possible when there are some limitations in your life anyway. And I think it is dangerous to not live with restrictions, because you will become a spoiled child, in my opinion…*". When she said "*things that are also possible*", she meant infection control was possible with restrictions in place. A little later in the conversation she further added "*…I would also love that behavioral changes could have stopped this epidemic, but it's been proven that that doesn't work (laughs)*". Her comments highlighted the challenge with NPI compliance. People did not always comply with social distancing and the quarantine rule, leading to a surge in COVID-19 cases. Among the participants who followed the NPI guidelines, lack of social freedom appeared to impact their NPI compliance. One participant (M26) said, "*If you want to move forward, to get back to a normal life, you have to go through this*". He meant to overcome the pandemic, people will have to follow the guidelines. He further added, "*It's the axis of tension between 'freedom/security' but today it's security that has to come first*". The choice people had to make between social freedom ('freedom') and not getting infected by COVID-19 ('security') influenced the compliance levels.

Another participant (F19) said "*The worst part of the last two years is that we don't kiss our parents or our kids. That's the worst part of Corona*".

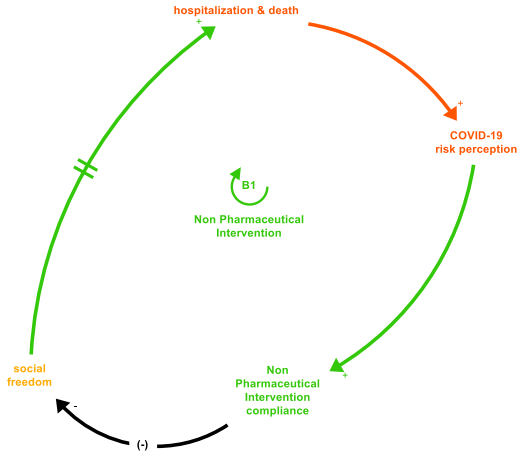


Figure 3: Non-Pharmaceutical Intervention Loop

While many participants complied to NPI, perceiving high risk of the disease, few participants were non-compliant as they did not see the risk of COVID-19 to be high enough . The factors causing these differing views among the participants regarding the risk perception and their intent to follow NPI is illustrated in the 'Microstructure Explanation' section in Supplementary Material.

These discussions further brought forward an interesting dynamic between loop **B1** (Non-Pharmaceutical Intervention) and **B4** (Social Freedom Induced Acceptance) which will be discussed in loop **B4**.

B2 – Accelerated Vaccine Production & Supply

This loop represents the relationship between risk perception of the disease and the need to expedite the vaccine development process. In the case of COVID-19, rising hospitalizations and reported deaths increased the risk perception of the disease which in turn increased the vaccine demand. As COVID-19 was a novel disease and no vaccine was initially available, this increased demand raised the urgency to accelerate vaccine development and authorization processes. Funds were allocated and resources were mobilized for vaccine research and development. Regulatory agencies adopted agile and flexible ways of working introducing the rolling review procedure. The regular timelines for scientific advice were shortened eventually reducing the time to complete the national dossiers for regulatory approvals.

One industry representative (IND6) said, "*I think if there are products which really are life-saving for patients, it would certainly be valuable to shorten the timeline. Because otherwise, your normal scientific advice timeline is between 40 to 70 days*". Talking about European Medicines Agency's (EMA) OPEN (Opening Procedures at EMA to Non-EU authorities) initiative another industry representative (IND1) said, "*EMA provided continuous, iterative advice on the development of the COVID vaccines and therapeutics. In particular, we had a constant dialogue with the regulators when we were developing the vaccine. Sort of like largely sitting alongside us as we're seeing, analyzing, and making decisions based upon the data from the trial*".

This collaborative approach of iterative advice from European Medicines Agency (EMA) for the development of vaccine and parallel processing of trial data by regulatory resources, accelerated both development and approval. Highlighting the severity and urgency, one participant (M7) stated that, "*if COVID-19 had been less severe and more like the flu, it would have been more sensible to develop and test the vaccine for a longer period of time, so more information about the vaccine's protection would be available"*. Another participant (M23) said, "*we should be grateful that it was possible to develop a vaccine - Look at AIDS, we still don't have a vaccine, it's been 50 years since this disease exists, and we still don't have a vaccine. So it was not a foregone conclusion that we would have something that would solve the problem*".

The accelerated development expedited the vaccine production and supply process and therefore increased the vaccinated population cohort. As the number of vaccinated people increased, the number of COVID-19 related hospitalization and deaths reduced thus decreasing the risk perception. It is also important to mention that although regulatory approvals played a crucial role in enabling rapid vaccination, COVID-19 mutations reduced overall vaccine efficacy and coverage during initial vaccination doses. Therefore, the efficacy of vaccine against the mutations has to be considered as a key quality parameter of a vaccine.

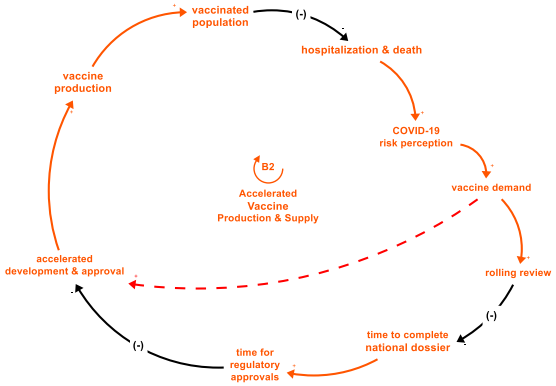


Figure 4: Accelerated Vaccine Production and Supply Loop. The dashed link represent the accelerated vaccine **development** alongside accelerated **approval**.

B3 – Conditional Marketing Authorization

As explained in loop **B2**, rapid scientific advice and recommendations expedited the rolling review process. The quick iterative process paved ways for quicker conditional marketing authorization (CMA) and WHO's Emergency Use Listing (EUL). This conditional authorization process allowed the Comirnaty COVID-19 mRNA vaccine from Pfizer/BioNTech to receive emergency validation from WHO within a year. CMA allowed quicker market access supporting early vaccination and COVID-19 prevention.

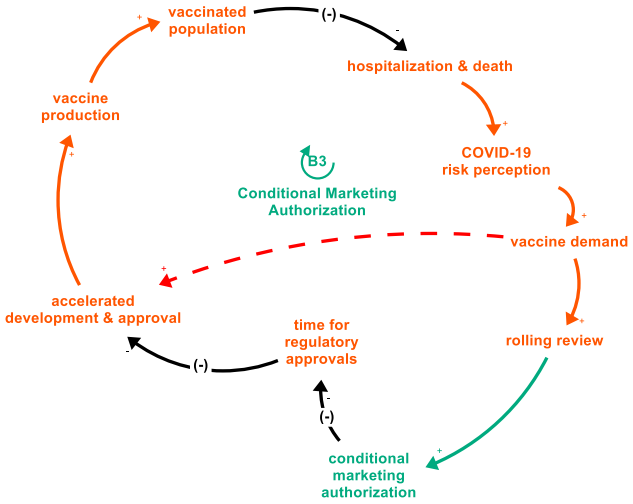


Figure 5: Conditional Marketing Authorization Loop

While many participants considered the CMA tool to be essential, some participants also reported about the expanded use of CMA leading to an unforeseen burden on both industry and regulators which will be further discussed in loop **B6** (Pressure on Regulatory Resources).

B4 – Social Freedom Induced Acceptance

As mentioned in **B1** (Non-Pharmaceutical Intervention), due to increased risk perception of COVID-19, Belgian government introduced a series of Non-Pharmaceutical Interventions (NPIs) like social distancing and quarantining the exposed and infected patients. These NPIs decreased the social freedom which in-turn stimulated the COVID-19 vaccine acceptance.
One participant (M4) looked forward to living a normal life again and said, "*sitting down on the terrace, going out for dinner, being able to go on vacation by plane and stuff, normally taking the train or bus again, all of those things*". Another participant (F8) said, "*I actually took the vaccine to please my husband and to travel again without any worries*". Increased acceptance for vaccination for social freedom increased the total vaccinated population which in turn reduced the hospitalization and death.
Seventeen participants (n = 17/30), thought that the lifting of restrictions, and the associated social freedom and mental peace are nice bonuses. Being able to travel again was seen as an important advantage of vaccination by most participants. Participant (F22) said, "*I have friends who were against vaccination, but still got vaccinated because they went on vacation with the whole family and the cost of getting tested was just too much. I really don't think that's the right reason*". These participants share the view that even individuals who are skeptical or opposed to vaccination eventually choose to get vaccinated due to the constraints on mobility and social life and not out of conviction. This shift brings in an interesting dynamic between this behavior shift and its impact on the trust factor which will be discussed in **R2** (Sensational Reporting Induced Trust Erosion loop).

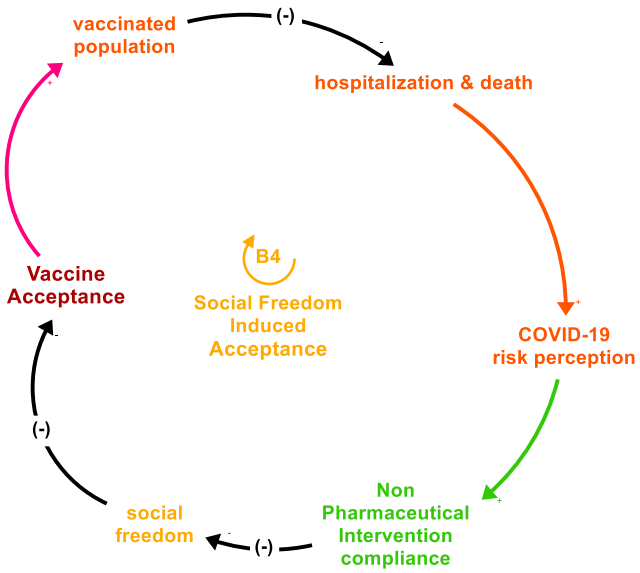


Figure 6: Social Freedom Induced Acceptance Loop.

B5 – EU Joint Procurement

The joint procurement loop below shows how the EU's coordinated purchasing improved vaccine affordability and increased vaccine production following the consolidated COVID-19 vaccine demand. As the COVID-19 risk perception increased so did the demand for COVID-19 vaccines. To improve vaccine equity, the EU introduced a joint procurement policy to make vaccines more affordable and therefore more accessible through better pricing. This approach coordinated European vaccine demand and allowed new vaccines to enter all European markets simultaneously and at uniform prices, ultimately boosting vaccine production and supply.
One industry representative (IND5) said, "*I think it would be beneficial for Europe to take this into their own hands and say for new drugs we start as of today and you put benchmarks. Then we have the prices of all the products in all the countries in Europe. In most of the countries the prices are publicly available. It's possible to put benchmarks and say okay, you have a new drug, is it as good as something that exists? Okay, then you have to stay within the threshold of 90 to 105% for example.*"
Although most participants believed that joint procurement eased the negotiation timelines by centralizing negotiations. Some participants also reported limitations and raised concerns on pharmaceutical industry sustainability. These discussions and causality are shared in loop **R5** (Pharma Market Sustainability).

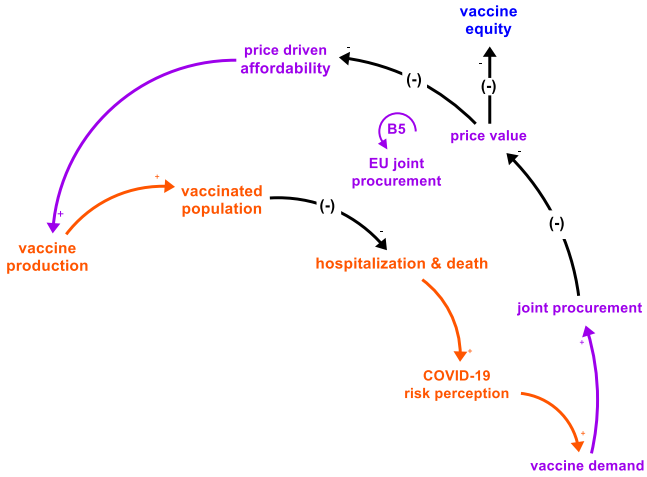


Figure 7: EU joint procurement loop

B6 – Pressure on Regulatory Resources

As shown in Loop **B3** (Conditional Marketing Authorization), participants noted that the conditional marketing authorization (CMA) moved faster because regulatory reviews were carried out in parallel, under the condition that additional data will be submitted and reassessed. This conditional authorization caused submission of premature datasets. While this approach enabled quicker access to vaccines during the pandemic, it also introduced new responsibilities after conditional approval. Since CMA required ongoing submission and assessment of additional evidence, both regulators and industry faced a steadily increasing workload. Over time, this accumulation of post-authorization duties placed considerable pressure on already limited regulatory resources, creating strain within the system.

One industry representative (IND8) said, *"its expanded use led to a considerable accumulation of workload for both industry and regulators."*

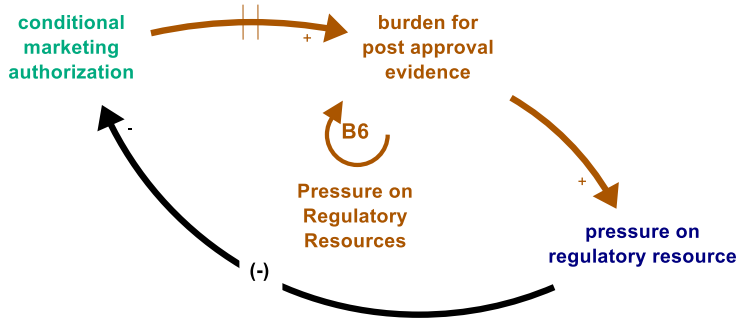


Figure 8: Pressure on Regulatory Resources loop

B7 – Social Pressure

This loop of social pressure illustrates how increasing risk perception increases the moral expectations from close contacts, such as friends, family, and co-workers influence individual vaccine acceptance. As the COVID-19 risk perception increased, social pressure from people increased encouraging vaccination uptake. This increased pressure in turn increased the vaccine acceptance ultimately increasing the vaccinated population.

Participants expressing concerns for the public health and protection of others, particularly vulnerable groups, appeared to realize the risk and hence influenced others to vaccinate. One participant (M7) went ahead to frame vaccination as a civic duty extending beyond personal health. He said, "*This is not only for your own safety, it goes way beyond that; the safety of my family, the elderly in my family, my neighbours, but also really the protection of the fellow man. And of course, we should get vaccinated as fast as possible to prevent mutations. That is really important*". Similarly, participant (M23) dismissed conspiracy theories as a barrier to uptake, and added, "*Not everyone is able to fully understand what is going on. Therefore it would be good that the government would make the vaccine mandatory*". Five participants (n = 5/30) even argued to make the vaccination mandatory.

Several participants shared that social influence directly motivated their decision to get vaccinated. For instance, participant (F8) admitted that her decision to get vaccination was influenced by her husband and said, "*I actually took the vaccine to please my husband…*".

Other participants who also eventually got vaccinated, stressed the importance of voluntary choice. Participant (M13) said, "*If it becomes impossible to live, then you have to. Is that free will? No, it is not free will. It is an involuntary choice*". Echoing this, participant (M5) argued, "*You have to let people voluntarily go to the vaccine, not by overstimulating it*".

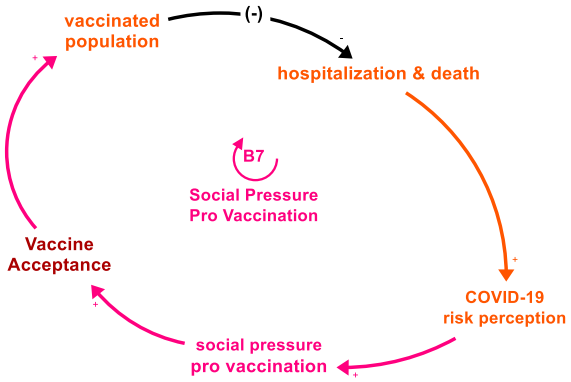


Figure 9: Social Pressure Pro Vaccination Loop.

As we discussed in loop **B1**, not everyone perceived the high risk of COVID-19. People who didn't perceive any risk of COVID-19 disease, appeared to influence others against vaccination. Participant (F6) said, "*I can imagine that if you are in such a circle where few people want to be vaccinated, the peer pressure is very high. And yes, I find this problematic, because my opinion is clearly pro-vaccination*".

Likewise, participants with a critical view, pointed out that the debate had become too polarized, leaving little room for critical reflection. One Participant (F9) said, "*There is too little room to look critically at the entire corona policy. The moment you question certain things, you will get recognised as a 'corona-denier' or an 'anti-vaxer'*". She described experiencing "*an enormous amount of social pressure*". Another participant (M13), reported receiving "*a lot of mean comments*" and being labeled "*unethical*" and "*asocial*".

Some participants mentioned that the information obtained from peers is variable. Participant (F30) said, "*I had made an appointment to be vaccinated and then I was told that it would make me sterile, that I might not have children etc. and in my plans I would like to have children later on. Others told me that no, it has nothing to do with that, it doesn't make you sterile. So I was really hesitant, sitting between two chairs*".

Taken together, these perspectives reveal a spectrum of experiences and illustrate how social pressure can influence the vaccine acceptance. These diverse experiences and views relevant to the social pressure are explained at a granular level in the 'Microstructure Explanation' section in Supplementary Material.

B8 – Fear of Side Effects

This loop captures the unintended consequences of vaccination side effects on public vaccine acceptance. As the vaccinated population increased following the vaccination, people reporting Adverse Effects Following Immunization (AEFI) increased. The increase in AEFI reporting decreased the COVID-19 vaccine acceptance. The lower vaccine acceptance reduced the vaccinated population and hence increased COVID-19 related hospitalization and death.

One participant (M18) said, "*We don't know. Its effectiveness is one thing, the side effects are another*". Sharing a critical perspective participant (M18) said, "*You'd think you were in an ad for washing powder: there's a huge stain, you put a tiny drop and it disappears. That's the salesman. Here it's the producer of the vaccine who says that his vaccine is effective and that there are no side effects*".

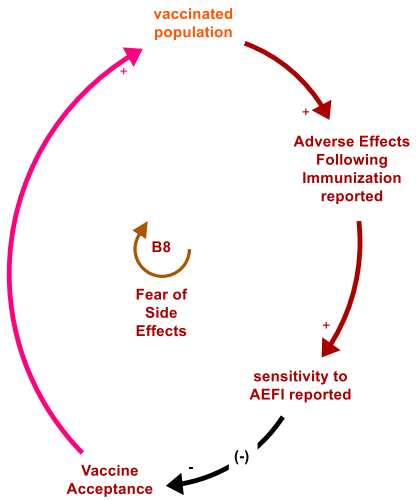


Figure 10: Fear of Side Effect Loop

The majority of the interviewees (n = 15/30) thought that the risk of short life-threatening side effects was small, or that there was no risk at all. As far as long-term side effects are concerned (n = 6/30) participants considered the long-term health risks of the vaccine as an absolute counter argument to take the vaccine. Hence, this was one of the reasons for them to refuse the vaccine. Remaining (n = 9/30) participants remained skeptical and expressed more difficulty with the evidence gap.
These views from the participants reflect two distinct perspectives regarding the fear of vaccine side effects which has been captured distinctly in the 'Microstructure Explanation' section in Supplementary Material.

R1 – Acceleration-Induced Hesitancy

As discussed in loop **B2 (**Accelerated Vaccine Production & Supply), when the perceived COVID-19 risk increased, so did the demand for vaccine. The increasing vaccine demand increased the need for accelerated development of a vaccine which was achieved by implementing rolling reviews and processing data parallelly during vaccine development and approval processes. This accelerated vaccine development and approval however increased peoples' doubtfulness towards the quality of the vaccine. The shortening of regulatory approval timelines was perceived to reduce the quality of vaccine leading to decreased vaccine acceptance.
One participant (M10) said, "*But because of the pandemic, pharmaceutical companies have pushed through to the EU to bring it to market on an accelerated basis. This is completely scandalous. I will never get vaccinated with these things*". He further added that the vaccines do not work at all: "*because people who are vaccinated still massively get infected*". Another participant (F20) said, "*I've always had a number of things at every stage of my life, so I could have said to myself, because of that, get vaccinated. My thinking is different, I'm one of the rebels, it's liberticidal, it's useless*". Based on their experiential knowledge, few participants had the impression that vaccine development and approvals took so many years. When they saw vaccines being developed at such a rapid pace, they became uncertain and raised concerns about testing and trials, associating the shortened timelines with reduced quality of vaccine.
One participant (F20) said, "*It takes so many years to develop a vaccine and here in 3 or 4 months they are there and in several companies moreover. It was illogical, it wasn't normal. Then you notice that you're in the test phase, that they didn't finish*".
The accelerated vaccine development was a major reason to refuse the vaccine for (n=6/30) participants.

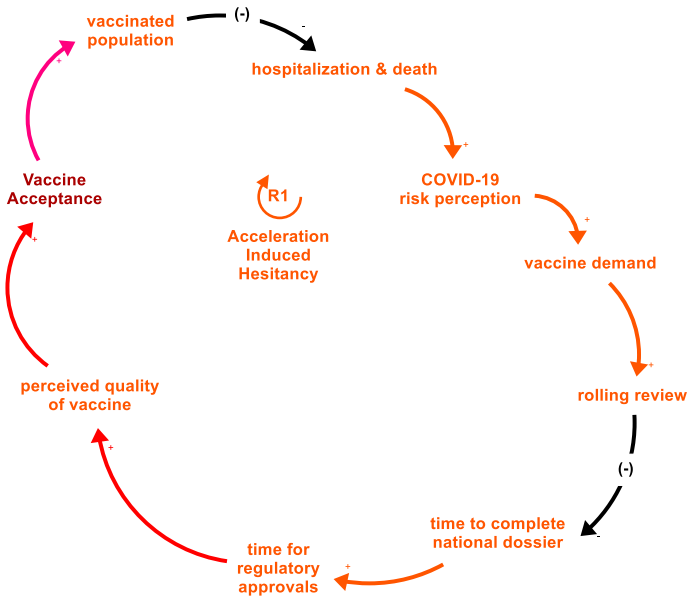


Figure 11: Acceleration Induced Hesitancy loop

Although there were people who refused vaccination due to the accelerated development, a notable portion of the interviewees (n=11/30) were not worried about the accelerated vaccine development and were in fact, confident about it. Similarly, thirteen participants (n= 13/30) were anxious about the accelerated development, but this did not stop them from taking the vaccine. From their perspective, the development had to be accelerated out of necessity.

So on one hand, we had people who experienced rapid vaccine development as one of the reasons to oppose against vaccination. On the other, we had people who acknowledged the need to accelerate the vaccine development and were in fact grateful for the rapid vaccine development and authorization. We have captured these differing views in the 'Microstructure Explanation' section in Supplementary Material illustrating the quality perceptions and pathways to vaccine acceptance following accelerated vaccine development.

R2 – Sensational Reporting Induced Trust Erosion

This loop of sensational reporting induced trust erosion shows how communication plays a pivotal role in changing public behavior during crisis.

As COVID-19 cases surged the COVID-19 risk perception increased, information dissemination intensified which was influenced by both official and unofficial communication channels, including social media. Furthermore, to attract public attention, the sensationalist reporting increased and while doing so reduced the transparent communication. This decreased transparency in communication by both unofficial and official media reduced the levels of institutional trust and further impacted the vaccine acceptance.

During uncertain situation like COVID-19 where prior information about the disease was not amply available, people looked for information themselves. On gathering information one participant (F8) said, "*It almost became an obsession*". She further added about sources of information or misinformation and said, "*from all possible media, a bit of everything to have the broadest possible view. We also searched online. And yes, the anti-vaxers and the weird stories, you'll pick those out in no time. Those can be found on the Internet too, but I don't get caught up in that*".

Speaking about sensational reporting, one participant (M21) said, "*it is not possible for the media to remain objective if sensationalism and criticism are the focus, the media are subjective, because they are funded by the government*". A smaller group of the interviewees distrusted the media due to the lack of transparent communication and the manipulative nature

of the media. As a result, they understood this can take away the trust from people. Participant (M18) said, "*I have a problem of trust in fact. Towards the so-called experts as well as politicians and even towards, I'm not going to say medicine, but in a general way*". According to one participant "*there is no room for criticism and edge cases*". Another participant (M21) was dissatisfied to the extent to deny any credit to the media or the government and said, "*I don't give any credit to the media or the Government...They are weak, they know nothing at all*".

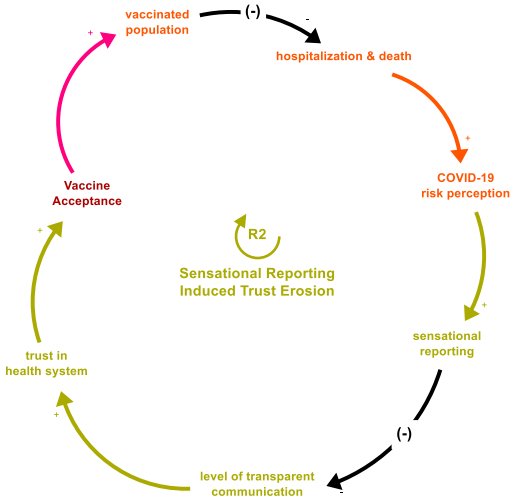


Figure 12: Sensational Reporting Induced Trust Erosion loop

While sensationalist reporting reduced trust among a minority of participants, the majority maintained firm trust in the government and official media regarding COVID-19 and vaccine information. Taken together, these findings suggest that the sensitivity to media reporting and the freedom to express concerns created the diverging levels of trust seen in the healthcare system which consequently reduced the vaccine acceptance.
These differing views are illustrated in the Sensational Reporting Induced Trust Erosion microstructure explanation section (Supplementary Material).

R3 – Premature Data Submission

The present loop builds on the insights gained from loops **B2** (Accelerated Vaccine Production & Supply), **B3** (Conditional Marketing Authorization) and **R4** (Clinical Trial Regulation Implementation) which highlighted the challenges associated with the rolling review process and the increased pressure put on regulatory resources, which in some cases contributed to gaps or delays in clinical trial activities. This loop shows how sustained pressure on regulatory resources slows down the very processes that rolling reviews are intended to accelerate.
The rolling review process shortened the approval timelines by allowing submission of data packages and study results to the European Medicines Agency (EMA) as soon as they become available from ongoing studies unlike the standard process, where all data on quality, safety, and efficacy must be consolidated and submitted as a single, complete dossier before evaluation. This accommodation increased premature submissions of data. Some participants noted that the expanded use of premature submission resulted in a considerable accumulation of workload for both industry and regulators. This additional burden, while not a structural inefficiency of Conditional Marketing Authorization (CMA) itself, was seen as a consequence of its broader application under crisis conditions.
Speaking about the premature data submission, one industry expert (IND8) said, "*the disadvantages are that you might prematurely submit something and then regulators spend a lot of their time looking at it and then that's a waste of time because it turns out that the product*

is not working or the safety profile isn't good enough. So you can waste your assessor's time and assessors time is very precious".

As regulatory resources got overwhelmed by the volume of pre-mature dossiers, their ability to conduct timely assessments diminished. This delay, in turn, prolonged the overall regulatory approval timeline reducing the rate at which new vaccines receive market authorization. This slowdown ultimately decreased accelerated vaccine production and supply, demonstrating how overload on assessors can negatively impact the effectiveness of accelerated regulatory pathways.

One participant (IND2) sharing thoughts about premature data submission said, "*There are lessons learned that can be taken to see whether it is possible to work for the assessment of a medicine in a more iterative way. Not the rolling review, but in a more iterative way that you're providing information when you think that you have a sufficient package of information*".

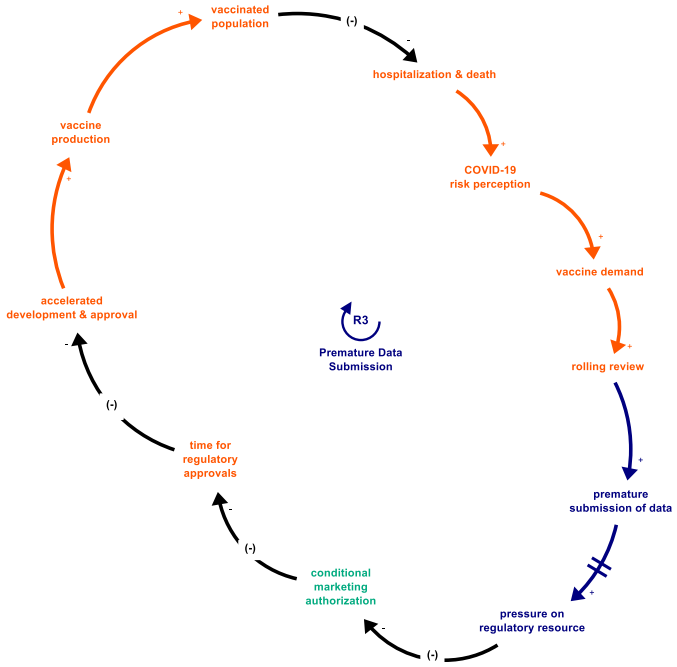


Figure 14: Premature Data Submission loop

R4 – Clinical Trial Regulation Implementation

This loop captures the consequences of the rolling review process reported by participants which helped accelerate the vaccine production and supply. Regulators reported that the parallel processing allowed submission of premature data increasing personnel commitments and time spent on reviewing dossiers.

One participant (IND8) reported, "*the disadvantages are that you might prematurely submit something and then regulators spend a lot of their time looking at it and then that's a waste of time because it turns out that the product is not working or the safety profile isn't good enough. So you can waste your assessor's time and assessors time is very precious*".

Several participants also reported that the **EU Clinical Trials Regulation (CTR) 536/2014** was not yet fully implemented during the early phase of the pandemic. This lack of full implementation of clinical trails was perceived by many industry experts to have been rushed for vaccine development and approvals. This perceived rushed vaccine development and approvals lead to reduced public preference for COVID-19 vaccine.

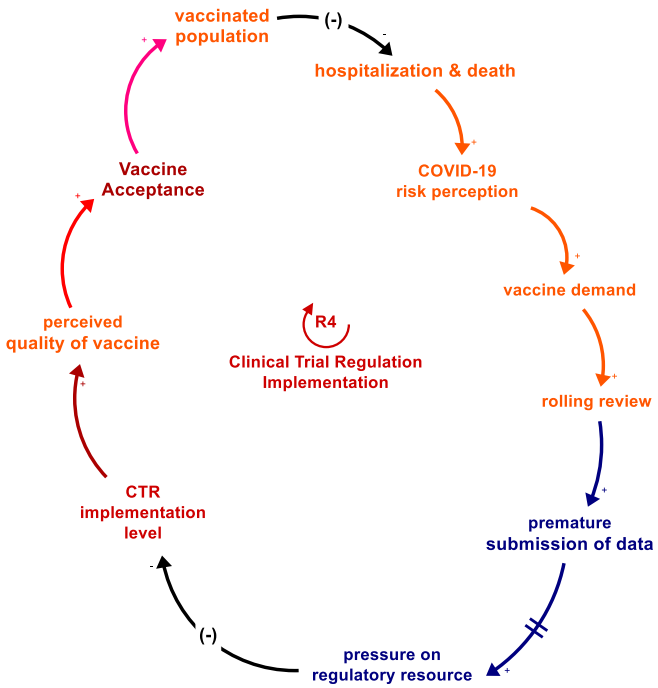


Figure 8: Clinical Trial Regulation Implementation loop

R5 – Conditional Authorization Communication Gap

This loop illustrates how the gap in communication following the conditional market authorization of rapidly developed COVID-19 vaccines contributed to reinforcing the vaccine hesitancy.

As discussed earlier in loops **R1** (Acceleration Induced Hesitancy) and **B3** (Conditional Marketing Authorization), the use of parallel review of trial data, along with coordinated information sharing and scientific advice, made the rolling review process possible and allowed conditional market authorization (CMA) to be granted rapidly increasing the desired need for transparent communication to inform public. As the conditional authorizations were being granted, stakeholders reported a lack of transparent communication to the public about how such shortened timelines had been achieved. The lack of proactive communication from the government following the conditional authorization increased the gap of transparent reporting. This communication gap compounded the effects of sensational reporting by further lowering transparency, reinforcing declining trust in health system and contributing to reduced COVID-19 vaccine acceptance.

Highlighting the relevance of transparent communication, one participant said, "*CMA should only be applied in the case of unmet medical need, and further, when CMA is used, it should be communicated better to the public to generate more trust and limit hesitancy*".

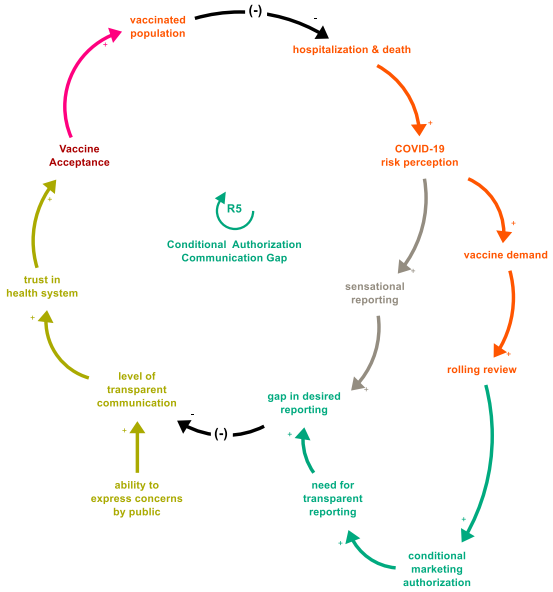


Figure 13: Conditional Authorization Communication Gap loop

R6 – Pharma Market Sustainability

This loop illustrates how the joint procurement process, while negotiating for a uniform price and improving equity through access, impacted the market sustainability.

Following the high vaccine demand and inequitable vaccine access, centralized negotiations by the EU managed to keep the price at an affordable level. The controlled/limited sales margin of the vaccine, however, reduced the attractiveness and sustainability of the COVID-19 vaccine market. This reduced the overall production capacity eventually impacting the availability of these vaccines.

One policymaker/advisor (PMA8) shared a critical view and criticized member states and the commission for negotiating a low price. He said, "*the European Commission is always in the dilemma that they have to take care of the public health of the community, of the population, but also they want to have a competitive pharma industry. While health ministers on the national level almost only have the perspective of purchasing goods for the public, and they don't look whether the pharma companies are making enough money and whether they are competitive. So this double perspective of the European Commission is definitely difficult*".

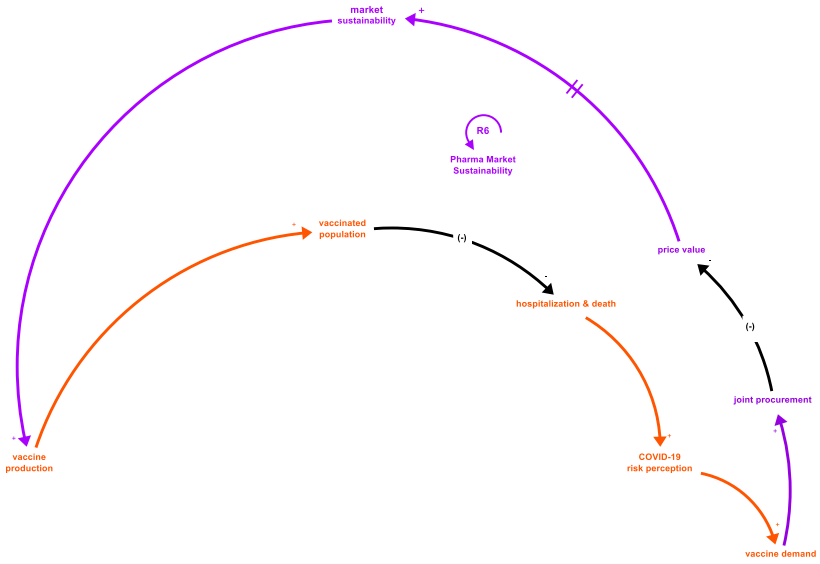
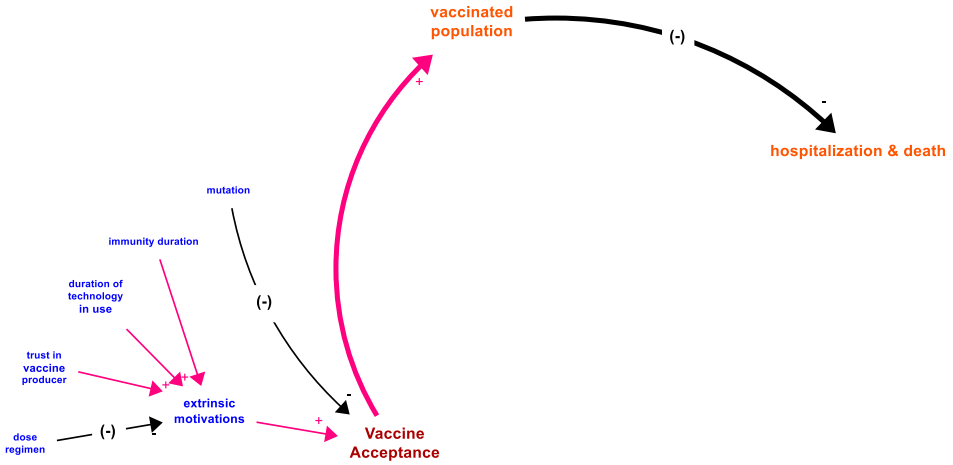


Figure 15: Pharma Market Sustainability loop

Exogenous drivers

Our synthesis examined key endogenous reinforcing and balancing feedback loops underlying the COVID-19 immunization system, with a specific focus on vaccine acceptance in Belgium. These loops are often triggered through various factors that are exogenous to our model. Those include, among others, personal risk factors like age, medical history, pregnancy, work environment. The most relevant ones influencing preference of vaccine are shared below.



COVID mutations – Participants expressed concern about the impact of viral mutations on vaccine effectiveness and the potential need for ongoing adaptation of vaccination strategies. On mutation (F8) said, "*Otherwise you would have been vaccinated for nothing. If with Pfizer, for example, you would only be protected against the first variant, the British one, and not against the others, then it has actually been a bit of a half-measure. So of course that is also very important*". Another participant (M1) said, "*I even expect that it could stay for a few years, maybe longer, like influenza and that we would continue to have to arm ourselves against that, by, for example, a new vaccination every year, taking into account the new strains*".
These reflections highlight how mutations introduce uncertainty around vaccine protection and led a decreased vaccine acceptance. The ineffectiveness of COVID-19 vaccine against mutations pointed to the potential need for recurrent vaccination campaigns reinforcing the need for adaptive vaccine development and deployment loops.
Trust in vaccine producer – Participants' trust in vaccines was influenced not only by the vaccine itself but also by its producer and the country of origin, reflecting deeper concerns about transparency, regulatory standards, and geopolitical trust. When discussing where the vaccine is sourced from, participant (M26) said, "*We are a developed country, we have many universities, we have a lot of exchanges whereas in China which is a communist dictatorship, where they don't tell everything, I would be more suspicious*". Echoing the sentiment, another participant (M11) said, "*A vaccine approved in China is not the same to me as a vaccine approved in Flanders or Belgium. Belarus, for example, is also the first country to have its vaccine, but everyone was doubting that a little*".
These quotes illustrate how perceptions of governance, scientific credibility, and political transparency in the vaccine's country of origin can significantly influence public trust and vaccine acceptance. This becomes particularly influential in scenarios where domestic vaccine supply is limited and there is a need to import vaccines from other countries.
Immunity duration, dose regimen, and vaccine technology – Several participants raised concerns about scientific uncertainties related to vaccine characteristics, including the duration of immunity, dosing schedules, and the use of new vaccine technologies. On the issue of Immunity duration one participant (M18) said, "*We don't know. Its effectiveness is one thing, the side effects are another, and how long the vaccine will protect you, there's not much, we're*

not too sure, it's very very unclear". This uncertainty contributed to hesitancy, as individuals struggled to evaluate the long-term benefit of vaccination. Concerns also extended to vaccine dose spacing and regimen. For instance participant (F27) commented, "*The problem with Astra was mainly, at that time anyway, the delay between the 2 doses that was particularly long so if only for that, I found Pfizer was better suited*".

In addition, a few participants expressed apprehension about the use of new vaccine platforms, particularly mRNA technology. Participant (M13) said, "*RNA can be expressed on the cell wall, research has been done on that. This can be associated with auto-immune diseases, such as lupus*". Another participant (M14) emphasized the lack of choice in vaccine type, stating, "*I think it's not fair that people, without wanting it, are less protected against corona, just because they didn't have the choice about which vaccine they want to take. That's kind of unfortunate then*".

All these factors are linked to the vaccine research and development (R&D) process. For instance, choices made during vaccine development can influence public perceptions of safety, efficacy, and trust either reinforcing hesitancy or supporting uptake. While these dynamics highlight the importance of scientific decisions in shaping immunization outcomes, however, they are intentionally excluded from endogenous representation in the current CLD.

Discussion

This CLD explains the diverse opinions about COVID-19 vaccination from the patient's perspective along with the viewpoints from pharma industry personals, assessors, regulators and policymakers offering a system-wide perspective on the factors influencing COVID-19 risk perception, vaccine acceptance, and behavioral responses from both public and policymakers. The model integrates feedback loops based on public preferences, health policies, trust in authorities, and social behaviors all within the Belgian context. Importantly, it highlights how population heterogeneity, particularly the coexistence of pro-vaccination, skeptical, and anti-vaccination subgroups, complicates both communication strategies and policy effectiveness. Based on our analysis of 30 interviewees data, below table provides the distribution of views across key vaccination-related themes.

Theme	Related Loops	Positive (Vaccinated)	Apprehensive (Vaccinated)	Apprehensive (Undecided)	Negative (Unvaccinated)	Neutral (Undecided)
Accelerated Vaccine Development & Approval	B2, B3, R1, & R4	11 (36.7%)	3 (10%)	10 (33.3%)	6 (20%)	0
Social Freedom–Induced Acceptance	B1 & B4	17 (56.7%)	0	0	0	13 (43.3%)
Fear of Side Effects (Long-Term)	B8	6 (20%)	12 (40%)	7 (23.3%)	5 (16.7%)	0
Fear of Side Effects (Short-Term Life-Threatening Side Effects)	B8	14 (46.7%)	10 (33.3%)	0	6 (20%)	0

Table 1: Distribution of views across key vaccination-related themes.

The following subsections present the dynamic from the consolidated CLD and implications of these interactions on policy decisions and vaccine acceptance over time. These insights will offer support for more robust pandemic preparedness by guiding future decision-making guidelines and policy frameworks that better align vaccine strategies with public expectations and acceptance.

NPI : Balancing Control vs. Social Freedom

Interviewees described Loop **B1** (Non-Pharmaceutical Interventions) as a dynamic in which public's perceived risk heightened as the COVID-19 cases increased, prompting governments to impose NPIs such as lockdowns, travel bans, and social distancing. Participants indicated that these measures initially reduced disease transmission but became less effective over time due to declining compliance. Based on our analysis, the prolonged restriction led to erosion of compliance. However, restricted social freedom was not the only reason for non-compliance, it was compounded by the fact that few participants did not perceive the risk of COVID-19 disease. The reflections suggest that reliance on NPIs without parallel trust-building measures may reduce long-term effectiveness.

The literature indicates that Belgium was an early adopter for a range of progressively stringent measures including obligatory face-covering, suspending public assemblies, and mandating remote work starting February 2020. As the crisis continued, through the Easter and summer periods of that year, policymakers were faced with depreciated compliance to NPIs (Risk Assessment Group BE, 2020; Zaki et al., 2023). Literatures also suggest how individual governments implemented strong and decisive public interventions, at times violating International Health Regulations, 2005 (IHR). In imposing travel restrictions against China during the outbreak of COVID-19, many countries were violating the IHR. (Habibi et al., 2020; WHO, 2016). Such fragmented approaches taken by countries which is not in-line with the WHO guidelines can cripple WHO's ability to coordinate the world's response to health emergencies (Habibi et al., 2020).

Accelerated Vaccination : Pathway to Normalcy or Policy Resistance

Loops **B2** (Accelerated Vaccine Production & Supply), **B3** (Conditional Marketing Authorization) and **B4** (Social Freedom Induced Acceptance) capture the societal hope placed in vaccines as a sustainable exit strategy from social restrictions caused by **B1** (Non-Pharmaceutical Interventions). In the absence of known treatment or vaccine, rising infections and hospitalizations intensified the demand for accelerated vaccine development, which in turn fostered rapid production and deployment. Our analysis suggests that accelerated production enabled a faster vaccination process which was positively reinforced by public desire to regain social freedom constrained following the NPIs. A significant portion of participants viewed vaccination not just as a health intervention, but as a medium to restore social, economic, and emotional wellbeing. However, the same acceleration that made vaccines quickly available also introduced uncertainties regarding vaccine quality, which contributed to reduced vaccine acceptance, as captured in loops **R1** (Acceleration Induced Hesitancy) and, **R4** (Clinical Trial Regulation Implementation). While many participants acknowledged the rationale for speed, a non-negligible segment remained concerned about the robustness of safety testing and the unknowns regarding long-term effects. These concerns were aggravated by misinformation, lack of transparent communication and, rising reports of adverse effects **B9** (Fear of Side Effects), creating a reinforcing loop of doubt that further decreased the vaccine acceptance.

Developing a successful vaccine generally takes an average of 10 to 15 years. In response, the EU took a number of measures to support efforts to compress the COVID-19 vaccine development timeline to as little as 12-24 months (IFPMA, 2019). According to the EU pharmaceutical legislation, the standard timeline for the evaluation of a medicine alone is a maximum of 210 active days. However, for COVID-19 treatments, the European Medicines Agency (EMA) handled marketing authorization applications in an expedited manner, reducing review timelines to less than 150 working days (Marinus et al., 2022b). Our analysis is in-line to the literatures which indicated the rapid pace of COVID-19 developments and the spread of misinformation contributing to a crisis of the image of science as the provider of certainty (Kattumana et al., 2023).

Joint Procurement : Equity vs. Sustainability trade-off

Joint procurement was widely discussed among industry experts and policymakers. Loop **B5** (EU Joint Procurement) showed how consolidated demands and centralized negotiations facilitated faster market access by enabling simultaneous entry of new products across Europe at uniform prices, thereby improving equity and reducing parallel trading. Although many stakeholders viewed it as an efficient mechanism, as EU-level negotiations replaced separate national processes, several participants also raised concerns that pointed to pharma market sustainability, loop **R6** (Pharma Market Sustainability). Industry experts and advisors perceived the negotiated prices as too low, highlighting the European Commission's challenge of balancing public health goals with maintaining a competitive pharmaceutical sector. Additionally, few participants reported of continued bilateral negotiations by some member states for their own price reducing overall efficiency.

COVAX was a historic multilateral effort starting from 2020 through 2023. During the COVID-19 pandemic, COVAX aimed to accelerate the development and manufacture of COVID-19 vaccines and to guarantee fair and equitable access for every country in the world (WHO, 2020a). In the EU, safe and effective vaccines started to be distributed by the end of 2020. Since then, the European Commission has secured up to 4.2 billion doses of COVID-19 vaccines. Vaccine deliveries to EU countries increased steadily, and as of August 2023 a total of 84.8% of the adult population had been vaccinated at least once against the virus (European Commission, 2023).

Although stakeholders raised concerns about unsustainable pricing, literatures suggest public funding to corporations had directly or indirectly financed all phases of vaccine research, development, testing and manufacturing, including the development of the innovations on which the RNA platform (mRNA) and other vaccines are based. Funding was extensive enough that meant little investment or sunk costs for corporations to recover, except perhaps for those associated with manufacturing the vaccines themselves. In addition, company costs for liability were minimized, as were the large marketing costs typical of pharmaceutical products. (Light & Lexchin, 2021).

Trust and Communication as Potential System Leverage Points

Loop **R2** (Sensational Reporting Trust Erosion) underscored the critical role of transparent, consistent, and credible communication. Despite showing strong evidence of vaccine safety and efficacy (WHO, 2020b), sensationalist media coverage reduced transparency and damaged institutional trust, which in turn increased vaccine hesitancy. Loop **R3** (Conditional Authorization Communication Gap) showed that clear and transparent communication is essential for building and maintaining public trust during accelerated approval processes. Participants acknowledged the emotional and mental pressure of navigating conflicting narratives, and some expressed frustration at the lack of space for critical yet constructive debates.

Vaccination hesitancy is not new (Kattumana & Larson, 2025; Larson et al., 2014, 2018) , but recent declines in vaccine confidence are linked to misinformation in traditional and social media, falsely associating vaccines with serious conditions, a phenomenon referred to as "infodemic" by the WHO (Rubinelli et al., 2022). The traditional process, whereby debates occur within scientific institutions and only settled science would be presented to the public, was no longer at play during the pandemic. However, others have criticized this tendency and called for greater involvement of the public in evolving scientific issues (Kattumana et al., 2023). Literatures also suggest that people were confronted with a crisis of communication that had multiple aspects: transparency dilemmas, communication difficulties due to the fast pace of the pandemic, and misinformation and media coverage. Literature further highlights the importance of open communication and real-time data sharing in maintaining public trust (Sommers et al., 2025). Research done on public trust during COVID-19 reflects that if existing distrust toward the medical system is not addressed, then space is created during crises-periods

for distrust to be mobilized in ways that compromise public health goals (Kattumana & Larson, 2025).

Conclusion

Overall, the CLD reveals the complex interplay between COVID-19 risk perception, vaccine development and approval timelines, safety concerns, and decision-making in shaping COVID-19 immunization outcomes. Key feedback loops reveal how efforts to accelerate vaccine development can inadvertently reduce vaccine preference through reduced vaccine quality perception, increased adverse effect concerns, and inadequate clinical trials, ultimately affecting uptake. Moreover, consequences of the cumulative regulatory burden imposed by these expedited authorizations should not be underestimated, particularly in relation to the long-term effectiveness and sustainability of these accelerated pathways. In addition, the analysis demonstrates that while EU joint procurement can enhance equity and efficiency, its long-term success ultimately depends on achieving a balance between fair pricing and the sustainability of the pharmaceutical market. Furthermore, effective and transparent communication emerges as a potentially critical lever in building and maintaining public trust, especially in contexts where rapid policy or scientific decision-making is required outside the traditional norms. By mapping these interdependencies, this research highlights the need for more integrated and anticipatory policy responses that balance urgency with public trust. Understanding these feedback mechanisms is critical not only for managing current vaccine strategies but also for strengthening the resilience of immunization systems in future health emergencies.

From a policy perspective, the CLD highlights the need to:

- Treat “trust” not as a static factor, but as an evolving driver influenced by experience, communication, narrative, and social influence depending on the population clusters. Therefore, t**ransparent and consistent communication** is key to maintain public trust during rapid decision-making.
- Include **end-user preferences,** for instance the use of vaccine technology**,** as early as possible during R&D phase of vaccine development.
- Adopt a **systems-based**, anticipatory policy approach that minimizes unintended consequences (resistance) caused by accelerated pathways.
- **Strengthen capacity** to manage the additional workload created by accelerated authorization pathways.
- Support **sustainable pharmaceutical markets** by aligning fair pricing approaches with long-term industry viability.
- Establish a **systems-based** routine review and optimization process to shorten regulatory timelines where feasible so **improvements are made proactively** rather than only in response to public health emergencies.

Strength and limitation

Qualitative system dynamics approach (CLD) effectively maps the dynamic relationship between constituent elements of the health system highlighting the complex interactions between them. Using interview data to construct the CLD increases the confidence and validity of the resulting CLD. By consolidating insights from in-depth patients interviews with perspectives from policymakers and industry experts, the study captures a more holistic view of COVID-19 immunization system. This integration helps explain the drivers (causes) of policy decisions during the pandemic while also revealing the underlying public concerns (consequences), allowing a more nuanced understanding of participants' opinions and preferences regarding COVID-19 vaccination. Similarly, by illustrating varying views using

microstructure CLD, the consolidated CLD captures more accurately the structures of the system as experienced by individuals (their mental model) within the system.
We realize that disease surveillance and economic aspects are not represented explicitly in the CLD as the interviewees focused on involving the broader community from an end-user perspective complemented with views from policymakers and experts. Similarly the R&D decisions and supplier side views were not included as part of this research. However, our follow-up work will include the insights from supplier side on different decision-making steps across the drug life cycle with the purpose for long term strategic and operational pandemic preparedness.

Future Research

Future research will build on the strengths of this study by (Bureš, 2017; Kim & Andersen, 2012; Newberry & Carhart, 2024)translating this qualitative CLD model into a complementary system dynamics simulation model following participatory group model-building workshops (Decouttere et al., 2016; Rouwette, 2016). Once the model is validated, it will then be used for what-if and scenario analysis to evaluate various immunization design options. Finally, the set of 'best-in-class' scenarios will be brought to the decision makers' table. A final choice for future implementation can be made, with the knowledge that there is a series of good preparedness alternatives.

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Ethics approval and consent to participate

Approved by the Ethics Committee Research UZ/KU Leuven (S65264), KU Leuven, Belgium.

Availability of data and materials

The datasets generated and analyzed for this study can be found in the 'Interview data synthesis' file (.pdf).

Declarations

Competing interests

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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