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Identifying vulnerabilities in essential health services: Analysing the effects of system shocks on childhood vaccination delivery in Lebanon

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ABSTRACT

Shocks effects are under-theorised in the growing literature on health system resilience. Existing work has focused on the effects of single shocks on discrete elements within the health system, typically at national level. Using qualitative system dynamics, we explored how effects of multiple shocks interacted across system levels and combined with existing vulnerabilities to produce effects on essential health services delivery, through the prism of a case study on childhood vaccination in Lebanon. Lebanon has experienced a series of shocks in recent years, including large-scale refugee arrivals from neighbouring Syria, the COVID-19 pandemic and a political-economic crisis. We developed a causal loop diagram (CLD) to explore the effects of each shock individually, and in combination. The CLD was developed and validated using qualitative data from interviews with 38 stakeholders working in Lebanon's vaccination delivery system, in roles ranging from national level policy to facility-level service delivery, conducted between February 2020 and January 2022.

We found that each of the shocks had different effects on service demand- and supply-side dynamics. These effects cascaded from national through to local levels. Both Syrian refugee movement and the COVID-19 pandemic primarily exposed vulnerabilities in service demand, mainly through slowly emerging knock-on effects on vaccination uptake behaviour among host communities, and fear of contracting infection in crowded health facilities respectively. The economic crisis exposed wider system vulnerabilities, including demand for vaccination as household income collapsed, and supply-side effects such as reduced clinic time for vaccination, declining workforce retention, and reduced availability of viable vaccine doses, among others. Finally, important pathways of interaction between shocks were identified, particularly affecting the balance between demand for vaccination through publicly supported facilities and private clinics. Future research should incorporate dynamic approaches to identifying within-system vulnerabilities and their potential impacts under different scenarios, as a precursor to improved resilience measurement, system preparedness, and intervention targeting.

1. Introduction

Shock effects – as challenges to system resilience – are under-theorised in the health systems literature (Ismail et al., 2022). This is a critical deficit because meaningful action to improve resilience – understood here as the capacity to absorb shock impacts, or adapt or transform in response to them while maintaining essential structures and functions (Blanchet et al., 2017) – is impossible without clarity as to what a system should be resilient to.

While some studies consider ways in which different categories of shock affect system resilience (spanning, for example, armed conflict, disease epidemics and economic crises), these analyses provide a limited view of how shocks interact with health system vulnerabilities and capacities to produce risks to health, and do not address in detail potential mechanisms contributing to these risks (Thomas et al., 2013, 2020; Hanefeld et al., 2018). Secondly, existing literature tends

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overwhelmingly to adopt a macro-level (national) lens (Hanefeld et al., 2018; Haldane et al., 2021; Biddle et al., 2020; Ling et al., 2017), although there is increasing awareness following the COVID-19 pandemic of the importance of dynamics at multiple health system levels (from local to national and even supra-national) (Mayhew et al., 2021; Saulnier et al., 2020). Thirdly, the literature has predominantly looked within the health sector alone for factors contributing to system resilience (Biddle et al., 2020). There has been far less attention to cross-sectoral linkages which may give rise to "multi-systemic" risks over time (Wernli et al., 2021).

Finally, existing work on health system resilience tends to look at the effects of single shocks in isolation. In reality, health systems in many contexts (and especially humanitarian ones) must often address effects arising from multiple overlapping shocks at the same time. Work on multi-hazards in other fields, by contrast, has demonstrated how sequential shocks can interact to produce amplified, and sometimes wholly new, risks to human systems (Gill and Malamud, 2017; Kappes et al., 2012; Pescaroli and Alexander, 2018; Pescaroli et al., 2018). Failure to adequately account for this may undermine health system resilience-building and preparedness efforts.

In this paper – in keeping with terminology in the health systems literature – we use "shock" to describe a hazard as conventionally understood in the world of disaster risk reduction (DRR), i.e. "a process, phenomenon or human activity that may cause loss of life, injury or other health impacts, property damage, social and economic disruption or environmental degradation" (UNDRRa; UNDRR, 2020).

1.1. Insights on shock conceptualisation from domains outside health

Theoretical and empirical work in other fields offers a much richer view of shocks, emphasising the need to consider inter-relationships between different kinds of event, the interactions between them, and the risks they can give rise to across a range of social, political, economic, and environmental systems when combined with pre-existing vulnerabilities (Ismail et al., 2022; Sillmann et al., 2022). These literatures invite us to move away from event-based typologies (distinguishing shocks caused by different types of climatic event, for example), towards instead characterising the attributes of shocks that are of relevance for determining health system effects. These may include [i] shock intensity, temporal and geographic scope, [ii] inter-relationships between shocks and the elements of the system of interest, and [iii] the role of path dependencies and other potential sources of system vulnerability (e.g., institutional, poverty and other population vulnerabilities). Characterising shocks in this way, relies on methodological approaches that can capture change over time, and can model dynamic behaviour within complex systems (de Savigny et al., 2017; Chang et al., 2017; Savigny and Adam, 2009).

Recent work in DRR and environmental science outlines how systemic risks can arise as a result of the combined effects of discrete shocks and interactions between these (Tilloy et al., 2019; Gill and Malamud, 2014; De et al., 2022). It also shows how systems both shape shocks and are exposed to them. Combinations of shocks (compound shocks) can give rise to risks that are qualitatively different from those that would have arisen had those shocks occurred separately in time and space (Gill and Malamud, 2014, 2016, 2017; Kappes et al., 2012; Zscheischler et al., 2018; Hochrainer et al., 2020). A key concept emerging from this literature for health systems is the notion of *cascading risk*, in which critical system vulnerabilities may be acted upon by different shocks to create progressively amplifying impacts. The example frequently cited to illustrate this is Hurricane Katrina: a natural disaster that interacted with substantial pre-existing social, economic, political and institutional vulnerabilities in New Orleans in the United States, giving risk to catastrophic public health effects including more than 1800 fatalities (Pescaroli and Alexander, 2018). This implies that – given the difficulty of predicting the range of macro-level shocks to a system that may occur – preparedness and resilience-strengthening work should instead focus on identifying and acting on recognised points of vulnerability within the system and addressing these.

In this study, we aimed to improve the theorisation of shocks as applied to health systems by conducting a focused case study on shock effects on delivery of an essential health service: childhood vaccination. Specifically, we set out to explore the effects of compounding shocks on the vaccination delivery system in Lebanon and identify real or potential sources of vulnerability within that system. We focused on vaccination as a tracer system for our analysis because it is one of the most effective public health interventions available and a major contributor to reductions in mortality and morbidity globally especially among children under five (Phillips et al., 2017; Watkins et al., 2017; McGovern and Canning, 2015; Chang et al., 2018; Sim et al., 2020), but vaccination coverage in many crisis-affected contexts is low (Close et al., 2016; Connolly et al., 2004).

Our case study was Lebanon, a country that has recently experienced a series of overlapping shocks in recent years. These shocks included large-scale Syrian refugee arrivals, the COVID-19 pandemic, and a multi-dimensional political and economic crisis. Our focus was on better understanding how successive shocks affected activities at multiple levels (from national down to facility-level) to create within-system risks to vaccination delivery, and how and where these shocks interacted in their effects within the system. An important focus in our analysis was on understanding sources of vulnerability within the vaccination delivery system – in other words, system characteristics or causal pathways increasing system susceptibility to shock effects (UNDRRb). In so doing, we present here to our knowledge the first analysis of interactions between multiple shocks as applied to health systems.

We applied qualitative system dynamics (SD) modelling, a methodological approach that generates visualisations – called causal loop diagrams (CLDs) – of cause-and-effect relationships within a system underpinning behaviour over time (see **Appendix 1**) (Sterman, 2000; Tomoaia-Cotisel et al., 2017). We did so because SD offers a rich set of tools for capturing interconnections and feedbacks within systems (Richardson, 2011). In contrast to analytical approaches that have conventionally been applied to study health system responses to shocks, such as the WHO building blocks framework, qualitative SD allows for conceptual mapping of causal relationships within systems over time, and the potential for unintended consequences when new interventions or contextual changes are applied to them (Borghi and Chalabi, 2017; El-Sayed and Galea, 2017; Herrera de Leon and Kopainsky, 2019; Ismail, 2023). SD has previously been applied to the analysis of resilience in health systems including in humanitarian contexts, but not to consider multiple, overlapping shocks (Ager et al., 2015; Jamal et al., 2020). We used system dynamics in preference to other systems methods because our focus was at the aggregate system rather than the individual level. This method also enabled us to identify key variables and pathways (sequences of causally interconnected elements and feedback loops) mediating the impact of individual shocks on vaccination delivery, and cascading effects arising from multiple shocks over time, to build a theory of system responses to them (Cloutier and Langley, 2020). This included identifying points of interaction between the shocks over time, and system vulnerabilities exposed by each shock individually and in combination.

2. Methods

This was a qualitative system dynamics modelling study.

2.1. Study setting

This study was set in Lebanon, a small country in the Middle East covering around 10,500 km^2, and with an estimated population of just over 6 million in 2021 (World Bank). Historically, the health sector in Lebanon has been highly fragmented with powerful private and not-for-profit actors (Jagarnathsingh et al., 2016; Kronfol, 2006; Kronfol

and Bashshur, 1989; Ammar, 2003; Sen and Mehio-Sibai, 2004). Vaccination access points in Lebanon vary by population, but the primary delivery modes have been through private clinics and dispensaries (pharmacies), the charitable sector, the Ministry of Public Health's (MoPH) primary healthcare centre (PHC) network, and a network of Social Development Centres (SDCs) operated by the Ministry of Social Affairs (MoSA). Many dispensaries and all PHCs operate through partnership arrangements with local and/or international non-governmental organisations (NGOs) that provide financial, technical and other forms of support.

The Syria Crisis is the proximate cause of the latest in a long series of large-scale population displacements in Lebanon. There were around 815,000 registered Syrian refugees residing in Lebanon as of December 31, 2022, down from a peak of just under 1.2m in April 2015. There is in addition a sizeable, unregistered refugee population, the magnitude of which remains uncertain. However, over the course of this study between 2019 and 2022, the country was engulfed by a compound crisis stemming not just from the population movement described above, but in addition an economic crisis, one of the largest non-nuclear explosions ever recorded (in Beirut in August 2020) (el Sayed, 2022), and finally, from early 2020 onwards, the COVID-19 pandemic. These three shocks have overlapped in space and time and interacted in particular ways to give rise to cascading risks to public services including vaccination delivery in Lebanon (R4HC -MENA, 2022; Hamadeh et al., 2021).

Routine data and published analyses of coverage for key antigens in Lebanon are indicative of large declines in national coverage broadly coinciding with the shocks described above (Mansour et al., 2021; Mansour et al., 2018; Mansour et al., 2019; UNICEF Lebanon, 2021; Lebanese Ministry of Public Health, 2016) (Fig. 1).

2.2. Approach to primary data collection

2.2.1. Study settings and participant recruitment

Interview participants were sampled purposively from organisations with a stake in routine immunisation delivery in Lebanon. These included representatives from government (the MoPH), from donors and agencies supporting the Lebanon Crisis Response Plan (LCRP), from NGOs supporting primary care service delivery, and finally from service managers and practitioners involved in front-line primary care. Table 1 provides a breakdown of participants by group.

Facility-level interviews took place in two governorates in Lebanon:

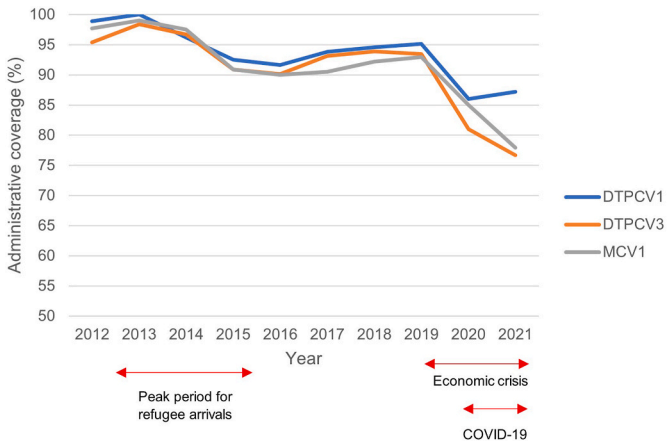

Fig. 1. Administrative vaccination coverage rates (national) for selected antigens in Lebanon in the period 2012-21.
Approximate timing of key shocks investigated in this study are indicated in red lines near the base of the diagram. Abbreviations: DTPCV1 = first dose diphtheria, tetanus and pertussis vaccination; DTPCV3 = third dose; MCV1 = first dose measles vaccination. Source: WHO Immunisation Statistics (World Health Organization (WHO)). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Table 1
Breakdown of interviews conducted, by stakeholder group and timing, showing the distribution of interview transcripts across the analysis and validation sets for CLD development.

Stakeholder group	Sub-category	*Wave 1 (Feb-Mar 2020)*	*Wave 2 (Jul 2021-Jan 2022)*	Analysis set	Validation set
National	Government	2	1	16	2
	Donors	0	4		
	Agencies	5	5		
	Private sector	0	1		
Regional bodies and implementing partner organisations		1	12	11	2
Local – facility level	Akkar	0	5	6	1
	Beirut	0	2		
Wave total		8	30		
Overall total		**38**		**33**	**5**

Beirut and Akkar. These locations were chosen to reflect the breadth of service delivery challenges across the country. Beirut incorporates the country's capital, the focal point for logistics and supply chains relevant to vaccination delivery, and has been the major hub for humanitarian actors, NGOs and others supporting the humanitarian response to the Syria crisis in Lebanon. Akkar is a border governorate in the North of the country which hosts a large refugee population and where a large proportion of the host community population are socio-economically deprived. It has also historically suffered from lower investment in public services than in other areas of Lebanon and has been among the areas worst affected by the economic crisis since late 2019.

2.2.2. Interview design and conduct

A total of 38 interviews were carried out in two waves (February–March 2020, and then July 2021–January 2022), n = 8 of these in-person in Beirut, and the remainder remotely via Zoom. Interviews were semi-structured and gathered information on participant roles within the system, generic structures supporting vaccination delivery, and pathways and system behaviours that stakeholders identified as relevant to each of the various shocks. They lasted on average 1 h with national and regional stakeholders, but typically around 30 min with those working at facility level. Interviews were recorded, transcribed into MS Word and where necessary translated from Arabic into English prior to analysis.

2.3. Generation of the CLD

The CLD was generated in three steps. First, a CLD was developed for each individual interviewee to represent their understanding of the effects of each of the shocks in Lebanon on childhood vaccination delivery. These were then combined using a stepwise process, before a final validation step, as mapped out in Fig. 2.

2.3.1. Step 1: generation of individual CLDs

Interview transcripts were split into two sets – a core analysis set from which the CLDs were derived, and a validation set to be used later (Fig. 1). Individual interview transcripts from the core analysis set were coded in MS Word using purposive text analysis (Kim and Andersen, 2012; Tomoaia Cotisel et al., 2022). This approach identifies language that is explicitly causal. Text segments were coded if they described events, processes or items (e.g., stocks of a particular good) relevant to vaccination delivery system responses to the arrival of refugees from Lebanon, or ongoing efforts to strengthen vaccination delivery across refugee and host community populations in the context of the COVID-19 pandemic and the economic crisis in Lebanon. Finally, text segments

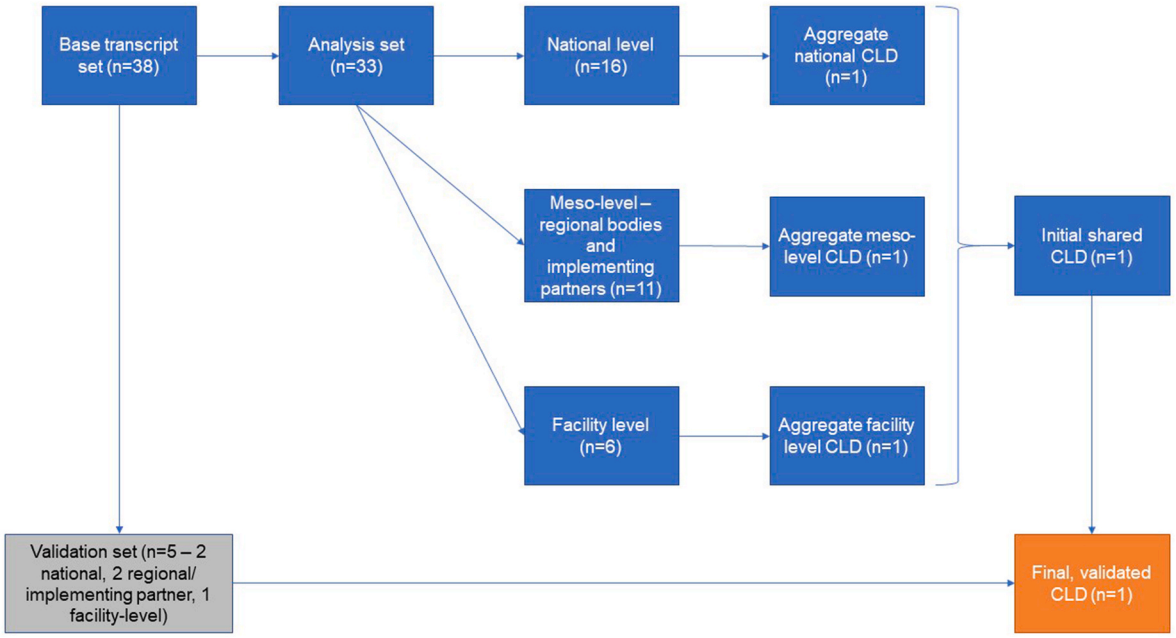

Fig. 2. Schematic representation of the process for generating the initial, shared CLD from the analysis set.

were coded if they addressed relevant local (i.e., facility-level), meso- (i.e. regional) or macro-level (i.e. national) system behaviours.

Coded segments were then transferred into a separate MS Excel template for Rigorously Interpreted Quotations (RIQ). RIQ analysis provides a systematic approach to deconstructing text segments to identify relevant variables and causal language that link one or more variables together, determining the directionality and polarity of these relationships, and whether any significant material or information delays are identifiable (Tomoaia Cotisel et al., 2022). The process by which this was performed in this study is illustrated using a sample quote in **Appendix 2**. Variables and relationships identified in this way were then visualized in Vensim® (Ventana Systems Inc). This process was repeated for each interview transcript in the analysis set, to develop a total of n = 33 individual CLDs.

2.3.2. *Step 2: combining CLDs*

CLD combination followed a process described in Tomoaia-Cotisel (2018). Individual diagrams were first grouped according to the stakeholder set from which they originated, and then ordered in terms of their complexity. The most complex CLDs within each stakeholder group were chosen as the base diagrams for combination for each stakeholder group, because they contained the richest information. These were termed the "anchor" CLD for each group, with which individual CLDs were combined, in order.

Before any combination was attempted, individual CLDs were first mildly pruned. In this process, only delays (any instance in which there was a material or information delay between two variables in a link) and feedbacks (any instance where there was a clear circular link or set of links between variables, whether positive or negative) were retained in this mild pruning process, following an approach set out by Yearworth (Yearworth and White, 2013). A principal function of this pruning step was to focus analysis on structures contributing most to system behaviour over time according to each participant's mental model.

Within each group, the anchor CLD was combined with the next most complex CLD. The process of combination was to compare the two CLDs with one another, and to identify variables and loops that were contained in the second CLD but missing from the anchor. These were then added to a copy of the anchor. Where two CLDs described the same causal process but in different ways, the more complex representation was retained on the basis that this was likely to give a fuller understanding of the causal structure involved in that section of the CLD. This process was repeated within and then across stakeholder groups to yield an aggregate diagram. A final, full pruning step was then carried out to retain only delays and feedbacks incorporating three or more links – once again to focus analysis on structures identified as central to system behaviour over time.

2.3.3. *Step 3: validation and derivation of the finalised CLD*

Validation consisted of two steps as described in Tomoaia-Cotisel to strengthen confidence in the CLD development process (Tomoaia-Cotisel, 2018). Saturation in CLD development was captured by tracking the number of additional variables, links, delays and feedback loops introduced with each additional combination step (see **Appendix 3** – Fig. 11) (Tomoaia-Cotisel, 2018). Saturation was interpreted as having been achieved once the number of new variables, links, delays and feedback loops added to the aggregate CLD with each additional individual CLD had fallen to zero. Saturation was achieved using the analysis set. We then proceeded to validate the draft, aggregated CLD, by reviewing interview transcripts from the validation set. These interviews were coded and analysed in the RIQ template to determine whether their contents confirmed the structure in the CLD, or whether revisions needed to be made (e.g. through addition of new variables, links, delays or feedback loops – see Fig. 12 in **Appendix 3**). Saturation was also reached within model validation set interviews, with limited modification to the structure through validation. **Appendix 3** provides the saturation curves for both model development and model validation set interviews.

2.4. *Analysis and interpretation of the CLD*

Once the validation process had been completed, the CLD was analysed to identify the shock effects and interactions and revealed system vulnerabilities. Firstly, balancing and reinforcing feedback loops were identified based on the simple rule of thumb set out by Sterman (2000), namely that.

- Balancing loops are those in which the number of negative links is odd (these loops are labelled "B" in all figures in the remainder of the paper);

- Reinforcing loops are those in which the number of negative links is even, or in which all links within the loop are positive (these loops are labelled "R" in all figures in the remainder of the paper).

Secondly, changes to the structure of the system over time in response to specific shocks were identified by return to material in interview transcripts, and by tracing pathways from variables describing points of shock impact (e.g. "Refugee arrivals", "COVID-19 caseload") to downstream variables within the system (see **Appendix 4**). This allowed for differentiation of usual pathways and relationships between system components (when operating under "normal" conditions), from pathways relevant to the distribution of the effects of different shocks through the system.

To identify system vulnerabilities, links emerging from the shocks of interest (represented by variables such as "refugee arrivals", "COVID-19 caseload") were traced through the CLD to identify feedback loops and delays endogenous to the vaccination delivery system that were directly influenced by those variables. These correspond to the bold lines in the CLDs that follow in the remainder of this paper. Effects on these feedback loops were interpreted by reference to material in the original interview transcripts, and relevant quotes drawn from the RIQ template. Points of interaction were identified where common feedback loops or delays were causally linked to more than one of the shocks. Finally, the number of times a specific link, loop or feedback was identified by interviewees was used to inform assessment of the strength of evidence for specific types of behaviour in response to each of the shocks.

3. Results

We identified a series of causal pathways explaining effects linked to the three main shocks in Lebanon outlined above. Fig. 3 provides a high-level overview of the vaccination delivery system, showing two loops representing connections between vaccine supply (Fig. 3, loop R) and vaccination demand (Fig. 3, loop B). This visualisation shows that each of the shocks acted on the system in different ways. While the refugee arrivals acted principally on actual demand for vaccination this occurred with a substantial delay, and both the COVID-19 pandemic and in particular the economic crisis had wide-ranging effects on both the demand and supply sides of the system. Remaining sections below explore these effects in more detail.

3.1. Refugee arrivals from Syria

In this section, we focus on delays and feedbacks directly influenced by population movement from Syria (see Fig. 13 in **Appendix 4** for a whole system visualisation). Interviewees were clear that refugee arrivals did not immediately translate into increased demand for vaccination services (Fig. 3). Many Syrians initially prioritised subsistence needs (e.g., food and shelter) over access to preventive services, and knowledge of service access points for childhood immunisation in the initial phases of the crisis was also limited. Additionally, a large proportion of refugees settled initially in informal settlements often some distance away from PHCs. This resulted in low demand through mainstream services early on, although there was some attempt to address emerging needs through use of mobile medical units (MMUs) that were

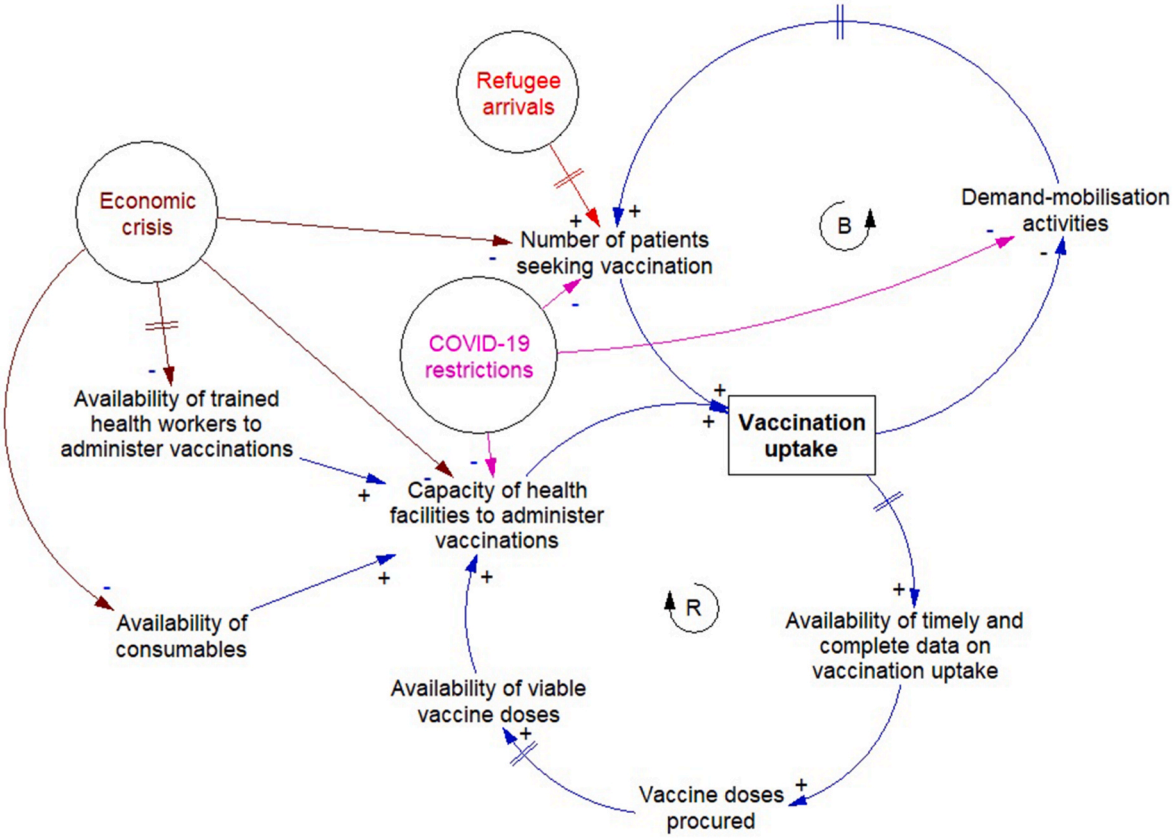

Fig. 3. High-level CLD describing the effects of shocks on vaccination delivery in Lebanon.
Stable elements of the supply (R) and demand (B) sides of the vaccination delivery system are represented in blue, feeding into the primary outcome (vaccination uptake); dynamics linked to the various shocks are highlighted in red (population displacement), purple (the COVID-19 pandemic) and brown (the economic crisis) respectively. In this visualisation, "availability of consumables" describes access to vaccine administration equipment, personal protective equipment and other necessary elements for vaccine administration; "demand mobilisation activities" refers to the combination of communications activities and engagement work carried out to drive up vaccine uptake. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

conventionally used for outreach into remote areas.

Instead, a slowly unfolding cascade of effects at multiple system levels occurred over time. Effects were seen initially mainly at national level. Here, early system responses to refugee arrivals were motivated by growing concern at the perceived risk of vaccine-preventable disease (VPD) outbreaks, based on assumptions that the proportion of unvaccinated and partially vaccinated people in Lebanon was now rising. This perceived risk was also reinforced by reported VPD outbreaks in Syria. This heightened concerns among decision-makers in Lebanon about the risk of an outbreak of a high-consequence VPD, particularly polio. It provided an additional rationale for the early, national vaccination campaigns that took place in 2013-14:

> *"Considering the polio outbreak in the neighbourhood countries, it was not possible for the Lebanese Ministry and for the sector also and the humanitarian agencies to wait until all these refugees settle and know where are the primary healthcare centres and go for their vaccines. It was very important for us to mobilise for the vaccination activities to go and reach them [with] door-to-door vaccination activities in order to prevent any major outbreaks and to help the system withstand all this pressure." [LFS01, agency representative]*

As facility-level demand for vaccination services linked to population movement gradually increased in 2014-15, vulnerabilities within the system became more apparent (Fig. 3). Better awareness of PHC locations and the fact that Syrian refugees could obtain vaccinations there free of charge spurred an increase in PHC attendance and in some cases facility-level crowding, occasionally resulting in clinic closures when staff felt demand outstripped local capacity to administer vaccines (Fig. 4, loop B1). Vaccination uptake was also influenced by declining availability of clinic time to vaccinate, as health worker workload in PHCs and other primary care facilities increased (Fig. 4, loop B2). Increasing demand for vaccination at facility level also increased the risk of vaccine stock-outs (Fig. 4, loop B3), although interviewees emphasised that in general supplies of vaccine doses to facilities had kept pace with emerging needs following the main period of cross-border movement from Syria.

Rising demand for vaccination through PHCs driven by increasing attendances by Syrian refugees also spurred an important shift in vaccination uptake behaviour among host communities. Historically, host communities across income groups had sought vaccination predominantly through private clinics, because of a perceived link between cost and quality of care (Fig. 4, loop R1). Rising use of PHCs by Syrians and resulting facility crowding resulted in private clinics being perceived to offer better quality care than PHCs, which catered mainly to refugees (Fig. 4, loop R2).

This reinforced the historical preference of host communities for vaccination through private clinics (Fig. 4, loop B4).

> *"Syrians overwhelmed the centres … so the Lebanese who used to go to those centres stopped going, and the Lebanese do not get their vaccinations in those centres, who mainly go to the private sector." [LFSE1, agency representative]*

> *"The Lebanese population know where are the centres. But they don't prefer to go to the centres. This is because unfortunately of a lack of trust to the public system. So you can find a Lebanese family that's somehow poor, or moderate, in need of financial support. However, they prefer to pay, I don't know to borrow $100 from a neighbour and take their children to get vaccinated in a private clinic, and they don't go to get the free vaccination in the PHC next door." [LFS06, agency representative]*

3.2. The COVID-19 pandemic

Effects related to the pandemic were seen principally at the micro-level (i.e. at individual health facility level or interaction between providers and individual service users), affecting both demand for, and supply of, services (Fig. 5 below, and see the overarching CLD presented in Fig. 14 in **Appendix 4**).

From a demand perspective, a new causal pathway emerged linking ability to socially distance in facilities to carers' perceived risk of contracting SARS-CoV-2 (the pathogen that causes COVID-19) which in turn reduced vaccination uptake as clinic attendances declined (Fig. 5, loop B5). This was mirrored by a new supply-side loop in which health workers' perceived risk of contracting infection increased the likelihood of clinic closures, reducing access to vaccination (Fig. 5, loop B1(adj.)). Perceived risk of contracting SARS-CoV-2 was linked to both facility-level crowding, and knowledge of the background caseload. The result

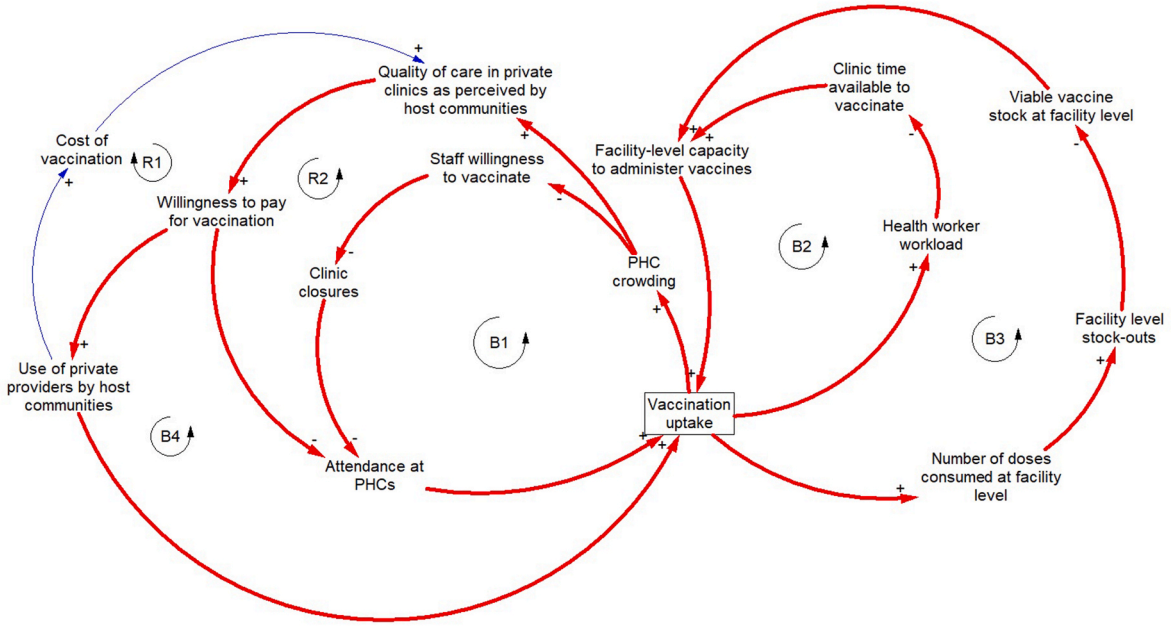

Fig. 4. Relationships between PHC accessibility, vaccine dose availability, refugee-host community relations and vaccination uptake over time following refugee arrivals from Syria. Pre-existing structures directly activated by the shock are highlighted using bold, red lines; light blue lines describe causal relationships present under "normal conditions". (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

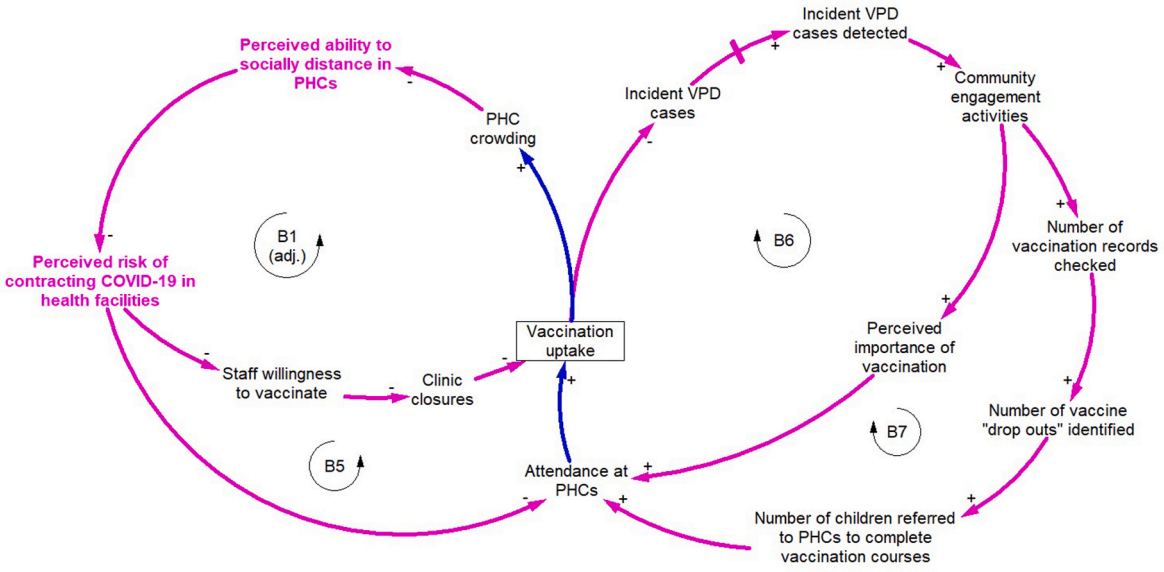

Fig. 5. Links between perceived risk of contracting SARS-CoV-2 in health facilities, intensity of VPD surveillance in the community, and vaccination uptake in Lebanon during the pandemic. Pre-existing structures directly acted upon by the shock (the COVID-19 pandemic) are indicated by bold, purple lines; new structures are indicated by bold purple variable names and associated links. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

was de-prioritisation of preventive services including vaccination:

> *"Even if we have been given lists of defaulters by the MOPH, when we contact the family and find a defaulter and try to persuade the family to attend a PHC, then we find there is fear or areas or health services where there is perceived to be a risk of contracting the virus* e.g. *at the health centre or hospital, then they say they would prefer to go the PHC later, or they may say that they don't think it is important" [LFS08, implementing partner]*

At the macro-level, several interviewees highlighted vulnerabilities created by the re-allocation of MoPH resources to the pandemic response and away from VPD case surveillance. Interviewees in wave 2 expressed concern that this increased the risk of VPD cases emerging undetected. They highlighted that without adequate surveillance, there was a risk that response work using community engagement to increase demand for vaccination in areas where new cases had been identified would not be triggered in a timely way (Fig. 5, loops B6, B7):

> *"During COVID all the [Epidemic Surveillance Unit] systems and the active surveillance were focusing more on COVID, so the active surveillance was not properly done so we don't know if there were really acute flaccid paralysis cases that were not properly detected …" [LFS11, government official]*

Movement restrictions imposed to reduce the spread of SARS-CoV-2 had wide-ranging effects on demand for vaccination from host communities and refugee populations alike. Clinic attendances fell precipitously especially during the first lockdown because of these restrictions – although as the CLD shows this pathway was not, in the view of interviewees, fully endogenous to the vaccination delivery system. School closures also disrupted a key point of verification of children's vaccination records, a process that typically happened at the beginning of the school year. Several interviewees highlighted the impact this had had on ascertainment of children with incomplete vaccine courses, and system capacity to address this (Fig. 5, loop B7).

Movement restrictions also hampered the effectiveness of community engagement activities to increase demand for vaccination. Implementing partners consistently highlighted the impact that changing from face-to-face to remote community engagement work had had on their ability to engage target populations, in turn influencing ability to emphasise the importance of vaccination and to identify children who had not received per-schedule vaccines:

> *"In the peak of the pandemic in Lebanon, we were so frustrated because we shifted to the online modality and even if you know you are so motivated and so engaged, you cannot have this impact as when you are physically present in the household … interacting with them" [LFS10, implementing partner]*

Although second wave interviewees emphasised that demand had recovered to some extent as pandemic restrictions were eased, this recovery was only partial because of worsening economic conditions – as the next section will show.

3.3. The economic crisis

An overarching view of CLD structures affected by the compound crisis is presented in Fig. 13 in **Appendix 4**. In this section, we focus specifically on effects arising from the economic crisis. From a vaccine supply perspective, a majority of interviewees highlighted concerns regarding the impact of increasingly irregular electricity supplies on cold chain integrity. This was linked variously to failures in the domestic power grid in Lebanon, the rising cost of fuel for backup generators and the effect of import restrictions on the availability of spare parts for solar-power fridges widely used in PHCs by 2019-20. Inability to maintain sufficient cold storage at facility level reduced the availability of viable doses locally, and therefore the capacity to administer vaccines. Irregular electricity supplies also reduced capacity to deliver simply through reductions to clinic working hours because managers could no longer afford to keep facilities open.

A key driver of vulnerability at multiple levels across the system – and affecting both demand and supply – was the declining value of the Lebanese Lira (Fig. 6):

> *"To be honest, I don't believe that nowadays with this dollar inflation, that the PHCs alone can act, or the MoPH or the government alone can act without the humanitarian support or donors, it's impossible for the system to run" [LFS12, implementing partner]*

Nationally, currency inflation intensified the workforce retention problem at central and local level (Fig. 6, loop R6). Inflation reduced

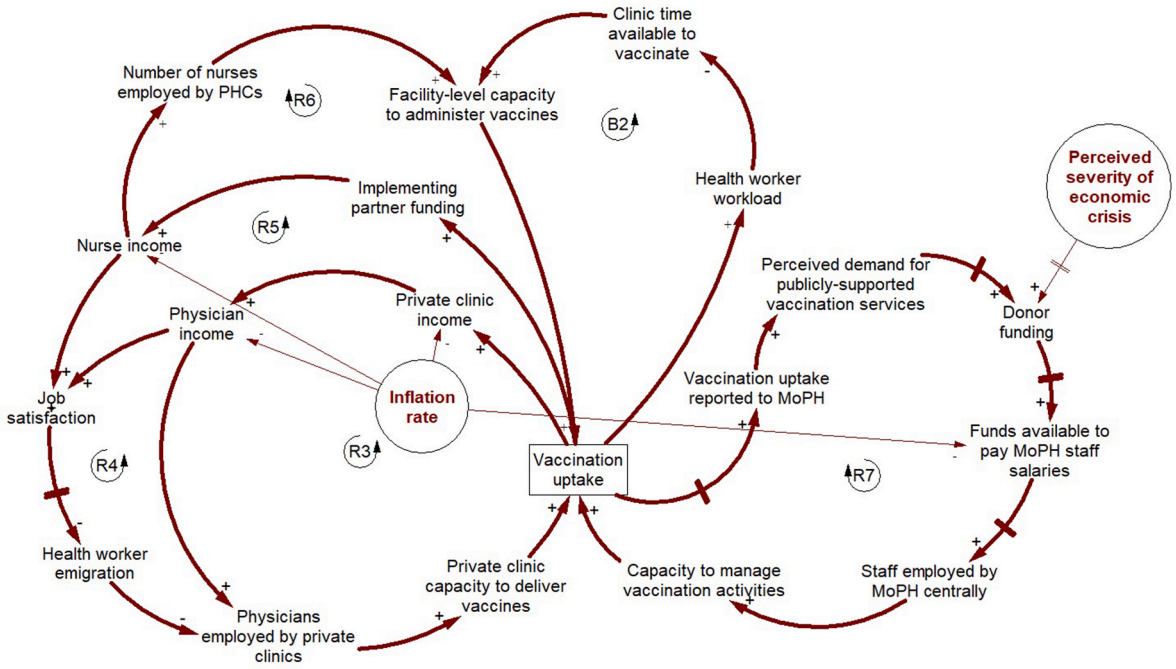

Fig. 6. The role of currency inflation and donor perceptions of the severity of the economic crisis in influencing system vulnerabilities relevant to vaccination uptake in Lebanon from late 2019 onwards. The inflation rate and perceived severity of the crisis are modelled as exogenous factors influencing system structures. Pre-existing structures acted on by these exogenous factors are show using bold, brown lines. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

funds available to pay salaries and the value of those salaries. At facility level, interviewees highlighted the difficulty of trying to recruit and train replacement staff under current conditions:

> *"Every day we are losing some staff and vaccinators … because they are not satisfied any more with their salaries. They used to be paid for example US$600 now they are paid US$50, so some of them are leaving to work abroad and we are losing a lot of them that PHCs and dispensaries … we are trying to train again and again new staff and this staff needs also experience and not only experience in how to provide the vaccine but also in communication and how to know their community and how to deal with people" [LFS11, government official]*

Those that could – predominantly medical doctors – looked for opportunities to emigrate. This had implications particularly for private clinic capacity to vaccinate because they relied mainly on physician-led administration of vaccines (Fig. 6, loops R3 and R4). The declining value of nurse salaries also contributed to workforce attrition (Fig. 6, loop R6), and although this was reported by interviewees to be less significant in numerical terms than among doctors, it contributed to a worsening problem of unsustainable workloads for clinic staff in the PHC network (Fig. 6, loop B2).

From a service demand perspective, rising inflation (and resultant declines in household income) had two main effects. Firstly, it reduced host community willingness to pay for vaccination through private clinics because of the cost to households. This reinforced the problem of physician retention because vaccine administration had previously been a lucrative business for many paediatricians working in private clinics (Fig. 6, loop R3). Secondly, it increased the relative cost of transport to health facilities. The former spurred a surge in vaccination uptake by host communities through PHCs where costs of vaccination and other essential health services were much lower. The latter to some extent counteracted this effect by increasing barriers to accessing fixed sites, especially when combined with the effects of pandemic movement restrictions.

3.4. The Beirut explosion

The Beirut explosion was the fourth and final system shock considered in this study – occurring in August 2020. Interviewees highlighted the destruction of the national storage facility for vaccine doses in the port area, and damage to some PHCs in Beirut as immediate consequences of the blast. However, rapid transfer of intact vaccine doses to the largest public hospital in the country in Beirut, within 24 h, helped to temper effects arising from the loss of the central storage facility. Facility-level effects were predominantly felt in greater Beirut.

3.5. Compounding effects arising from multiple shocks

Although refugee arrivals were separated to some extent in space and time from the COVID-19 pandemic and the economic crisis, interactions did occur in some key sectors of the CLD. These reflected effects on common points of vulnerability in the system. This section focuses on two example CLD sectors that were affected by at least two of the shocks.

3.5.1. Interactions amplifying vulnerability within a loop: PHC crowding and vaccination uptake

Fig. 6 shows a central loop from the CLD on which two of the shocks acted together to reduce vaccination uptake. As outlined above, refugee arrivals from Syria gradually drove an increase in demand for vaccination, but this took time to emerge. As it did so, rising PHC attendances contributed to facility-level crowding, and in some cases clinic closures, as demand outstripped the capacity health workers perceived they had to administer vaccines (Fig. 7, loop B1). This reduced uptake especially among host communities. The pandemic produced a similar dampening effect although the mechanism was different. Here, crowding increased service-user and health worker fears of contracting infection in facilities, which reduced supply as clinics were closed (Fig. 7, loop B1 adj.) and reduced demand as service-users opted not to attend (Fig. 7, loop B5). In the context of the pandemic, the effect was also universal across host communities and refugee populations.

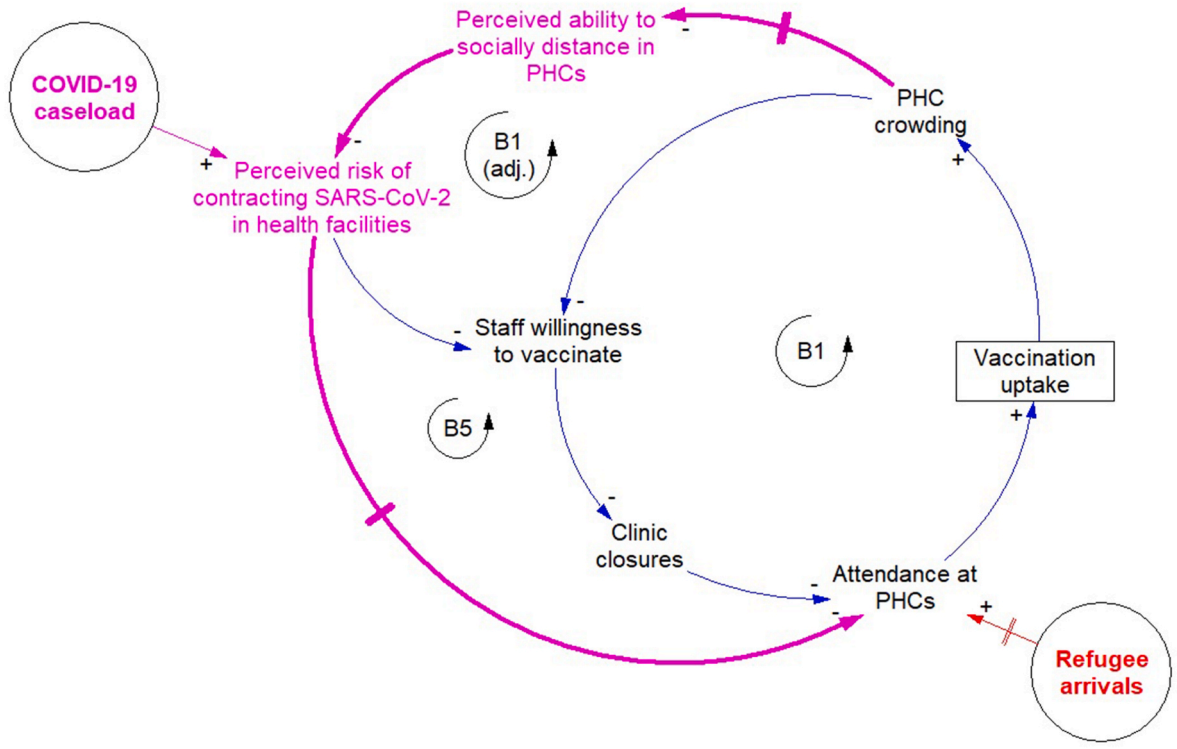

Fig. 7. Points of interaction influencing demand for vaccination.
Key points of interaction with each of the relevant shocks (refugee arrivals and the COVID-19 pandemic) are given in red and pink text and lines respectively. Delays – in this case affecting the relay of information between different parts of the system – are indicated by hashed lines. A basic feedback loop shown in B1 underwent subtle change in the context of the pandemic (B1 adj.) so that staff willingness to vaccinate was influenced not just by PHC crowding per se, but also by a secondary causal chain linking crowding to the perceived risk of contracting the infection in facilities. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

3.5.2. Interactions producing a change in vaccination demand behaviour

One illustrative series of loops helps to understand the balance between vaccination uptake through PHCs and private clinics, principally by host communities. Here, sequential shocks acted on existing vulnerabilities to produce a shift in population behaviour (Fig. 8). Interviewees consistently noted a basic preference among host communities for vaccination in private clinics despite higher cost, founded on an assumed virtuous link between cost and quality of care in these settings (Fig. 7, Panel A – loop R1). Following the major cross-border movements from Syria, however, attendance at PHCs by Syrian refugees gradually increased, contributing in time to facility crowding. Perceived quality of care in private clinics relative to PHCs among host communities rose further because of this (Fig. 7. Panel A – loop B4). The effect was to reinforce the core, positive feedback loop in R1 (Fig. 7, Panel A). The effect of rising COVID-19 caseloads appears to have further intensified this dynamic. Concerns over PHC crowding and perceived risk of contracting infection in these facilities imposed further restraints on PHC attendance for vaccination via a new structure (Fig. 7, Panel A – loop B1 adj.).

However, interviewees indicated that the economic crisis reversed the basic pattern of host community behaviour described in loop R1. Collapsing household incomes reduced willingness to pay for vaccination so that a reinforcing loop favouring PHC attendance for vaccination (Fig. 7, Panel B – loop R5) now dominated over what had been the core loop.

4. Discussion

4.1. Summary of main findings

In this study, we used CLDs to describe effects linked to a series of shocks on the Lebanese routine vaccination delivery system. A companion study considers system responses, and sources of resilience, to these shocks (Ismail et al., 2023). While near-term effects of each of the shocks were exogenous to the vaccination delivery system, each interacted with existing system structures in multiple ways and at multiple levels, amplifying pre-existing sources of vulnerability.

Refugee arrivals from Syria contributed mainly to changes in patterns of demand for routine immunisation. However, these took time to feed through because of a combination of [i] lack of obvious access points for Syrian refugees at the beginning of the crisis, [ii] initially limited awareness among new arrivals of how to navigate the (complicated) network of providers in Lebanon, and [iii] the initially low priority accorded to preventive health services by refugees. The COVID-19 pandemic and the economic crisis influenced supply and demand dynamics in important ways, but the economic crisis had by far the most wide-reaching effects of all of the three shocks in terms of the scale and scope of its impact on vaccination delivery. The economic crisis affected everything from retention of staff at central level (and in turn capacity to manage the national vaccination program) through to staff numbers and cold chain integrity at facility level. It also influenced demand dynamics especially for host communities in Lebanon. By contrast, the Beirut blast of August 2020 did not feature prominently in interviewees' accounts. Effects on vaccination delivery from this event appeared to have been largely limited to Beirut, and contingencies were rapidly put in place to offset some of the greatest risks arising from it.

We identified a series of pathways or points in the system that proved to be sources of vulnerability for some or all of the shocks in Lebanon. These operated predominantly at facility level. A series of feedback loops linked facility-level crowding to reduced vaccination uptake via either demand problems (concerning service-user perceived risk of contracting SARS-CoV-2 in PHCs), or supply issues (concerning staff

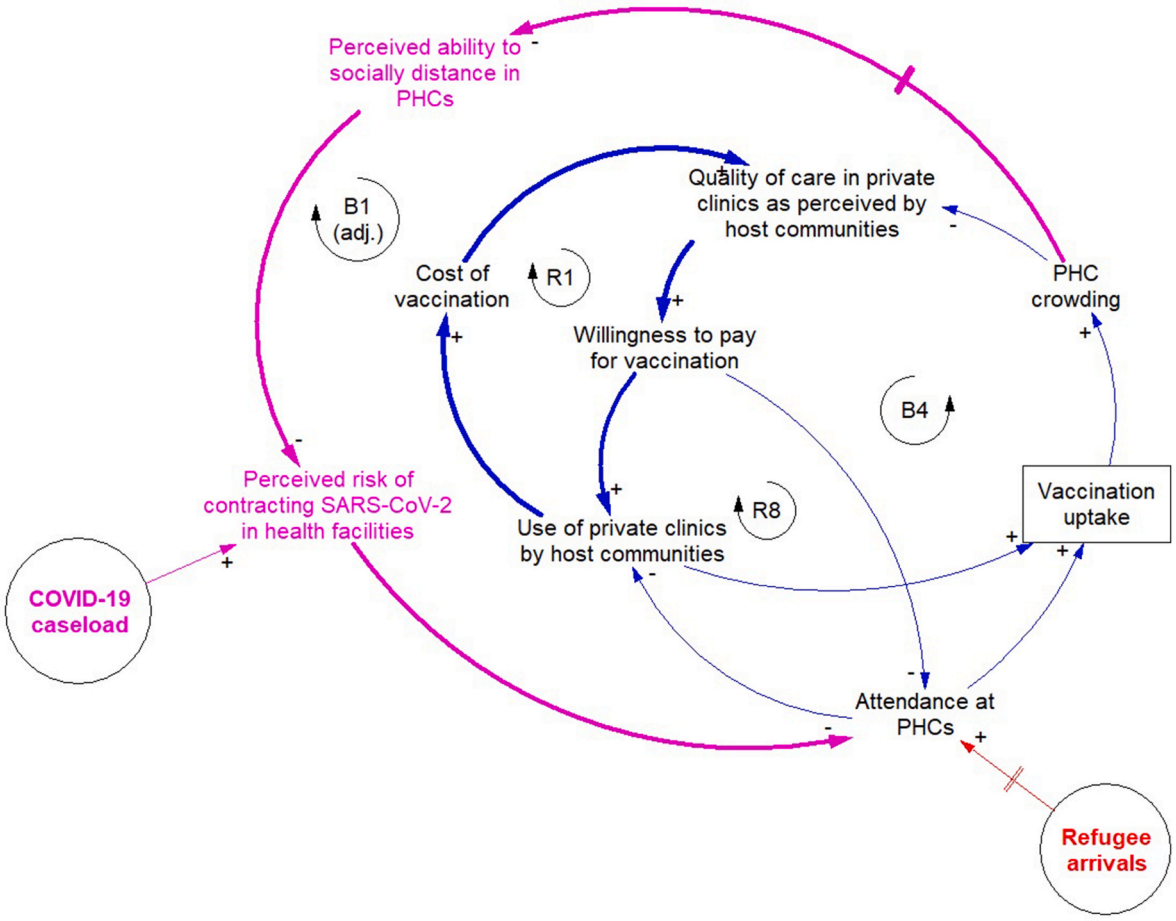

Fig. 8. Interacting loops describing household-level behaviour influencing demand for vaccination through PHCs and private clinics.
Panel A highlights the dominant loop (loop R1) influencing host community service access behaviour following the refugee arrivals and in the context of the COVID-19 pandemic. Panel B shows how the shape of the dominant loop shifted as declining household income altered clinic attendance behaviour, with loop R5 now dominant.

willingness to vaccinate patients, or staff-perceived risk of contracting SARS-CoV-2). Analysis of a second set of connected feedback loops relating uptake through private clinics and PHCs demonstrated how dominant behaviours in part of the delivery system can shift in response to different shocks. Here, a historical host community preference for vaccination through private clinics was amplified by refugee arrivals and the pandemic but then reversed by the economic crisis because people could no longer afford to pay for vaccination. From a demand perspective, willingness to pay for vaccination was a key determinant of service user behaviour for host communities. Interviewees contrasted this with expectations among Syrian refugees, who arrived from a country with a long-standing history of providing childhood immunisations through public providers, pre-conflict. Facility-level crowding also proved a key driver of both demand- and supply-side behaviour by influencing both perceived risks (e.g., contracting SARS-CoV-2 infection) and perceived service quality. From a supply perspective, the key vulnerability pathways influencing facility-level capacity to administer vaccines concerned health worker workload, and the availability of viable vaccine stock locally.

Findings also point to detrimental effects arising from an accumulation of risk over time owing to sequential shocks. While aggregate assessments of vulnerability or resilience should be handled cautiously, there were growing indications from interviews towards the end of the second wave that the intensification of risks especially under the pressures of the economic crisis was pushing the vaccination delivery system towards a tipping point beyond which vaccination delivery might no longer be sustainable. Evidence for this included the combination of effects on both supply- and demand-side dynamics, at multiple system levels, and over and above those already exposed by refugee arrivals and by the pandemic, and in trend data on population vaccination coverage from Lebanon. Clearer – potentially quantitative – determination of points at which cumulative risk pushes systems towards tipping points is an important area for further development. Analysis of the impact of sequential shocks and their implications for resilience has been scant in the health systems literature, and while their importance is increasingly recognised in other fields there is broad acknowledgement that currently available analytical tools are not well attuned to capturing accumulating risks of this kind (de Ruiter et al., 2020).

To the best of our knowledge, this is the first study to consider vaccination delivery system responses to shocks using a dynamic approach grounded in systems thinking. While a handful of prior studies have mapped out system effects linked to single shocks – including in response to the Syria crisis (Ager et al., 2015; Jamal et al., 2020) – this is also the first health systems study to consider how effects from multiple, overlapping shocks can exacerbate vulnerabilities. It is also, to our knowledge, the first study to consider health system effects arising from the economic crisis in Lebanon. Our findings suggest a series of pathways by which risks arising from each of the shocks were propagated from national through to local levels, in line with Pescaroli and Alexander's description of cascading disasters (Pescaroli and Alexander, 2018). An important methodological strength of this analysis was the application of system dynamics, enabling the identification of causal

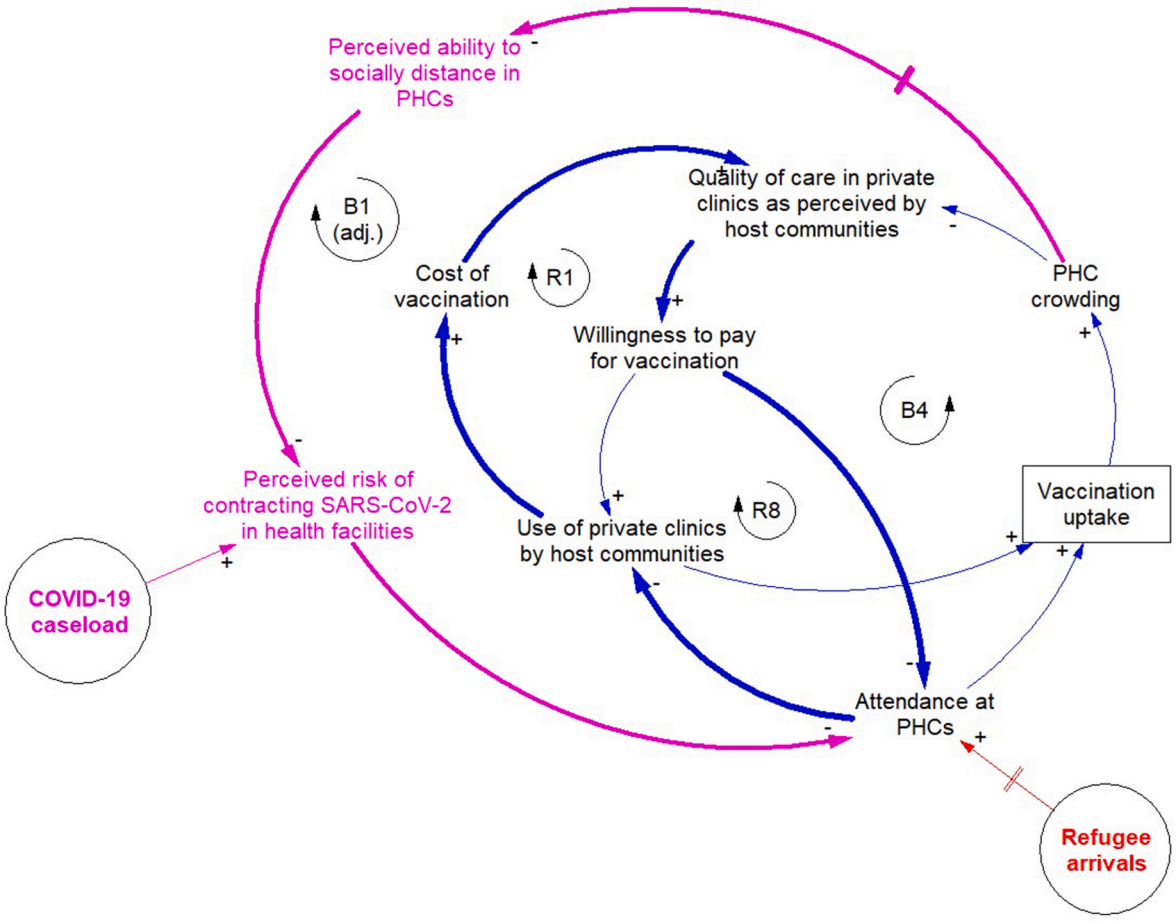

Fig. 8. (*continued*).

pathways linking exogenous shocks to feedback loops integral to the system structure, and enabling a qualitative assessment of how these were differentially affected by each shock (Meadows, 2008).

Key findings also support those found in the relatively small number of empirical studies of resilience published elsewhere but add important new insights. Previous analyses considering system resilience in humanitarian settings have predominantly focused on service delivery in the round (Ager et al., 2015; Jamal et al., 2020), or on domains such as mental health (Noubani et al., 2020). The second of these studies identified human resource attrition and declining motivation as major threats to long-term system resilience in a conflict-affected setting, as well as threats to service uptake because of fear in a context of insecurity (Ager et al., 2015). Our findings – from a humanitarian setting but one in which insecurity was much less of a feature – reinforce the importance of health workforce retention and the role of fear (e.g., of COVID-19) in driving service demand, but also point to wider factors including availability of key commodities (in this case, vaccine doses).

4.2. Limitations

Limitations of this analysis include that a full exploration of demand-side dynamics affecting system behaviour over time was not possible because data collection focused on policymakers and service providers only and did not extend to service users. This decision was made pragmatically given the challenge of adequate sampling for interviews across service user groups in Lebanon, and the enormous difficulties of on-the-ground data collection at the time of the study in light of pandemic-related restrictions and growing domestic political and economic instability.

Secondly, given that data collection commenced in early 2020, and most Syrian refugee movement into Lebanon occurred in the period 2014-15, there is a risk of recall bias in the findings reported here. A number of steps were taken to address this risk, including [i] explicitly asking interviewees to highlight areas in which they were not confident their recollection was correct, or during which they had been working in other roles not directly relevant to vaccination delivery; [ii] recruiting participants with varying degrees of experience in the system, ranging from a few years to in excess of 20 years in several cases; and finally [iii] recruiting participants working at various system levels.

Thirdly, data analysis was performed largely by the lead author, potentially introducing bias into CLD development. However, various safeguards were built into the study design to address this, including [i] the application of purposive text analysis as a structured approach to analysis of interview transcripts; [ii] the use of a standardised RIQ template for quote interpretation; [iii] CLD combination using a clearly documented process in which the order of combination was determined based on a quantitative appraisal of diagram complexity; and most importantly [iv] validation of a draft, aggregated CLD using both a dedicated set of interview transcripts.

Finally, there are limitations as to what we may infer from findings presented here. Firstly, CLDs allow us to infer important system behaviours, they cannot deduce them (Lane, 2000). For this, formal simulation modelling is required. A quantitative system dynamics model from this study is currently under development. Secondly, while we may draw some insights regarding shock response from focused case studies of the kind presented here, further work is needed to understand the generalisability of those findings both to other settings, and to other health service domains (beyond vaccination).

4.3. Policy implications

Findings from this study underscore the central importance of sufficient human resourcing at multiple system levels to sustain vaccination delivery irrespective of the shock. The ability to retain staff in the face of worsening economic conditions had major implications for service delivery as the economic crisis intensified, but workforce retention problems at central level predated this and were linked to a central government hiring freeze. Findings also emphasise the importance of measures to promote financial protection across populations. The PHC network provided an important avenue for care access for displaced Syrians following refugee arrivals and then increasingly for host communities because of the availability of vaccination at nominal cost as living conditions became more challenging. Finally, findings demonstrate how demand-side dynamics influence system resilience, but also the extent to which effects differ according to the nature and intensity of the shock. Effects were most pronounced during COVID-19 (where risk-perception conditioned vaccine uptake behaviour) and especially during the economic crisis as worsening conditions appeared to downgrade the perceived importance of vaccination relative to other immediate priorities for many households.

These and other findings also point to areas potentially amenable to measurement in identifying accumulating risks across the vaccination delivery system. Stability in human resourcing (from facility through to national level), volume of financial inputs at different system levels, and measures of time to mobilisation of response funding, disbursement of financial resources to facility level, or mobilisation of viable vaccine doses to facility level may all prove useful indicators of system capacity to respond to shocks of differing types and magnitudes.

5. Conclusion

This study has shown how a series of shocks in Lebanon, overlapping to varying degrees in space and time, interacted with existing system structures to reinforce existing, and create new, risks for vaccination delivery. In particular, it has shown how the compound nature of recent shocks significantly amplified risks in specific parts of the vaccination delivery system, pointing to potential leverage points for action. Future research should consider both the generalisability of these to other service areas and contexts, and consider intervention approaches that might meaningfully address vulnerabilities in the interests of long-term system resilience.

Data statement

Due to the sensitive nature of the questions asked in this study and risk of identification, participants were assured raw data would remain confidential and would not be shared.

Ethical statement

Ethical approval for the research project of which this study forms part was secured in the UK from the London School of Hygiene and Tropical Medicine (ref no 17461), and in Lebanon from the American University of Beirut (ref no SBS-2019-0376).

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CRediT authorship contribution statement

Sharif A. Ismail: Writing – review & editing, Writing – original draft, Visualization, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Andrada Tomoaia-Cotisel:** Writing – review & editing, Supervision, Methodology, Formal analysis, Conceptualization. **Aya Noubani:** Writing – review & editing, Project administration, Investigation, Data curation. **Fouad M. Fouad:** Writing – review & editing, Supervision, Methodology, Conceptualization. **Robert Šakić Trogrlić:** Writing – review & editing, Validation, Conceptualization. **Sadie Bell:** Writing – review & editing, Supervision, Methodology, Conceptualization. **Karl Blanchet:** Writing – review & editing, Supervision, Methodology, Conceptualization. **Josephine Borghi:** Writing – review & editing, Supervision, Methodology, Conceptualization.

Declaration of competing interest

None reported.

Data availability

The data that has been used is confidential.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.socscimed.2024.117260.

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