Systems Approaches to Public Service Delivery: Lessons from Health, Education, and Infrastructure

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Abstract

Public services are delivered through complex bureaucratic systems. Recent research in economics and political science on bureaucratic performance and public service delivery typically seeks to abstract from these complexities to identify specific causal relationships, but this narrow focus risks ignoring the complementarities and contingencies that mediate these relationships in practice. How can research on government bureaucracies take account of their systematic characteristics while preserving methodological rigor and theoretical precision? This background paper reviews the development of systems approaches in the health, education, and infrastructure sectors. We survey: the definition and scope of systems approaches; theoretical frameworks; empirical methods and applications; and linkages to policy. While the scope of systems approaches is common across sectors, as is the close linkage to policy, there are notable differences in the direction and extent of theoretical development and empirical application. These differences suggest opportunities for cross-sectoral and cross-disciplinary learning. We conclude by discussing the potential for a systems approach to research in public management and public finance.

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1. Introduction

In recent years, the idea of taking a *systems approach* to understanding public service delivery has gained currency with academics and policymakers alike. One motivation for this has been the increasing awareness not only of the importance of policy implementation and bureaucratic performance, but also their complexity and unpredictability (Pritchett 2015, Hawe 2015). Similarly, as rigorous impact evaluations of public policies and service delivery have proliferated in recent years, so too have questions about whether policies that have been successful in one context or at small scale can be successfully transported to other contexts or scaled up (Pritchett and Sandefur 2015, Bold *et al* 2016, Bates and Glennerster 2017). This has been matched by a programmatic concern about the limited effectiveness of standard programmatic strategies like providing additional inputs or narrow interventions aimed (for example) at particular diseases or pedagogical tools, and by an increasing appreciation of connections and interdependencies among the social, economic, political, environmental, and bureaucratic determinants of public service outcomes (Travis *et al* 2004, De Savingy and Adam 2009).

This paper reviews the development and current state of systems approaches to public service delivery, which have been shaped by these questions and concerns. Our survey encompasses the three sectors in which systems approaches have become most prevalent: health, education, and infrastructure. To date, the development of systems approaches has taken place within these separate sectors mainly in isolation, with education and health as a partial exception (Hanson 2015). While there have been numerous sector-level survey papers on systems approaches[1], our contribution is to compare and contrast the development and state of systems approaches across these three sectors. In addition to identifying opportunities for cross-sectoral 'arbitrage' and learning, these insights present useful lessons for the development of systems approaches in sub-fields such as public management and public finance where such approaches are not yet common but may be especially useful.

Among studies that self-identify as focusing on systems, an important distinction is between studies that are system-focused *in substance* (due to their scale or topic) and those that are system-focused *in approach* (due to their emphasis on issues of context, complementarity, and contingency as determinants of actions and outcomes). This review focuses on the latter category. While this category is itself exceptionally diverse in theory and method, studies in it have in common a skepticism about the epistemological or practical usefulness of trying to 'hold all else constant' and treating units of analysis as independent and acontextual in order to understand the effectiveness of particular government policies or processes. 'Taking a systems approach' is thus more akin to a frame of mind that weights the importance of understanding interdependence and contingency relatively more heavily than obtaining narrowly identified causal estimates, compared to prevailing approaches to evidence-informed policymaking. It is an approach which employs a set of analytical tools with the aim to

[1] See for example Gilson (2012) and Carey *et al* (2015) for health, Pritchett (2015) for education, and Saidi *et al* (2018) for infrastructure.

understand how complex systems function, with a focus on understanding the dynamic relationships between system components, and an emphasis on studying the system as a 'whole' instead of individual components (De Savingy and Adam 2009, Hawe et al 2004). The goal of system approaches, therefore, is to encourage a more holistic approach to programme design which takes account of various interdependencies and contingencies, a careful evaluation of policies which aim to understand what works, for whom, and why, and a broader scope for forming research hypotheses.

There are a number of commonalities in how systems approaches are operationalized across the three sectors reviewed. Systems research tends to be much more question- or problem-driven than other research within the same sectors, and is frequently closely linked to government in its conception and execution. All three sectors have been self-conscious in attempting to create overarching conceptual frameworks to understand the systemic nature of the sector, and in each sector this has been accompanied to an extent by confusion about whether such frameworks should be descriptive (focused on categorizing or organizing research questions) or analytical (focused on specifying mechanisms and particular relationships). All three sectors draw on complexity theory and systems thinking to inform the scope of research, to varying extents. While work in each sector has made some progress on the issues that motivated taking a systems approach (probably more so in infrastructure), there is nevertheless the sense that conceptual and practical challenges have meant that this progress has fallen well short of stated goals (Carey *et al* 2015). However, each sector has evolved unique and promising research approaches building on longer-term collaborations with governments to create and synthesize outputs beyond the time horizon or scope of individual research outputs.

There are also a number of differences across sectors. Systems approaches are significantly more developed and widespread in health and infrastructure than in education, with dedicated journals and sub-fields. Whereas health systems has developed as a highly interdisciplinary field, education systems has in practice been more grounded in economics, and infrastructure more in geography and engineering. Relatedly, health systems is methodologically very diverse and has made more progress towards integrating quantitative and qualitative methods, whereas education and infrastructure have so far been dominated by quantitative studies. The theoretical and methodological responses to the challenges of interdependence and contingency have also varied accordingly, although in this respect there is as much diversity within sectors as across them. Each sector has addressed different types of policy questions. While health has focused largely on impacts of decentralization and health financing, infrastructure has focused more on questions such as how to prioritize infrastructure investments, capacity considerations or environmental concerns, and education has focused on conducting system-wide diagnostics to set the foundation of meaningful systems work. In general, given the nature of the research is policy-focused, the direction of research is often determined by national priorities, multi-lateral organizations or availability of data.

The remainder of this review proceeds as follows. Section 2 surveys the motivation, definition, and scope of systems approaches, Section 3 discusses theoretical frameworks, and Section 4 reviews empirical methodologies and applications. Each section is sub-divided into health, education, and infrastructure. Section 5 then discusses linkages to policy and research funding models, and Section 6 concludes with a brief discussion of this review's implications for the potential for systems approaches in the field of public management and public finance.

2. Motivation, definition, and scope of systems approaches

Health, education and infrastructure are three very distinct sectors but the motivation, definition, and scope of systems research in these sectors highlights several important commonalities which lend clarity to the understanding of systems research and how it is operationalized across different sectors.

The detailed review of each sector in the sub-sections below highlights that across all sectors, several common factors determine the scope and definition of systems research. First, the focus on interdependencies within the system and the overall problem-driven and policy-focused nature of the field. Second, borrowing certain ideas from complexity theory and systems thinking such as how systems include agents that are indirectly related to each other and generate non-linear feedback loops, create emergent properties that would not have existed if the agents had not interacted, and demonstrate path dependence such that decisions in the present are also a function of decisions taken in the past (McDaniel et al 2009, De Savingy and Adam 2009).The sub-sections below illustrate these common themes.

2.1 Health: motivation, definition and scope

Health systems research developed as a field for over more than decade ago as a way to understand complexities, interrelationships, and structural constraints within a health system. The importance of health systems and the need to understand the system as a whole in a more nuanced way was established through the following. Firstly, major health epidemics and the growing threat of other microbial diseases underscored the need for coordinated action across individual health system components such as policy-actors, health service providers/recipients, and various social, cultural, economic and political realities for a truly meaningful and effective response. In addition, the sluggish progress of key health indicators around the world brought the effectiveness of narrowly designed interventions into question and a simultaneous focus on structural weaknesses within health systems (WHO Framework for Action 2007). Such insights highlighted that addressing key gaps in health systems was necessary to achieve the health MDGs in low and middle income countries (Travis et al 2004, WHO framework for Action 2007). This created a push towards systems approaches in health to understand health systems better.

The Alliance for Health Policy and System Research (AHPSR), a health systems research forum initiated by the World Health Organization (WHO) in collaboration with the Global Forum for Health, defines health systems research (HSR) as the "production of knowledge and applications to improve how societies organize themselves to achieve health goals".[2] This definition implies a focus on how the 'whole' system functions instead of a narrow focus on any single aspect of its individual components (Hanson 2015).[3]

Three key features summarize the scope of research in this field. First, health systems research has a specific focus on real world issues. It aims to address questions which are practically faced by countries within the health sector. Second, it is multidisciplinary. This is closely linked to the first point. Real world issues about health systems could be of the 'why', 'what' and/or 'how' nature. Hence the disciplinary or methodological grounding of research is determined by the question of interest. Third, the research is applied with a unique focus on policy with the goal to influence policy. This implies that research with respect to how policy is made and implemented is a key area of research for the field (Mills 2012, Gilson 2012).

The type of research questions which the field addresses follows naturally from the scope of research. The example of research on decentralization illustrates this clearly. The field has explored several questions on this real-world topic through multiple angles and disciplinary frameworks. This includes questions such as how the intervention functions through drawing on economic theoretical frameworks such as the principle-agent model, what the impact of the intervention is through analyzing quantitative data on expenditure and utilization rates, and qualitative case-study approaches to acquire deeper insights into the process of its implementation (see for example, Bossert 1998, Bossert *et al* 2003, Tsofa *et al* 2017). In general, relevant research in the field looks at system-level interventions which focus on a specific sub-system (such as health workers) but have system-wide effects, types of interventions which aim to create a change across all system components such as new accountability mechanisms, questions which explore interdependencies in system components to understand how to implement reforms better, and questions which explore how the entire system or a sub-system is organized. We discuss such applications in more detail in Sections 3 and 4.

In contrast to existing research approaches in the health sector, a key point of departure is the reliance on complexity theory and systems thinking and conceptualizing health systems as 'complex adaptive systems' which demonstrate system/complex properties. This interest in complexity theory and systems science has generated research where entire systems or sub-systems of health are modeled through quantitative methods to identify entry points for change or to improve decision-making by identifying unexpected effects and feedback loops (Carey *et*

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[2] AHPSR comprises of health practitioners and academics from around the world, has taken instrumental steps in defining the scope, boundaries and agenda of the field through several publications.

[3] The Alliance included the word 'policy' in what is commonly known as health systems research and renamed it to 'Health Policy and Systems Research (HPSR)' to capture two key facets of the field which do not clearly come through in the definition – first to highlight the importance of social and political realities within a health system and second, to recognize the applied, policy, and question-driven nature of the field.

al 2015, Maglio *et al* 2011). It has also produced a series of review papers which discuss how to tackle theory and causality of interventions in complex systems (Hawe 2015, Hawe 2004, Pawson and Tilley 2007). We revisit such applications of complexity theory and systems science in more detail in Sections 3 and 4.

2.2 Education: motivation, definition, and scope

Education systems research has recently emerged as a field from the growing recognition that massive investments in various inputs such as textbooks, hiring of new teachers, and increased salaries have not had the effects that governments and researchers hoped for (Glewwe and Muralidharan 2015, WDR 2017). For example, Indonesia doubled teacher wages incurring an expenditure of nearly 4.5 billion USD which produced near-zero impact (De Ree et al 2015). Similarly research from India and Africa shows that reduction in class-sizes does not always produce the desired impact if other systemic features such as teachers, incentive structures, and curriculum do not change (Pritchett 2015). Learning remains starkly low - according to the 2014 UNESCO Global Monitoring Report, 250 million children are unable to read, write, or do basic mathematics, and 130 million of those children are in school. This has led researchers and practitioners to argue that the global 'learning crisis' requires addressing system weaknesses and making the whole education system within a country coherent with learning (Pritchett 2015, WDR 2018). This puts a greater weight on understanding the interdependencies between various components such as education system's policies and institutions for governance, accountability, information, financing rules, and school management (World Bank 2014, WDR 2018).

Since education systems research is still in its infancy, clear definitions and boundaries of the field are yet to be determined. A few global institutions are making strides towards understanding education systems better and defining critical research gaps and opportunities, which may clarify definitions. For example, Research on Improving Systems of Education (RISE), initiated in 2015, aims to conduct empirically and theoretically well founded research to develop analytical frameworks for understanding education systems and identifying underlying features which can lead to system reform and/or failure. Systems Approach for Better Education Results (SABER) is a World Bank initiative which was launched in 2011 and collects data on system capacities and gaps through a range of survey tools designed for each education sub-system. Another example is the General Education Quality Analysis/Diagnosis Framework (GEQAF) - a UNESCO led effort which aims to improve systemic constraints to achieving educational gains. Through a comprehensive tool kit of 15 different survey tools, it collects diagnostic data on how different components of the education system function.

The scope of research in education has close parallels with health and is defined by the following key features. First, it aims to be 'question-driven' which employs various disciplines as per the need of the question. For example, systems research in education could explore questions ranging from the impact of a national teacher training intervention through economic quantitative techniques to questions about how power and accountability structures are formed between school heads and the community through ethnographic accounts. Second, the questions focus on real-world issues which either pertain to the system as a whole or a specific sub-component. For example, while questions about teacher recruitment or training policy would be relevant for the teaching system sub-component, questions about a specific teacher training programme in 10 selected villages by a specific NGO would not be relevant as they would not have any implications for the teaching system or the education system as a whole. Third, systems research in education aim to explore questions which relate to learning gains. Fourth, it studies reforms which have the potential for scale and fit the context of the specific region (Pritchett 2015b, Hanson 2015).

2.3 Infrastructure: motivation, definition, and scope

Systems research in infrastructure is conducted with the primary aim to understand and manage complex interactions within and between various infrastructure sectors. Such research in infrastructure can be clearly demarcated into two categories where each has its own motivation and objective: 1) sector-specific system analyses which allows thinking systemically within sectors, and 2) systems-of-systems analyses where research is conducted across various infrastructure sectors to explore infrastructure risk, and conduct resilience and long-term systems-of-systems analyses. While the former is relatively well-established, the field of system-of-systems analyses is still relatively immature (Hall *et al* 2016).

Sector-specific system analyses are motivated by the idea that efficiencies and synergies can be accrued over the life-cycle of individual infrastructure components by understanding feedbacks and managing their demand. More broadly, these benefits are achieved through enabling policy decision-makers in assessing system-wide efficiencies of capital investments, operational budget allocations, and through meeting sustainability goals (Saidi *et al* 2018). A systems-of-systems approach (i.e an integrated systems approach across infrastructure sectors) takes account of the cross-sectorial interdependencies between infrastructure sectors and is motivated by two key challenges that infrastructure systems face. First, the need for adequate planning for future operation, capacity and environmental performance of infrastructure systems in light of future socio-economic changes such as through population changes, per-capita infrastructure demands and economic growth. Second, being able to ensure resilient operation of infrastructure services in the face of increasing climate and socio-economic risks. These challenges are exacerbated by the fact that infrastructure networks have become increasingly interdependent, providing potentials for knock-on effects causing major economic and societal disruptions. For example, a power failure in a major electricity exchange can result in the temporary loss of broadband service for hundred thousand of households and businesses (BBC 2011). Hence, systems-of-systems approaches for short-term risk analysis aim to reduce the risk of cascading infrastructure failures, allow for more effective responses, and improved coordination (Dudenhoeffer *et al* 2006 in Saidi *et al* 2018). For long-term planning, systems-of-systems approaches help national decision-makers take a holistic view and explore strategic infrastructure investments across sectors for effective functioning of the entire infrastructure system.

An infrastructure system can be defined in several ways depending on the type of infrastructure or the scope of research analysis. This has a direct bearing on how infrastructure systems research is defined and understood. While generally infrastructure systems are defined as 'interdependent physical and socio-economic systems that facilitate the distribution of essential services and build the foundation of economic prosperity and human well-being' (Bissell, 2010), another approach to define infrastructure systems is through the types of assets within the system which can include energy, transport, water, waste, information and communications technology (ICT), and social infrastructures (hospitals, schools, etc.), financial services and the built environment (Cabinet Office, 2010). Analysis of infrastructure at a system level requires integration of various components – such as across different scales (e.g. urban, rural, or regional), across eco-systems (e.g. social, urban, land, water and climate), and between different structures or sectors (e.g. social, physical, health, economic and political). In view of this, systems-of-systems infrastructure analyses typically define infrastructure not as physical assets, but as the services they are intended to provide. For example, heating services may be provided by the heat network, gas or electricity (Saidi *et al* 2018, Hall *et al* 2016). Following this, Hall *et al* (2016) develop a definition of infrastructure systems as 'the collection and interconnection of all physical facilities and human systems that are operated in a coordinated way to provide a particular infrastructure service."

Similar to the health sector, the scope of systems research is characterised by the following. First, a real-world focus, where approaches and methodologies for systems assessments of infrastructure are direct real-world problems of planning, designing, and operating infrastructure. Second, it tends to be multi-disciplinary. While the bulk of analysis in the field includes quantitative modelling, it often combines qualitative approaches such as simulation modelling with decision science, policy and governance research, and adaptive pathways. Third, it focuses on directly impacting policy. For example, a number of infrastructure assessment methodologies inherently include adaptive pathways and policy recommendations. In terms of the areas of focus for research, infrastructure systems approaches are used to understand current infrastructure performance (for example, whether different infrastructure sectors currently meet demand, environmental standards, resilience criteria), predict future infrastructure needs, and to understand the impact of a newly built infrastructure asset on the entire system.

3. Theoretical frameworks

How should one conceptualize a system of public service delivery? The literature has produced a multiplicity of theoretical frameworks across sectors. This includes frameworks which model a system in terms of a) the functions it performs; b) its main stakeholders; c) interrelationships or flows of information, accountability, or resources among sub-systems; or d) the levels at which various stakeholders operate.[4] Such frameworks have offered much needed theory,

[4] In addition to purpose-built theoretical frameworks, theory in systems research can often include existing theories from economics, decision science, or sociology (to name a few) to explore a specific system-level hypothesis regarding a component within the larger system. This review focuses primarily on theoretical frameworks designed specifically for systems applications and does not review the use of theoretical tools 'borrowed' from other disciplines.

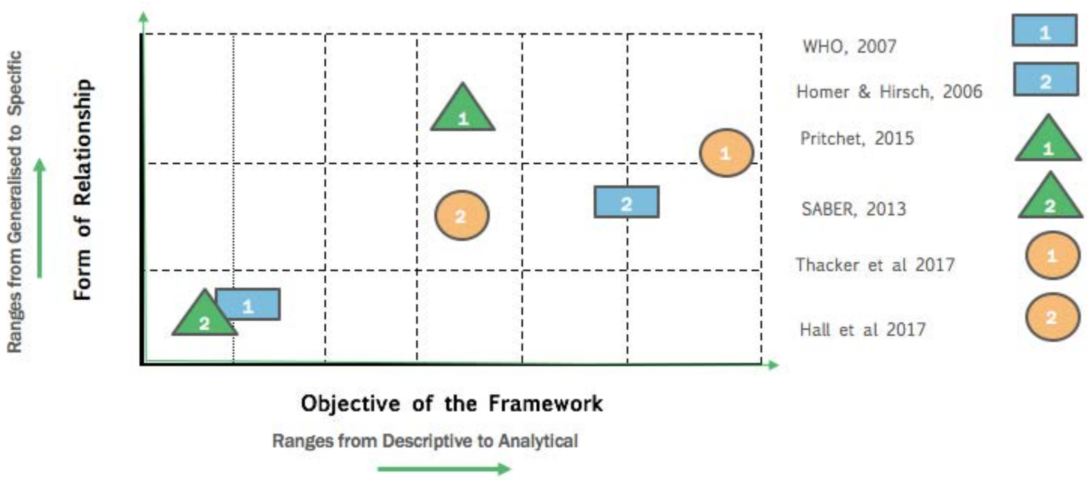
clarity, and structure to understand how systems are organized and their various components interact and a foundation for developing hypotheses.

Across sectors, an overarching distinction between different types of theoretical frameworks is whether they pertain to a whole system or to a specific sub-system within the larger system. The infrastructure systems literature clearly identifies this distinction referring to a framework as either a 'sub-system' or a 'systems-of-systems' framework and this distinction also exists in the health systems literature, but is less evident in education.

In addition to this distinction, the wide range of theoretical frameworks across health, education and infrastructure can be categorized according to two key defining features. First, whether the objective of the framework is descriptive or analytical. Purely descriptive frameworks which simply outline various system components are often policy documents which aim to categorize or define actors, but not specify particular mechanisms and relationships. On the other hand, analytical frameworks that specify system components along with their relationships and mechanisms more precisely, such as Thacker *et al* (2017), are developed to make clear predictions about system performance. The latter are more akin to the use of models in academic literature. Second, frameworks differ in the extent to which they specify the form or type of relationships within a system. For example, Pritchett (2015) specifies interrelationships in his education system framework very specifically as accountability links. On the other hand, Frenk (1994) identifies general interrelationships between patients, providers, the environment, and the state without using specific theory to define what exactly flows between these actors. Figure 3.1 below shows an example of three theoretical frameworks from Health, Education and Infrastructure and where they lie on the 'objective of framework' and 'form of relationship' spectrum.

A final commonality is that health and infrastructure systems research often explicitly draw on complexity/systems theory in conceptualizing interdependencies in their theoretical frameworks. Such frameworks generally incorporate concepts of self-organization, feedback loops and emergent behaviour from systems theory into their frameworks (Homer and Hirsch 2006, Seadon 2010). We discuss such frameworks in more detail below.

Figure 3.1: Classifying Theoretical Frameworks

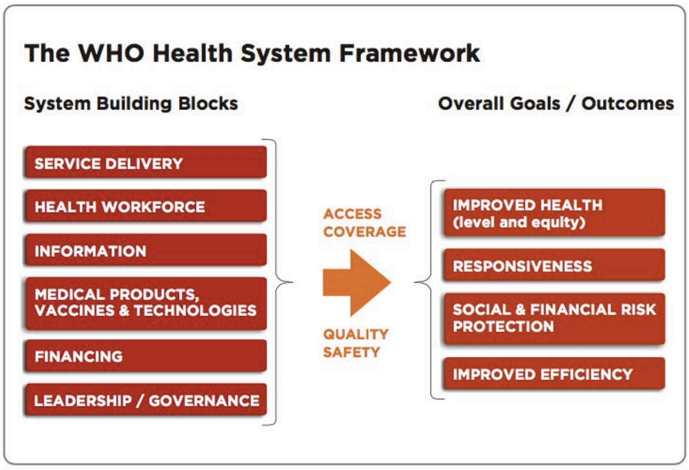


3.1 Health: theoretical frameworks

The existing literature has produced a variety of health system frameworks, spanning across the full range of the 'objective of the framework' and 'form of relationship' spectra. While, frameworks in health are evenly spread along the descriptive v/s analytical range, most frameworks define relationships in a more generalized vis-à-vis specific theoretical form.

Descriptive health system frameworks outline health system components in different ways, either in terms of functions of system components, stakeholders involved or the levels of operations. The seminal WHO framework defines the health system as comprising six key functional building blocks - service delivery, health workforce, information, medical products (including both vaccines and technologies), financing, and leadership and governance – and links them to the broader health system goals (WHO Framework for Action 2007).

Figure 3.1.1: WHO Health System Framework



Source: De Savingy and Adam (2009)

Frenk (2010), on the other hand, defines the health systems in terms of its stakeholders. He identifies patients, consumers, and tax-payers as key players in his health system framework since they provide the main source of financing and are co-producers of health. Fulop *et al* (2001) and Van Damme *et al* (2010) characterize a health system in terms of its level of operation which could be macro, meso or micro. As per their framework, macro includes the national and international context which determines policy such as the resource allocation/financing policy, meso involves the local health system and/or the organizational level which determines how policy gets implemented, and micro involves the people in the system (both patients and providers).

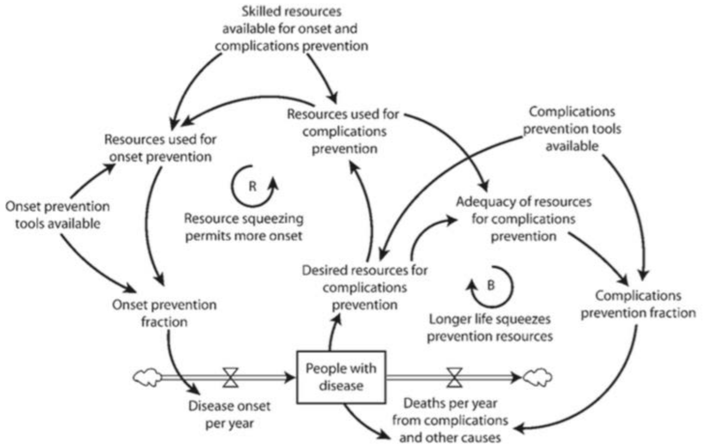
Some theoretical frameworks are more analytical in their objective, with an additional focus on specifying relationships within the system. However, these frameworks tend to specify the form of the relationship in a generalized or a specific way (i.e with a specific theory). For example, Frenk (1994) identifies the state, health providers, and the population as key components within a health system and defines a series of mediating factors through which these key actors interact. He argues that the relationship between providers and the population does not occur in isolation but is rather shaped by the organizations (i.e. workplace or norms of society) in which they operate, the heterogeneous nature of the organizations and the population, and by the state through setting policies of regulation and financing. While the author theorizes how and why these relationships exist, he does not employ specific theories to explain these relationships. On the other hand, Gilson (2003) focuses on the key relationship between patients and providers in a health systems and defines the relationship through very specific 'trust' relationships. She argues how behaviour of health system providers and patients is directly influenced by trust between the patient and the provider, and trust between the health agent and the wider institution.

Often frameworks which use specific theory to describe the form of relationships tend to focus on a sub-system or a system-level intervention. Kutzin (2000), for example, develops a health financing framework in which he uses the market structure of the financing system functions (revenue collection, pooling of funds, purchasing of services, provision of services) to identify policy levers for the government to improve access to health finance. Bossert (1998) develops a framework to study decentralization in health across countries. He uses the principle-agent model as his basis and extends the model through what he calls the 'decision space approach' to understand the degree of choice transferred from the center to local authorities and the impact of this choice on performance. Examples of such specific theories to model relationships in a full health system are less common.

The influence of complexity theory and systems thinking in health systems is demonstrated through two key applications. First, the development of formal models of health systems through quantitative systems modeling, causal loops, and concept mapping which often conceptualize health systems (or sub-systems) as complex adaptive systems. For example, Rwashana, Williams & Neema (2009) use dynamic synthesis methodology (DSM) to model sub-systems within the immunization system (parental participation sub-system and healthcare sub-system). They use this model to explain uptake of immunization in Uganda. Homer and Hirsch (2006) build a simple chronic disease prevention health sub-system model based on systems dynamic methodology which is grounded in concepts of accumulation and feedback from systems theory. Their model develops causal diagrams and policy scenario simulation models to understand the effects of chronic disease perception (see Figure 3.1.2).

Second, the advances in the theory of evaluation of complex interventions in complex systems (Hawe 2015). For example, health system researchers develop detailed logic models which outline how a program works. Such models differ from standard linear theory of change models as they include concepts from systems theory such as inclusion of several pathways indicating different causal chains for different contexts, concentric circles indicating virtuous (vicious) circles where a positive (negative) effect may reinforce/magnify its own effect, and feedback loops or delays (Rogers et al 2000).

Figure 3.1.2: A simple model of chronic disease prevention



Note. The rectangle represents a stock of people; thick arrows with valves and cloud symbols represent flows of people; thinner arrows indicate causal influence; arrows with minus signs indicate inverse causal influence.

Source: Homer and Hirsch (2006)

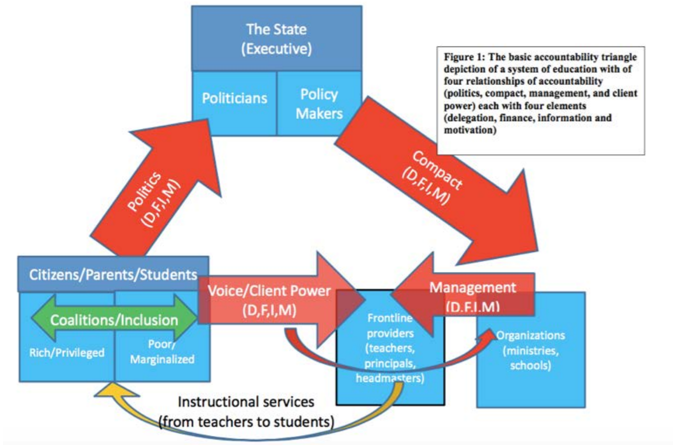
3.2 Education: theoretical frameworks

While education systems research is a very new field, several theoretical frameworks have emerged. Similar to health, these frameworks vary in their objective (i.e. how descriptive v/s analytical they are) and in way they specify the form of relationships.

Purely descriptive frameworks in the education systems literature have been often developed as a foundation for designing survey tools for system diagnostics. Two examples of such efforts are the World Bank SABER and the UNESCO GEQAF initiative. SABER at the World Bank adopts an inventory approach and defines the education system components in terms of its functions. It identifies 13 different education sub-systems which include 1) early childhood development (ECD); 2) education resilience; 3) education management information systems (EMIS); 4) the private sector; 5) equity and inclusion; 6) information and communication technology (ICT); 7) school autonomy and accountability; 8) school finance, 9) school health and school feeding; 10) student assessment; 11) teachers; 12) tertiary education; and 13) workforce development. On the other hand, GEQAF define 5 components of the education system, with each components catering to a specific impediment to learning. They structure the education system into: 1) supporting mechanisms (which includes governance, financing and system efficiency); 2) core resources (which includes curricula, learners, teachers and the learning environment); 3) core processes (which includes learning, teaching and assessment); 4) desired outcomes (which includes competencies and life-long learning; and 5) development goals (which includes relevance and equity). While these frameworks go in a fair degree of descriptive detail, they do not comment on the relationship between these components and/or the form of relationship.

Other theoretical frameworks specify relationships within the system more clearly. For example, Pritchett (2015) describes the education system components and the relationships between them through specific theory. He describes the education systems as a composition of the following actors - citizens/parents/students who are the direct participants and intended beneficiaries of instructional services via schooling; the executive apparatus of the state which makes key decisions (laws, regulations, policies and the allocation of budgets); organizational providers of schooling which are schools and organizations (like Ministries of Education) that control and manage the schools; and Teachers who are the "front-line service providers". In terms of how these actors are inter-related to each other, he identifies the direction of relationships and defines the relationships as 'accountability' links which act through 4 design elements– delegation, financing, information and motivation. He argues that the system of education works when there is an adequate flow of accountability across the key actors in the system across these four design elements. He further argues that many current accountability relationships in existing education systems are coherent for expanding enrolment but not necessarily for learning (see figure 3.2.1 below).

Figure 3.2.1: Accountability Triangle in the Education System.

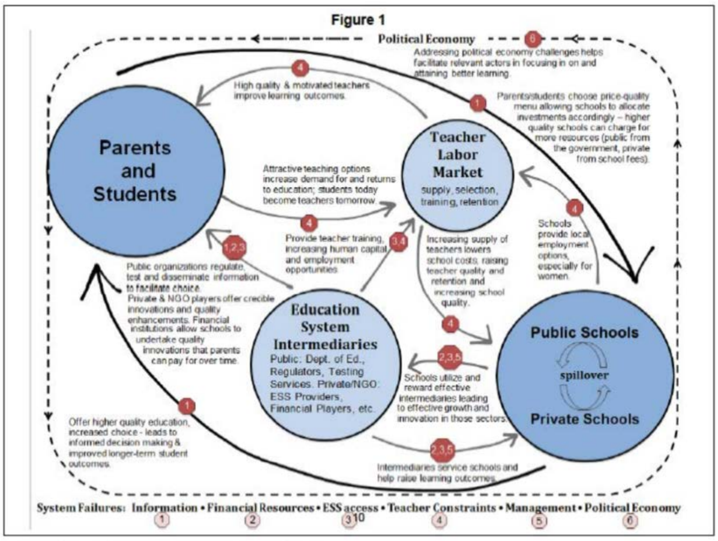


Source: Pritchett (2015)

Similar to Pritchett (2015) Muralidharan *et al* (N.D.) and Andrabi *et al* (N.D.) also describe the relationships within the education system through very specific theory. The former describe the education system in India as comprising of the high level bureaucracy, mid-level bureaucracy, principals, students, parents and teachers. [5] They further define interrelationships between different actors as a set of both accountability and information relationships. The latter describe the Pakistan education system as an economic market with key constraints and frictions along five dimensions: 1) access to information; 2) access to resources and financing; 3) knowledge and innovation markets; 4) labor market incentives; and 5) regulatory and governance structure. They argue that the functioning of the education system hinges on being able to address key frictions in the market long the above-mentioned dimensions. [6]

[5] https://www.riseprogramme.org/countries/india/rise-india-research-overview-technical
[6] https://www.riseprogramme.org/countries/pakistan/rise-pakistan-research-overview-technical

Figure 3.2.2: Market Frictions in the Education System.



Source: Pakistan technical proposal

Source: RISE Pakistan Technical Proposal

3.3 Infrastructure: theoretical frameworks

The key objective of theoretical frameworks in infrastructure systems is to determine how an infrastructure will function, whether the government should make a large investment in an infrastructure asset or to manage risks of infrastructure failures. Given these are high stake concerns for governments, frameworks mostly include tightly modeled specific relationships which can make accurate predictions.

A clear theoretical understanding of the form of relationships, which the infrastructure sector calls 'interdependencies', is especially necessary for developing successful systems-of-systems models. Researchers have adopted descriptive approaches to identify a range of such interdependencies. For example, Rinaldi (2001) outlines that interdependencies depend on the scope of the framework and can be classified as a) physical (material or physical flow from one entity to another); b) cyber (information transfer); c) geographical/spatial (physical proximity affecting components across multiple infrastructure systems); or d) logical (dependencies other than the above three categories). Dudenhoeffer *et al* (2006) further expand these classes to include two additional categories: a) policy/procedural which includes the effect of a policy or a procedure of one infrastructure on all other social and economic sectors; and b) societal which captures the effect of all influencing factors such as public opinion, confidence, fear, or cultural issues from one system component to another. These classifications of different types of interdependencies tend to form the basis of theories which specify relationships in infrastructure systems.

Infrastructure systems research draws on these theoretical definitions of interdependencies to develop infrastructure frameworks/models. Infrastructure systems are understood as complex systems (Saidi *et al* 2018). Hence, researchers borrow ideas from complexity theory and systems thinking in the way they model these interdependencies. Often, a starting point is to develop a 'multi-layer infrastructure network' which models such interdependencies and the resulting complex behaviors. These networks are then used as a basis for simulation modeling or other modeling techniques. For example, Dudenhoeffer *et al* (2006) use a conventional graph theory concept to define an infrastructure system as a collection of nodes, links and edges which represent the dynamic and complex nature of the system. The dynamic aspect of the system is demonstrated by the fact that the network can grow overtime (through increase in the number of nodes); it can evolve (through changing links between the nodes) or entail complexity (through non-linear effects of nodes on one another which also change the state of the nodes). Saidi *et al* (2018) develop a similar multi-layered framework for the civil infrastructure system (see Figure 3.3.1 below) which shows different types of interdependencies between various physical infrastructure sectors and the broader social, economic or political environments. The framework also clearly identifies the type of relationship as physical, geographical, logical or cyber. Such multi-layered networks offer a type of 'systems-of-systems' framework which model a range of interdependencies across different infrastructure sectors.

Figure 3.3.1: A systems-of-systems view with different dependency types

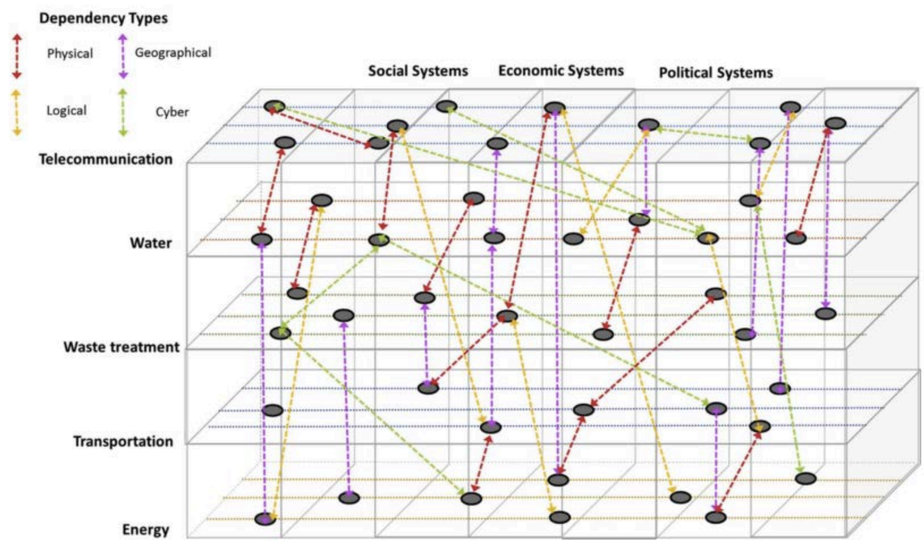
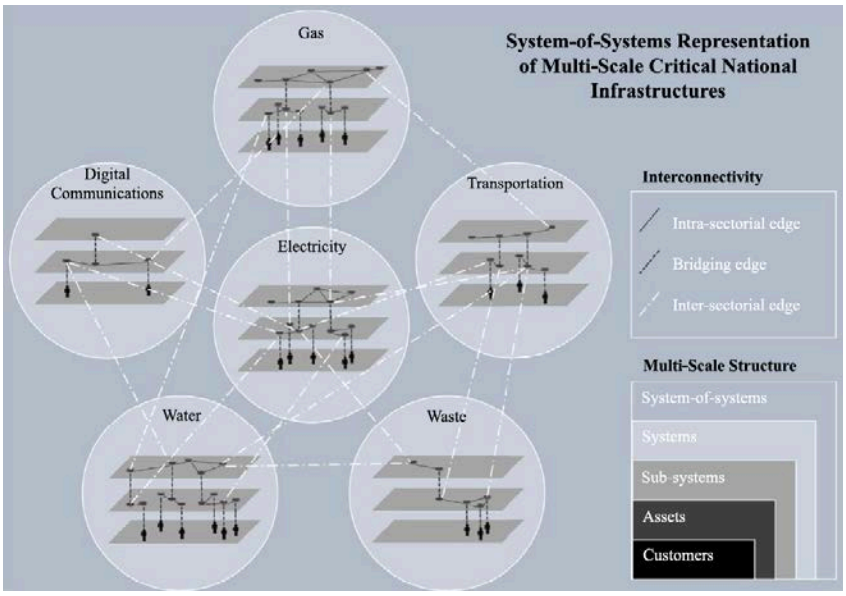


Fig. 1. Multilayer network of an integrated civil infrastructure system with different dependency type.

Source: Saidi et al (2018)

While theoretical frameworks in infrastructure mostly specify the form of relationships, the level of detail with which such relationships/interdependencies are specified varies, and primarily depends on the goal of the framework. For example, disruption analysis inherently involves detailed specification of interdependencies at the outset of the analysis whereas predicting long-term performance of infrastructure systems may not involve the same level of detail. Thacker *et al* (2017) characterize critical national infrastructures as a system-of-system to perform a multi-scale disruption analysis which requires a detailed specification of physical and geographic network interdependencies between sectors. By focusing on the physical dependencies, the authors map functional pathways through a multi-scale network between network source and sink assets across a range of operational scales. The network comprising of nodes and edges in the same infrastructure category is then called a sub-system, defined as fulfilling a specific function (e.g. a transmission network that facilitates the bulk distribution of the good or service). Viewed collectively, sub-systems form an infrastructure system, defined as a set of interconnected assets whose collective function is to facilitate the production and transfer of a service towards the customer.

Fig.3.3.2: System-of-systems representation of six critical national infrastructures



Source: Thacker et al (2017)

On the other hand, Hall *et al* (2016) develop a national infrastructure assessment framework with the aim to assist decision-makers in analyzing the long-term performance of interdependent infrastructure systems. In contract to Thacker *et al* (2017), this requires less detailed infrastructure interdependency modelling and a greater focus on understanding the common underlying drivers for infrastructure demands across sectors. This framework deals with each infrastructure sector – energy, transport, digital communications, water supply, waste water, flood protection and solid waste – in a consistent model and assesses exogenous socio-economic drivers which may impact on all sectors (e.g. population growth, the rise of integrated ICT systems changes the demand patterns for classical infrastructures). It focuses on explicitly specifying how one sector may place demands on other sectors, or how a sector-specific capacity installation (a waste to energy plant) may add capacity in another sector (to electricity production). The focus of this framework on the national, long-term, and capacity/demand perspective leads to a choice of a comparatively descriptive system, because a very detailed representation of the interdependencies would be overconfident, over-complex and consequently, unhelpful (Otto *et al* 2016).

Some theoretical frameworks do not focus on specific physical interdependencies but rather on explaining how a specific infrastructure project is influenced by its users, external stakeholders, asset managers, operators, and political decision-makers. Such frameworks often draw on qualitative disciplines to explain interdependencies which involve humans. For example, Masood *et al* (2016) develop a conceptual framework with the aim of future-proofing (i.e. anticipating future changes and needs to prepare appropriately, minimise ecological impact and capitalise on investments) infrastructure with two dimensions: infrastructure resilience (resilience to unexpected events) and change management capability (capability to adapt to changing needs). Given the focus on social interactions, theoretical frameworks within this area put an emphasis on participatory stakeholder methods and stakeholder engagement with the aim of understanding how a future-proof infrastructure project could be put into practice.

4. Empirical Methods and Applications

Systems research in health, education and infrastructure addresses a range of research questions where each type of question requires a different methodology. For the purpose of this analysis, we categorize research questions into three broad categories (see Table 4.1): 1) Category-A includes questions which are more theoretical in nature and seek to understand a system (and the relationship between components); 2) Category-B includes questions that are more exploratory and descriptive (mainly of the 'how' and 'why' nature) such as how various components of the system function, what those system components look like, how would a certain initiative effect a policy outcome in the future, how power relations and norms effect system outcomes, and so on; and 3) Category-C includes questions that are explanatory in nature, which aim to develop causal links between a certain event or intervention and an outcome of interest. The methods and applications for Category-A type questions have been outlined in detail in Section 2. We focus this section on methods and applications of Category-B and C type of questions in systems research.

For exploratory and descriptive questions (Category-B), the health sector uses a wide range of both quantitative and qualitative techniques. While education and infrastructure aim to do the same, they tend to be more focused on quantitative techniques in practice, with infrastructure drawing heavily on fairly technical quantitative techniques. This is in part due to the fact that understanding infrastructure systems often requires greater reliance on hard quantitative information as opposed to human factors, which makes it relatively easier to use rigorous quantitative models. For explanatory questions (Category-C), health again draws on a wider range, which span from rigorous experimental techniques to realist evaluations, whereas education primarily uses experimental or quasi-experimental techniques. The literature on causality in infrastructure is limited. This can be attributed to the nature of large investments in infrastructure which require careful theory building and testing to be front-loaded prior to roll-out, with the post-implementation analyses more focused on system performance instead of impact. Nonetheless, with the donor focus on value for money a small literature on the impact of development infrastructures is now emerging.

As Table 4.1 shows, the topics of research vary greatly across different sectors and are often motivated by policy interest, direction of international debates and availability of data (see details in the sections below).

Table 4.1: Methodologies and Topics in Systems Research

		A. Conceptual frameworks to understand components of systems and their interrelationships	B. Exploratory and descriptive work on any system component	C. Explanatory questions about how a certain intervention affects (or would effect) system outcomes
Health	**Common Methods**	• Case Study (Categorization) • Reviews of prior work • Use of existing/new theory	• Quant Survey designs including discrete choice experiments, cross-sectional/longitudinal analysis of existing data • Qualitative interviews and panels • Case study (creating categorizations) • Ethnographic field studies • Stakeholder analysis • **Formal modeling:** Systems modeling, concept mapping, causal loops	• Experimental and quasi-experimental designs • Case Study (theory building), learning sites • Realist evaluation techniques
	Topics	• Health system framework • Health sub-system framework	• Questions around decentralization • Identifying constraints in implementation of health reform • Questions surrounding dynamics around health workers • Modeling of health systems to show how an intervention would effect an outcome (e.g. GP integration)	• User Fees • Decentralization • Vouchers/Cash transfers C • Community based monitoring/community based healthcare
Education	**Common Methods**	• Reviews of prior work • Use of existing/new theory	• Quant Survey designs • cross-sectional/longitudinal analysis of existing data	• Experimental and quasi-experimental designs • Case Study (theory building)
	Topics	• Education system framework	• Diagnostics of education system components • School management • Private/public school interactions/dynamics	• Cash transfers • Incentives • Impact of interventions such as textbooks, impact of pedagogical interventions such as contract teachers
Infrastructure	**Common Methods**	• Reviews • **Formal Modeling:** System Dynamic based approaches, Agent-based simulation and modelling, Input-output models (economic flows), Graph Theory, Network-based approaches	**Current infrastructure systems (typically used for risk analysis):** • **Formal Modeling:** System Dynamic based approaches, Agent-based simulation and modelling, Input-output models (economic flows), Graph Theory, Network-based approaches, and Empirical approaches • other methods: qualitative interviews, case study **Infrastructure systems planning (future):** • **Formal modeling:** Simulation modelling with different scenarios • Other methods: Delphi methods, Participatory backcasting, robust decision making, adaptive planning	Pre - implementation: • **Formal modeling** to test performance of infrastructure intervention on different criteria (cost, carbon, etc.) Post-implementation (limited examples from development literature): • Experimental and quasi experimental designs • CGE models, cross-country regressions and sub-national geographic data analysis
	Topics	• Infrastructure interdependencies classification • Theoretical frameworks of infrastructure systems and sub-systems	• Infrastructure planning (decision-making) • Risk and resilience infrastructure analysis • Integrated systems modeling	• Prediction of performance of infrastructure intervention on different criteria (cost, carbon, etc.) • Impact of infrastructures on human lives • Impact of green infrastructures

4.1 Health: empirical methodologies and applications

Health systems research draws on a range of disciplines and methodologies to address different types of exploratory, descriptive, and explanatory questions to unpack the complexities of health systems (Mills et al 2008, Gilson Ed. 2012). This section highlights some key methodologies and their application. It also provides a commentary on areas of research where the field has made a notable contribution.

Understanding gaps in policy implementation is a key focus of health systems research (WHO 2002, De Savingy and Adam 2009). Sheikh and Porter (2010) conduct a stakeholder analysis to identify key gaps in policy implementation. They use data from 46 in-depth interviews with various stakeholders across 5 states India to understand bottlenecks in HIV policy implementation (from 9 hospitals selected by principles of maximum variation). Using the "framework" approach for applied policy analysis, combining inductive and deductive approaches, they find that key gaps in policy implementation included conflicts between different actors' ideals of performance of core tasks and conformance with policy, and problems in communicating policy ideas across key actors involved in implementation. The use of such methodological approaches can often generate findings that are important for understanding how a system interacts with policy change but may be difficult to infer through narrowly designed policy evaluation techniques.

Another key aspect which may determine how systems perform is the accountability relationships between different health system actors. However, capturing the complex social and political realities around such relationships requires techniques which allow deeper exploration. For example, George (2009) conducts an ethnographic analysis to understand how social dynamics may create individuals own meaning of accountability. He examines routine human resource management and accountability practices in Koppal state, India, showing how a complex web of social and political relations among different actors in primary health care influences local understandings and channels of accountability.

Understanding how to allocate limited resources to achieve health gains is central to health systems. For this purpose, one question that researchers and policymakers may seek to understand is key attributes of patient treatment or provider jobs, so as to determine appropriate investment in treatments and/or job incentives. Discrete choice experiments are a methodology which have been adopted and further refined by health economics over the last decade to understand questions such as patient preferences for different aspects of a treatments and health worker job preferences (Ryan 2009). This has enabled researchers to develop clarity on these questions, within a single and across several contexts, in a cost-effective way. For example, Blaauw *et al* (2010) use discrete choice experiments (DCEs) to evaluate the effectiveness of different policies in attracting nurses to rural areas in Kenya, South Africa and Thailand. They find that in Kenya and South Africa, better educational opportunities or rural allowances would be most effective in increasing the uptake of rural posts, while in Thailand better health insurance coverage would have the greatest impact. Such approaches are also helpful in developing a system-wide understanding of central questions such as job preferences.

Health systems research draws on complexity theory and systems thinking in some its metholdogies quite explicitly. Two examples of this include: 1) Modeling of health systems (or sub-systems) formally through quantitative modeling which involves feedback loops and non-linear relationships; 2) evaluation techniques which cater to the complexity of interventions and the health system itself.

Formal models which draw on complexity are mostly used to predict the impact of a potential change within the system. For example, Batterham *et al* (2002) use concept mapping to understand GP integration across primary and secondary health care systems in Australia. Similarly, Bishai *et al* (2014) explore how a hypothetical policy change of funding curative versus preventative services might lead to unintended consequences through complex relationships between stakeholders and financial resources. They identify several negative feedback loops that lead to stable model equilibria that were unexpected from the objectives of the original policies. While research in formal modeling of health systems continues to grow, the effectiveness of such models tends to be limited to their predictive ability instead of being able to study the actual impact of large scale interventions (Hanson 2015).

Given health systems researcher often deal with complex interventions in complex systems, the key question is how to think about research and evaluation design, measurement of outcomes, and process evaluation in a different way (Hawe 2015). To address such concerns, the field has seen a rise of 'realist evaluations' as a way to evaluate complex interventions and tease out causal relationships. This technique recognizes that many different variables may be interwoven which interact in different ways with the fabric of society. Hence, the aim is to identify 'what works in which circumstances and for whom?', rather than merely 'does it work'? (Pawson and Tilley 1997) More specifically, instead of looking at simple cause and effect relationships, realist research considers the interaction between context (the specific setting in which an intervention is rolled out), the mechanism (process of how an intervention works) and outcome. It develops 'middle range theories' through developing context-mechanism-outcome relationships which show how an intervention works (Greenhalgh *et al* 2016).

While such evaluations have been rising in the field, their uptake has been slow due to lack of clarity around the methodology, lack of guidance on its use, and its time-consuming nature (Marchal *et al* 2012). Despite such challenges, some researchers have been able to leverage the methodology effectively to tease out important insights. For example, Mac Kenzie *et al* (2009) use realist evaluation techniques along with a clustered randomization trial to understand the impact of a nutritional intervention during a smoking cessation programme. The authors argue that using realist approaches helped them build a more refined understanding of how outcomes and processes were related. While Mac Kenzie *et al* (2009) combined realist approaches with a rigorous experimental design in their work, a lively debate continues on whether realist approaches can be used together with experimental and quasi-experimental approaches. While proponents argue that realist approaches can be integrated with RCTs by focusing on standardizing processes and functions of interventions rather the components of the interventions (Hawe *et al* 2004, Bonell *et al* 2012), others argue that given RCTS are fundamentally based on a positivist paradigm, they would be unable to fully adapt to capture the complexity of interactions in a complex system.

Apart from realist approaches, health systems research also identifies several other techniques for meaningful evaluation of health systems. For example, Tsofa *et al* (2017) use a 'learning sites' approach in which a geographical space is specifically created where researchers and health system practitioners work together over long periods of time to uncover and address thorny governance challenges. As part of the learning site activities, formal reflective sessions are regularly held among researchers, between researchers and practitioners, and across learning sites to develop an in-depth contextual grounding to study complicated pathways to change. Using this approach, the authors study the impact of a new decentralization reform in Kenya on health resource allocation and budgeting. They conclude that the decision space, organizational capacity, and accountability structures are critical to achieving decentralization success.

As the field continues to grow through the types of studies highlighted above, there are several policy questions/areas of research where the field has specifically managed to make a substantial contribution via shaping global debates and the direction of research. The shifting global position on the effectiveness of user fees is one such example. The World Bank report "Financing Health Services in developing countries: An Agenda for Reform" made a case for implementation of user fees to increase government revenue in order to improve access to the remote poor, quality of health care, and create incentives for patients to use services more efficiently (Akin *et al* 1987). Following this report, many countries in Sub-Saharan Africa responded by increasing user fees in health care. This led to a series of research outputs on the health financing system, in particular the effectiveness of user fees in several different contexts. While some studies pointed to the positive effects of introducing user fees in the form of increased utilization rates (as in Livtvark and Bodart 1993), many others pointed to how the policy actually harmed the poorest (Deininger and Mpuga 2004). Some authors pointed to its positive effects whilst at the same time identifying the constraints which make the implementation of the policy challenging (Collins *et al* 1996). This evidence resulted in the World Bank shifting its position on user fees to how countries must have discriminating fees systems where only those who can afford to pay must pay. Ultimately the Bank moved to its current position in which they advice great caution in using user fees in health systems.

Decentralization is another area which has received a fair amount attention from health system researchers. While no definitive conclusions on the effectiveness of the reform have emerged, the literature has provided several useful insights which can make the reform effective – clarity of roles and objectives, need for capacity building, effective monitoring and evaluation processes to name a few (Brinkerhoff and Leighton 2003). Part of the reason for the lack of conclusive research in this area is the fact that decentralization tends to be a multi-faceted reform with technical, financial and political aspects. Since the reform is implemented in different countries with different objectives and functionalities, comparison across contexts is difficult (Brinkerhoff and Leighton 2003). In addition, implementation also varies greatly across contexts in terms of which functions get decentralized first and the degree of decentralization within each functionality (WHO 2002).

Despite these challenges, health systems research continues to investigate both the effectiveness of decentralization across contexts and propose methods for investigating the reform across contexts. For example, Bossert (1998) grounds himself in a principal agent framework and extends it through what he calls the 'decision space approach' to understand the degree of choice transferred from the center to local authorities and the impact of this choice on performance. He proposes this framework as a way to systematically understand and evaluate decentralization across countries. Abimbola (2018) carries out a realist synthesis of decentralization interventions to understand why, how and in what context decentralization effects health system equity, efficiency and resilience. The author identifies three mechanisms which may mediate the effect of decentralization on health outcomes: 1) 'Voting with feet' which captures how decentralization affects patterns of inequities in a jurisdiction; 2) 'close to ground' which captures how local governance allows for local initiative, input, feedback; and 3) 'Watching the watchers' which captures the mutual accountability links between the citizens and the government.

4.2 Education: empirical methodologies and applications

To date, education systems research has focused more on quantitative methods vis-à-vis other methodologies (See Table 4.1). While the field aims to incorporate other methodologies and disciplines as it grows (Hanson, 2015), there are several unique ways in which the sector is using quantitative techniques to lend useful insights.

The use of quantitative survey tools for conducting system diagnostics is on such example. SABER has implemented its system diagnostic tools in more than 100 countries to identify key constraints to system effectiveness (World Bank, 2014). In Jamaica the government's Early Childhood Commission is employing the SABER dataset to draft its new National Strategic Plan as well as a national multi-sector early childhood development policy. Similarly, in Tanzania, information from the diagnostic is helping the Government plan its education reforms (World Bank, 2014). Country teams in RISE have also adapted these tools locally to develop clarity on how various sub-components in the education system contribute to (or hamper) system effectiveness. Pritchett (2018) highlights key insights and challenges of using such system diagnostics. First, he points out that input indicators and other de jure (formal) policies which the tools aim to capture do not always explain learning - for example, Vietnam shows high learning scores in PISA assessments but indicators in the system diagnostic tools are unable to explain this success; Pakistan shows an impressive record of policies and projects, yet learning remains low. He argues that to understand the drivers the system effectiveness, it is essential to develop and implement tools which in fact aim to capture de facto (i.e. actual) policies. At the same time, he acknowledges that developing and implementing such de facto tools is challenging as the responses can vary, which can also make global advocacy difficult.

Nonetheless, developing accurate system diagnostics remains an active discussion in education systems research.

Another example where large quantitative datasets are generating useful insights is the Young Lives longitudinal study of 12000 students across the countries of Ethiopia, India, Peru and Vietnam covering a life span of 15 years. Within the education theme, Young Lives strives for equitable access to education for all and conducts school surveys to understand the impacts of early education, low-cost private schools and other education system components. This project has created a rich longitudinal household and student learning dataset overtime which has allowed the team to explore important systems research questions. For example, in India the household surveys and learning data have together shed light on the role played by low-cost private schools within the education system.[7] Woldehanna and Araya (2017) used the longitudinal data from Ethiopia to examine the contribution of preschool participation on successful completion of secondary education and the chance of transitioning to institutions of higher learning at the proper ages. They find that preschoolers are 25.7% more likely than their non-preschool counterparts to transition to higher learning.

When it comes to causal questions, the education literature has explored a series of systems-level questions mainly through experimental and quasi-experimental techniques. These include understanding the impact of large spending by governments (in the form of textbooks, cash transfers), governance reforms such as teacher incentives or community monitoring programmes, new pedagogical approaches in government schools (such as contract teachers or literacy and numeracy skills lessons), and the impact of school-based management reforms (see review by Glewwe and Muralidharan 2015) . A review of this evidence shows that improving pedagogy and governance (mainly teacher incentives and accountability) can lead to learning gains whereas large spending by government is mostly ineffective (Glewwe and Muralidharan 2015). While these studies address important systemic questions, they were not designed with the recognition of education systems as complex systems with careful mapping of contextual causal pathways of change. However, as the field grows there will most likely be an increase of interventions which are both designed and evaluated with a systems-level lens.

4.3 Infrastructure: empirical methodologies and applications

Methodologies for exploratory and descriptive work in infrastructure mainly include formal modelling techniques. However, the technique used varies depending on whether researchers are modelling the current national interdependent infrastructure system (which is mainly to determine short-term risk) or simulating infrastructure performance over the long-term. Modelling risk in current infrastructure systems requires a specific and detailed understanding of the current interdependencies between infrastructure assets while modelling performance for the long-term is typically more high-level, focusing on the interaction of the system with its political and social context. It is in the latter case where infrastructure systems research often

[7] https://www.younglives.org.uk/content/education

uses qualitative techniques along with formal modelling techniques for a more comprehensive understanding of the context.

For modelling current integrated infrastructure systems, the literature proposes several different approaches (Ouyang 2014, Rinaldi et al 2001, Zhang & Peeta 2011). These include five broad categories - system dynamic-based approaches, agent-based simulation and modelling, input-output models (economic flows), network-based approaches, and empirical approaches.[8] However, a growing number of studies suggest that the current infrastructure system is most suitably modelled using a network-based approach of nodes and edges, which capture essential interdependencies and indicate the flow of directionality across infrastructure assets (Lewis 2006). While no network modelling approach can answer all the questions (Brown *et al* 2004, Murray *et al* 2008, Eusgeld *et al* 2008), models which incorporate systems theory and develop networks which adapt to their environment are considered to be the state-of-the-art (Eusgeld *et al* 2008, Xiao *et al* 2008, Ouyang 2014, Bevir 2007).

Network-based models can take two forms. They can either adopt a topology-based method (where interdependencies are based on topologies and nodes remain discrete) or a flow-based method (where services or flows across infrastructure systems are taken account of and nodes can deliver and produce services). For example, Zhang and Peeta (2011) use a multi-layered infrastructure network framework (as in Figure 3.3.1) which is an application of the flow-based method. They combine the multi-layered network together with market mechanisms and computable general equilibrium theory to formulate network flow, cost, spatial characteristics, and interactions between system components for each infrastructure layer.

Other quantitative strategies for risk assessments in current infrastructure systems include empirical approaches which use historical accident data to quantify patterns and interdependencies to make empirically-based decisions, agent-based models and system dynamics which treat infrastructure systems as complex adaptive systems and simulate relationships between system components, input-output models, and computational general equilibrium theory which measure interdependencies in terms of economic relationships (Ouyang, 2014).

Apart from questions pertaining to current infrastructure systems, adequate planning and operation of infrastructure systems also requires responding to uncertainties in the future. Most methodologies for future planning of infrastructure systems are grounded in decision-analysis methodologies, which at times also draw on qualitative techniques. These include, for example, scenario modelling and robust decision-making methods which use multiple views of the future to identify conditions under which a decision would fail to meet its objectives (Lempert *et al* 2006, Lempert *et al* 2013), adaptive planning which focuses on the dynamic nature of infrastructure planning, and hybrid methodologies which integrate stakeholder input with the

[8] The details of these are further described by Saidi *et al* 2018, Pederson *et al* 2006, Eusgeld *et al* 2008; Xiao *et al* 2008, Ouyang 2014, Giannopoulos *et al* 2012.

above-mentioned methodologies. We give details on formal scenario planning, robust decision-making and hybrid methodologies below.

Formal scenario planning embraces the concept of multiple future views (Bradfield *et al* 2005). Scenarios are often presented as narratives of descriptions of possible paths into the future and can be differentiated in three classes. These include probable scenarios (what will happen); possible scenarios (what could happen) and preferred scenarios (what should happen). Such scenarios are typically produced in group exercises where three to four such possible paths are generated (Wilkinson and Eidinow 2008). These are intended as a set to stimulate group thinking and help decision-makers evaluate those strategies that perform well across multiple futures (Lempert *et al* 2009). While it can be difficult to capture a wide range of potential futures in a limited set of scenarios, scenario analysis is the least complex of these techniques and has been widely employed for policy review and in infrastructure assessments.

Robust decision-making is applied using computer simulation models to test strategies against a range of potential futures. This involves considering hundreds to millions of scenarios – enough that one matches the actual future (Lempert, 2003). Such an exploration of the future aids policy-makers in determining those strategies whose performance is relatively insensitive, in other words 'robust', to key uncertainties. For example, Kalra *et al* 2015 defined a robust portfolio of water reservoirs in order to implement Lima's long-term water resource plan. Such an approach can also help to define pathways that allow for flexibility and adjustment of the strategy once new information becomes available and future developments become more predictable.

Hybrid methodologies integrate stakeholders throughout the decision-making process for infrastructure, prior or post modelling. Prior to the modelling, stakeholders may be engaged in defining which infrastructure interventions to model, or which criteria for performance modelling to choose (e.g. determining those infrastructure investments with least cost, least environmental impact, etc.). Such stakeholder methodologies typically make use of a number of methods, including Delphi or participatory backcasting. Delphi methods seek agreement on future infrastructure trends from a wide range of experts (Gordon 1964). Such experts respond to a list of questions, review each other's answers, and revise their views accordingly in an iterative fashion. Stakeholders may further be integrated to define which infrastructure assets to model (e.g. building a new power plant, small solar parks, etc.) through participatory backcasting (Banister 2013, Touminen 2014). Post modelling, stakeholders can be integrated to encourage open discussion of trade-offs between different criteria, focusing on strategic, agreed-upon objectives rather than each stakeholder's personal cost and benefits.

Compared to health and education, assessing the impact of an infrastructure investment after its implementation is less practiced and hence the literature on the subject is meagre. This can be attributed to the nature of infrastructure - its long-lifetime and costly resources warrant investment into detailed modelling to simulate how different infrastructure investments perform in the future – with lesser focus on estimating the impact of the investment once it has been made.

One exemption to this is the development literature, where the effectiveness of an infrastructure intervention is often dependent on the local population using it. In such cases, impact of infrastructure is defined as how the infrastructure construction, rehabilitation or maintenance has effected people's lives (Hansen *et al* 2011). The focus of development agencies on results and value for money has led to an increase in impact evaluations to demonstrate the effectiveness of infrastructure development programmes (Hansen *et al* 2011). A range of quantitative methods are employed such as experimental methods (where random assignment is possible), quasi-experimental methods (in cases of large n), computational general equilibrium models (in cases of small n) and cross-country growth regressions. There has also been a recent surge in evaluating infrastructure investments for environmental outcomes, for example carbon emissions. Law *et al* (2017) for example use energy analysis, an environmental accounting system, to evaluate the direct and indirect energy inputs into these infrastructures to give an indication of sustainability outcomes. Such infrastructure evaluations are valuable to decision makers and urban planners who aim to improve standard design and implementation practices for infrastructure projects.

5. Linkages to Policy

Systems approaches are more policy-driven than most academic research, with governments and international organizations often closely involved in the research process tackling questions that are central to improving service delivery. While this generates practical, actionable and relevant research, a set of key steps need to be taken to ensure the field stays true to its spirit. First, effort towards careful stakeholder engagement planning to acquire buy-in from governments and international multilateral and donor organizations for this type of research. This includes advocacy to create funding opportunities. Second, efforts to ensure that the research remains contextually relevant. This often requires strong local partnerships and hence the need to build local capacity for research engagement with local policy partners over long periods of time.

While both the health and education sector have adopted several different approaches to ensure research in the field remains contextually relevant, funding remains a challenge. The infrastructures sector functions differently in this regard. Since governments make large investments in infrastructure, there is generally an appetite for supporting research (both through local engagement and funding) which gives clear predictions on how to make the system more effective.

In the health and education sector, governments often have competing priorities such as investing in disease-specific or input based (such as textbooks) interventions which have more visibility and are also traditionally thought of as being effective. This probably explains why despite being a well-developed field, health systems research has struggled to secure adequate funding at international and national levels. In a report, the Alliance showed that health systems research was only 0.017% of the total health expenditure in countries as opposed to the 2% recommended by the Commission of Health Research for Development (WHO 2002). While researchers have competed for funding for health systems research, several challenges contribute to the lack of adequate funding. First (and as mentioned above), there are often other national competing priorities for funding such as disease specific research which takes precedence. Second, donors often support research on specific diseases. Third, health systems research is not grounded in a discipline or methodology which limits potential avenues for funding (WHO 2002). Such challenges may also be confronted by education systems research as it evolves (Hanson 2015).

Despite these challenges, both health and education have taken promising steps to promote contextually relevant research and create funding opportunities for policy-relevant research. Across the two sectors, research and funding models have two commonalities. First, funding initiatives have mostly been initiated by multilateral organizations such as the World Bank, WHO and DFID. Second, they have a strong focus on building long-term research-policy engagement with involvement from local researchers. Examples from funding models from the health and education sectors below illustrate these two commonalities.

In health, the International Health Policy Programme (IHPP), initiated by the World Bank, Pew Charitable trusts, and the Carnegie Corporation, was an early effort to develop local capacity and promote systems research. It was initiated as a 10-year project across several countries as a way to encourage deep long-term research-policy engagement. Across all funding cycles, nearly USD 15 million were invested in health systems research (Andreano 2000, WHO 2002). Another example is the health systems work which is taking place through KEMRI, a collaborative effort between Kenya Medical Research Institute, the Wellcome Trust, and the University of Oxford. KEMRI adopts a learning sites approach to conduct health systems research in which local stakeholders (such as health managers as different levels) are active participants in the research process over a long term.[9]

In education, RISE is a large multi-country DFID funded grant which is supporting six country teams in India, Ethiopia, Pakistan, Tanzania, Vietnam and Indonesia. Similar to funding initiatives in health, exploring policy-relevant questions is central to how the RISE programme is structured. The six country research teams have been selected carefully on the basis of having strong linkages with policy-makers in their country, and work on a specific 5-year research agenda.

Apart from funding initiatives, the health sector has also been able to develop a large network of academics and practitioners from the developed and the developing world. This has contributed in developing necessary policy linkages and keeping the field relevant through setting a joint research agenda at various forums (such as the conference ‘Symposium on Health Systems Research’ which happens once in every 2 years; and the recently established professional society, Health Systems Global). In addition, the Alliance has also supported

[9] Other funding initiatives also include a focus on the local context - a 3-year WHO grant in collaboration with the Mexican health foundation which funded a total of 53 projects and a 3-year Alliance grant programme which funded over 90 projects (WHO 2002)

research on priority-setting at the international and national level which outlines how countries can make a case for health systems research by involving important government and international (i.e bilateral donor organizations) stakeholders through priority setting exercises. Such efforts play an important role in bringing a spotlight to the field.

As mentioned above, funding for question-driven and policy-relevant infrastructure systems research has been relatively accessible. This can be attributed to the interest and involvement of private actors in the provision and operation of infrastructure services and the direct interest of Governments in having operational infrastructure systems. Funding is mainly accessible for quantitative systems modelling and the development of decision-making tools on infrastructure investments, typically from governmental research councils (e.g. in the UK the Oxford-based Infrastructure Transition Research Consortium is funded by the Engineering and Physical Sciences Research Council). Funding from international organisations (UN, World Bank) focuses mainly on climate risk analyses to infrastructure systems, developing tools for identifying assets at risk and assessing options for increased sustainability and resilience of specific infrastructure sectors.

6. Conclusion: implications for public management and public finance

This background paper has surveyed the development of systems approaches to public service delivery across the health, education, and infrastructure sectors, highlighting similarities and differences. We now conclude with a (somewhat preliminary and speculative) discussion of the lessons this review might hold for the advancement of research into public management and public finance. These fields do not directly deliver services to the public, but do provide critical inputs – or crippling constraints – for service delivery across sectors and organizations. As with health, education, and infrastructure, for the purpose of this discussion we will consider public management and public finance as topics of study rather than as disciplines, encompassing relevant work from development economics, comparative politics, and public administration.

Although many studies in public management and public finance do focus substantively on systems topics, there is little literature on these topics that explicitly adopts a systems perspective in the methodological or theoretical sense discussed throughout this paper. The nascent economics literature on bureaucracy and state effectiveness in developing countries is overwhelmingly focused on identifying causal effects of policies in particular contexts with limited discussion of context, and the broader surveys of this literature categorize different research questions according to policy instrument or function but devote little effort to thinking about the interactions between them (Finan *et al* 2015; Bandiera *et al* 2016; Finan and Dal Bo 2017). This type of research is at the stage that education research was at perhaps a decade ago, with an increasing number of insightful and rigorous (quasi-)experimental studies but little cumulation of knowledge or development of integrative frameworks.

Comparative politics as a sub-discipline also contains little explicit discussion of systems approaches to bureaucracy, with Ang (2017) as a notable exception. Although also host to an increasing number of focused quantitative (quasi-)experimental studies (see review in Pepinsky *et al* 2017), comparative politics differs somewhat from economics in its explicitly comparative aims. The project of trying to explain how differences in context across cases lead to different policy choices or outcomes is remarkably similar to systems approaches' focus on understanding complementarity and contingency, even if it is not framed in these terms. The same is true of comparative politics' longstanding emphasis on the importance of discussing scope conditions for theory and empirical results. As Pepinsky *et al* (2017) emphasize, there is potential for this newer wave of mainly quantitative work to connect to a more established and typically broader and more qualitative comparative literature on governance and state capacity (e.g. Evans 1995, Tendler 1997, Woo-Cummings 1999).

While the turn towards quantitative rigor and causal identification in public administration is less advanced than in either comparative politics or development economics (James *et al* 2017), the types of questions asked by systems approaches have long been central to the discipline. Although not explicitly framed in terms of systems, research areas such as public sector reform (Hammerschmid *et al* 2016) and policy coordination (Kaufman 1991) are motivated and characterized by a high degree of attention to the complementarity and contingency of government structures and processes. Similarly, there are well established journals on systemic topics such as public financial management and human resources management.

Thus in public administration as in comparative politics, despite a lack of explicit 'systems' literature there is actually a large body of work on similar topics with a similar emphasis on complementarity among system elements and contingency of outcomes. What distinguishes this from systems approaches in other sectors (apart from nomenclature) is that whereas health, education, and infrastructure systems approaches were motivated by challenges in cumulating knowledge from numerous rigorous-but-narrow studies, public administration and comparative politics have arrived at these topics from the opposite problem: a historical lack of causally identified empirical studies. A key challenge and opportunity for the development of systems research in public management and public finance is thus to provide a framework that can integrate these broad, comparative, mostly qualitative insights with the growing number of more narrow studies emerging in these areas.

Finally, to what extent can the evolution of systems research in health, education, and infrastructure serve as models for developing this theoretical and methodological framework in public management and public finance? Health systems research is perhaps the best model for this, given its interdisciplinarity and greater degree of development than education. Infrastructure's reliance on intricate models of systems is perhaps even less applicable to public management than to health or education, given the highly contingent and difficult-to-measure nature of much of management, but is perhaps more applicable to public financial management, where it is also possible to measure and characterize flows more precisely. While these challenges are numerous, so too are the opportunities to make public management and public finance more rigorous, more relevant, and more attuned to local contextual differences.

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