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Analyzing antimicrobial resistance as a series of collective action problems

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Abstract

Antimicrobial resistance (AMR) causes over 1.27 million deaths annually, making it one of today's most urgent health threats. Given its urgency, there are often calls for large-scale global initiatives to address AMR. However, theories of collective action have yet to be applied to the problem in a systematic and holistic manner. Fuller engagement with collective action theory is necessary to avoid three risks, namely: mischaracterizing the kinds of challenges that AMR presents; over-simplifying the problem by reducing it to a single type of collective action problem while ignoring others; and overstating the ability of collective action theory to formulate effective solutions. This article relies on the work of Elinor Ostrom to develop an analytical framework for collective action problems around public and common goods. When analyzed through this framework, we find that AMR

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poses at least nine distinct collective action problems. This more granular framing of AMR provides, in our view, a better basis to develop policy solutions to address this multifaceted challenge. We conclude with proposals for future research.

KEYWORDS

antimicrobial resistance, collective action, global health

INTRODUCTION

Collective action problems occur when individual actions prevent a cooperative solution (Ostrom, 2010). Given the difficulties associated with overcoming collective action problems, there are entire fields of study devoted to understanding how they arise and evolve and how to manage them. Often, this includes the use of familiar models like the "tragedy of the commons" and "stag hunt" (defined later in Part II) (Kollock, 1998), with suggested solutions that rely on market or imposed governance mechanisms (Ostrom, 1990).

Characterizing a given policy issue as a collective action problem, or as a specific type thereof, can provide a useful diagnosis for policy. However, getting the diagnosis wrong may misguide such responses. The challenge, then, is to fine-tune the analytical tools for diagnosis or characterization. Some researchers have noted, indeed, that the imprecise application of collective action theory has the potential to generate conceptual confusion when a mischaracterization becomes widely—and uncritically—accepted (Moon et al., 2017; Smith & MacKellar, 2007).

The governance of AMR is one such area. AMR is a complex, multifaceted global challenge that poses an urgent threat to human health and well-being (Laxminarayan et al., 2013; Murray et al., 2022). It is caused by an evolutionary process that is accelerated by human behaviors, especially the overuse of antimicrobial agents in healthcare and agriculture, such as antibiotics. Through this process, microbes, including disease-causing bacteria, evolve to survive the agents designed to kill them or stop their spread (Murray et al., 2022). Consequently, the use of these very substances causes them to stop working, turning previously curable infections into untreatable and often deadly diseases. In 2019, an estimated 1.27 million people died due to bacterial AMR (Murray et al., 2022).

With limited global progress in addressing AMR, theories of collective action can illuminate the factors impeding cooperation and guide policy for this intensifying challenge (Hoffman et al., 2015). To simplify the challenge and help identify responses, AMR has sometimes been characterized within the language of collective action as a so-called "tragedy of the commons." Since microbes can evolve and develop resistance each time an antimicrobial agent is used, every use of an antimicrobial—even when prudent and appropriate—can potentially diminish the future effectiveness of these substances (Padiyara et al., 2018). In other words, what is rational at an individual level (e.g., antimicrobial use to promote health or productivity) generates a suboptimal outcome at the collective level (i.e., the depletion of the common-pool of antimicrobial effectiveness).

While this connection is well-made, collective action theory has yet to be applied systematically to elucidate other facets of AMR. And despite calls for large-scale global initiatives to address AMR, collective action theory has yet to be applied holistically to understand the problem. Although AMR is often presented as a collective action problem, such characterization is rarely fleshed out. In the cases mentioned above, AMR is simply treated as a tragedy of the commons, which is but one type of collective action problem. In other cases, antimicrobial effectiveness is mischaracterized as a global public good (i.e., a good that is non-excludable and non-rivalrous) rather than a common good (i.e., a good that is non-excludable and rivalrous). Simply stated, the effectiveness of antimicrobials is non-excludable yet *rivalrous*, as it can diminish with each use of an antimicrobial (Table 1). However, scientific uncertainty prevents quantifying the exact degree of this rivalry (Bell et al., 2014).

TABLE 1 Types of Goods (from Ostrom and Ostrom, 1977)

	Rivalrous	Non-rivalrous
Excludable	Private goods	Club goods
Non-excludable	Common-pool resources	Public goods

The lack of holistic engagement with collective action theory is not unique to AMR scholarship (Jagers et al., 2020), but in the context of the massive risks posed by drug-resistant infections, fuller engagement with collective action theory in the analysis of AMR is necessary to avoid three main risks: 1. mischaracterizing the kinds of challenges that AMR presents; 2. over-simplifying the problem by reducing the challenge to a single type of collective action problem while ignoring others; and 3. overstating the ability of collective action theory to formulate effective solutions. Such risks are not merely theoretical. Each of them could translate into misguided and thereby ineffective or even counterproductive policy responses. More generally, the massive effort required to mobilize the global community to provide a collective response to AMR can only succeed if there is sufficient clarity of purpose, which, in turn, requires a diagnosis of the problem that is as accurate as possible.

Leveraging and clarifying the rich tradition of social science research on collective action theory is thus crucial to avoid these risks, as different problems require distinct solutions. This is especially true when policy issues are complex with many actors facing multiple scenarios where they must decide to cooperate or not. Several approaches, such as "the ecology of games theory" (Berardo & Lubell, 2019; Lubell, 2013), offer valuable insights into navigating complex policy issues affecting strategic choice. However, no method exists to categorize and classify the collective action problems that exist within a given ecology of games.

To bridge this gap, we draw on the work of Elinor Ostrom (Ostrom, 1990, 2009, 2010) to craft a diagnostic tool for analyzing the structure of policy problems. We then apply this framework to elucidate various collective action problems affecting the effective governance of AMR. Using AMR as a case study serves a dual purpose: it not only enhances our grasp of collective action theory for future global AMR policy formulation but also demonstrates how this framework can be applied to other global challenges, such as climate change and biodiversity loss. Like AMR, these challenges require multistakeholder cooperation to overcome complex cooperation problems at multiple scales (i.e., local, regional, national, and global). By developing a method that deciphers the range of collective action problems facing policymakers, our framework offers a way to increase the precision of policy formation, enhance the effectiveness of global governance strategies, and, ultimately, contribute to more successful and impactful solutions.

The rest of this article proceeds in four parts. First, it reviews how previous research has applied only selective forms of collective action theory to the problem of AMR. Second, the article operationalizes a general framework to identify and catalog collective action problems. Third, the article applies the framework to five social challenges affecting AMR identified in prior research. In doing so, we present nine interlinked collective action problems relevant to AMR governance, including commons dilemmas, stag hunts, volunteer's dilemmas, and weakest link problems (defined later in Part II). These collective action problems arise around both common-pool resources and public goods for AMR governance (Table 1). The fourth part discusses the implications of applying this framework to AMR, including the strengths and weaknesses with this approach. Finally, the article concludes with some ideas for future research to address the collective action problems that AMR presents, arising from the findings and limitations noted above.

PART I: PREVIOUS APPLICATIONS OF COLLECTIVE ACTION THEORY TO AMR

Interdisciplinary research on AMR is flourishing. Within this burgeoning space, many scholars note that AMR presents a wide range of interlinked challenges that demand an even greater array of solutions

(Hoffman & Outterson, 2015; Rogers Van Katwyk, Giubilini, et al., 2020; Rogers Van Katwyk, Weldon, et al., 2020; Wernli et al., 2017). At minimum, prior research has identified at least five major social challenges affecting AMR, each presenting interdependent policy problems that require effective policy solutions. These are 1. improving *access* to antimicrobials, diagnostic technologies, and alternative therapies; 2. enhancing *conservation* to preserve the effectiveness of existing antimicrobials for current and future generations (also known as antimicrobial stewardship); 3. spurring *innovation* for new antimicrobial agents, diagnostic technologies, and alternative therapies; and 4. bolstering global infection *prevention* measures. These four challenges compound existing health inequities within and across populations (e.g., between high-income and low-income countries or between rural and urban populations), which must be recognized and addressed by any policy intervention. Thus, a fifth challenge, 5. the challenge of achieving *equity in policy responses*, represents a transversal issue that cuts across the first four (for a longer treatment of these five areas, see Weldon et al. (2022)).

Many AMR scholars have made a connection between collective action theory and these five social challenges affecting AMR governance (Hoffman & Outterson, 2015; Padiyara et al., 2018). This connection is sensible as collective action theory provides a framework for analyzing scenarios where multiple stakeholders must cooperate to address a shared problem. Indeed, such theories offer strategies for addressing issues like free riding, coordination, aligning interests, and crafting incentives for action. Yet, while most scholars recognize the need for cooperation and global collective action to effectively address the interconnected dimensions of AMR, they typically apply collective action theory in one of three limited ways.

First, some studies and reports explain AMR policy challenges with indirect references to collective action theory (Harbarth et al., 2002; Holmes et al., 2016; IACG, 2019; Laxminarayan et al., 2020; Léger et al., 2021; Outterson, 2005; Outterson et al., 2016; Wallinga et al., 2015; Weldon & Hoffman, 2021; Wernli et al., 2017; WHO, 2015). For example, the World Health Organization's Global Action Plan on AMR does not explicitly use the term "collective action problem." However, it nevertheless outlines various economic and political incentives that result in suboptimal investments in pharmaceuticals while calling for "national and international multisectoral action and collaboration" (WHO, 2015). In another example, Laxminarayan et al. (2020) discuss limited progress on global AMR, noting that commitments are not translating into policy action (Laxminarayan et al., 2020). In the face of this inadequate action, the researchers note that global cooperation and coordination are necessary to address the different facets of AMR. Finally, Eggleston et al. (2010) and Patel et al. (2023) refer to antimicrobials as 'global public goods' without fully defining a global public good, recognizing that antimicrobial effectiveness is rivalrous (and is therefore more of a common good), or considering the relevance of these matters to collective action theory more broadly. Without explicitly linking AMR to collective action theory, these works use the vocabulary of collective action to describe the characteristics of certain problems. Thus, the theory becomes the subtext, making it difficult to understand fully if or how it was applied to support certain conclusions.

In a similar vein, others make use of terminology from collective action theory to assert points without a formal theoretical justification. They suggest that AMR represents a collective action problem in need of global cooperation without defining what a collective action problem is (Årdal et al., 2016; Baekkeskov et al., 2020; Hoffman et al., 2015; Laxminarayan et al., 2013; Minssen & Nordberg, 2020; OECD, 2018; O'Neill, 2016; Outterson & Hoffman, 2015; Padiyara et al., 2018). For example, Outterson and Hoffman (2015) argue that conserving antimicrobial effectiveness is a global collective action problem that will require financial support for some countries. Årdal et al. (2016) similarly argue that addressing AMR will require global collective action, particularly in the areas of access, responsible antimicrobial use, and innovation. These references to collective action theory serve a purpose—they point to the potential relevance of the discourse. However, without fully clarifying what a collective action problem is and how these problems arise in AMR, there is little explanation of the factors causing the collective action problems, their consequences, or theory-led solutions.

Finally, some works are over-specific in their reference to collective action theory. They argue that AMR requires collective action to address a "global common pool resource challenge" and avoid a potential "global tragedy of the commons" (Andresen & Hoffman, 2015; Anomaly, 2010; Baquero & Campos, 2003; Dyar et al., 2016; Foster & Grundmann, 2006; Harring & Krockow, 2021; Moon et al., 2017; O'Brien et al., 2014; Porco et al., 2012; Rogers Van Katwyk, Giubilini, et al., 2020; Roope et al., 2019; Rushton, 2015; Woolhouse et al., 2015; World Bank, 2017). For example, Roope et al. (2019), the World Bank (2017), and Rogers Van Katwyk, Giubilini, et al. (2020) all define antimicrobial effectiveness as a common-pool resource. They proceed to argue that without effective collective action, the common-pool of antimicrobial effectiveness will continue to be diminished. More specifically, Roope et al. (2019) suggest that conceptualizing antimicrobial effectiveness as a common-pool resource could enable a closer application of economic theories and methods to the problem of AMR. Meanwhile, Rogers Van Katwyk, Giubilini, et al. (2020) argue that global attempts to manage the common-pool resource of antimicrobial effectiveness can learn important lessons from climate governance. While accurate, these works focus on the tragedy of the commons without fully defining other collective action problems. Thus, they risk reducing the multifaceted challenge of AMR to only the *conservation* of the common-pool resource of antimicrobial effectiveness.

These more selective approaches have their merit. For example, they help illuminate the barriers for cooperation around specific aspects of AMR. However, they risk overemphasizing one aspect of the problem at the expense of a more holistic and complete understanding. Doing so restricts the range of insights that can be developed and increases the likelihood of reinforcing existing path dependencies. A more holistic approach—one that considers the range of collective action problems and their interdependencies—allows us to recognize the intricate interplay between the various policy dimensions of AMR. Such an approach can uncover trade-offs and unlock synergies when addressing multiple aspects simultaneously.

A fuller range of AMR collective action problems can be identified, but this first requires a method to clarify, identify, and catalog the different types of collective action problems that can arise during global cooperation problems.

PART II: A METHOD TO CATALOG COLLECTIVE ACTION PROBLEMS

Broadly speaking, collective action problems are characterized by three traits: the interdependence of individual actions and their impact on collective outcomes (Ostrom, 2010); an inconsistency between individual and collective rationality (Ostrom, 1990); and the absence of mutuality (Kollock, 1998). These problems arise in policy situations when individual decisions impact the attainment of a shared goal or when the pursuit of individual interests and strategies hinders the achievement of the collective good. Problems of collective action often involve challenges around resource allocation, trust, externalities, and free riding.

There is a growing recognition that today's policy issues are increasingly complex, involving multiple, simultaneous, and interdependent collective action problems that influence strategic choice. Furthermore, these 'policy games' often occur in polycentric policy settings involving diverse networks of actors, stakeholders, institutions, and rules at various scales of interaction. The entrenchment of many complex problems within such complex environments creates both interlinking effects and externalities across policy areas (Berardo & Lubell, 2019). In the governance of AMR, this complexity is evident at both national and global levels, driven by the intersectoral factors that contribute to drug resistance (Weldon, Yaseen, et al., 2022). For example, national and global strategies face challenges around the historical compartmentalization of ministries and sectors, including health, agriculture, environment, and finance (Wernli et al., 2022).

This complex and dynamic landscape of modern policymaking is conceptualized by Lubell (2013) and further articulated by Berardo and Lubell (2019) as an "ecology of games." Their approach describes how various elements interact and evolve together, collectively shaping the policymaking context over time. More specifically, an "ecologies of games" is a systemic approach that incorporates various elements such as policy games (decision-making scenarios), issues (topics of public concern), actors (individuals or groups involved), institutions (organizing structures), and systems (overarching regulatory environments).

To effectively craft policies within a given ecology of games, scholars and policymakers need a comprehensive understanding of these interacting elements (Lubell, 2013). This includes understanding the nature of the underlying policy problems and their interdependent relationships, as emphasized by Berardo and Lubell (2019). An initial step thus involves fully analyzing the structural makeup of relevant policy games before considering effective policy solutions. To understand these essential structural elements, we return to the work of Elinor Ostrom.

Across her seminal works on collective action, such as *Governing the Commons* (1990) and *Understanding Institutional Diversity* (2009), Ostrom distinguishes at least four characteristics that tend to define various collective action problems. These are (i) the nature of the resource around which collective action problems arise; (ii) the regulatory rules that shape actions and pay-offs around the resource in question; (iii) the collective action problem(s) that emerge from these rules; and (iv) the strategic interests guiding the responses of the actors involved (Ostrom, 1990, 2009). These fundamental characteristics, further elaborated below, underpin our framework, which aims to identify collective action problems associated with globally shared common and public resources. It is important to note that Ostrom developed these typologies not as rigid categories but as flexible tendencies. For instance, in scenarios where the nature of goods or rules overlap, multiple and similar collective action problems may blend. The theory is designed to adapt rather than break under strain, often requiring context-dependent interpretation.

We classify and evaluate collective action problems affecting AMR cooperation by drawing on the five major social challenges for AMR elaborated briefly in Part I and more fully in prior research (e.g., see Weldon et al. (2023). We first determine whether that social challenge relates to a public good or a common-pool resource and ask whether it is a problem with the provision or use of that good. Next, we identify the rules that govern interactions and pay-offs around that good. We then use these rules to identify corresponding collective action problems. Finally, we evaluate the distribution of interests around questions of provision or use (Figure 1). The remainder of this section discusses these four components of our framework, while the proceeding section applies the framework to AMR.

The nature of the good

The inherent qualities of a particular good or resource determine whether it gets classified as a public good or common-pool resource. Public goods are nonexcludable and non-rivalrous (Table 1), meaning

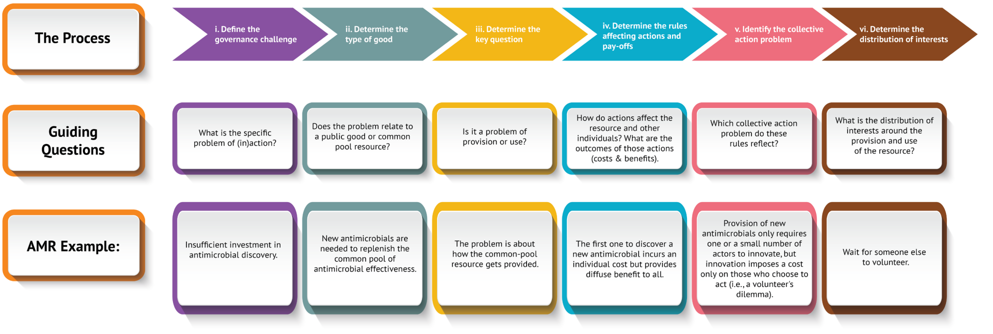

FIGURE 1 A process to identify and index collective action problems.

that actors cannot be easily prevented from using the good (nonexcludable), and one actor's use of the resource does not detract from the abilities of others to also use the resource (non-rivalrous). Conversely, common-pool resources share the characteristic of being nonexcludable but, unlike public goods, are rivalrous in nature. The characteristic of rivalrous use, which distinguishes common-pool resources from public goods, results in additional interdependencies among individual actions and outcomes related to the resource.

In this conceptualization, common-pool resources and public goods are not themselves collective action problems but are the resources around which such problems emerge. The key difference lies in the rivalrous or subtractable nature of common goods. Public goods, such as laws, streetlights, and information, require collective work to provide and maintain. Once provided, one person's enjoyment of a public good does not impede anyone else's enjoyment. In contrast, antimicrobial effectiveness resembles a common-pool resource where access is difficult to limit and use of the resource is rivalrous. Crucially, however, the rivalry in antimicrobials is not due to the finite nature of individual pills but rather the diminishing overall effectiveness of antimicrobial agents due to widespread use.

The inherent risk with common-pool resources is the potential for overuse by any or all actors, leading to depletion unless adequate measures are taken to restrict usage or replenish stocks. If not appropriately managed, the overuse and depletion of such resources jeopardize the collective interest of ensuring their long-term sustainability for the benefit of all (Dawes, 1975).

The structure of rules for actions and pay-offs around the resource

The dynamics of collective action unfold through specific rules that govern the interactions among actors, their relationship with the resource, and the distribution of pay-offs for possible outcomes. These rules derive from the inherent characteristics of the good itself as well as the institutional arrangements that emerge to regulate human conduct concerning said good. While rules for public and common goods may share similarities, there are crucial distinctions. Given that a defining feature of public goods is their non-rivalry, how public goods get used is less of a concern. Instead, the rules affecting public goods pertain to their provision and production. In contrast, common-pool resources involve a dual concern for "who provides" and "who uses" the resource due to their rivalrous nature, where one person's utilization affects the ability of others to do the same.

Numerous and distinct collective action problems may emerge around the provision and use of the same common or public resource (Ostrom, 1990). For example, in AMR, the rules governing how individuals access and consume antimicrobial agents—through social norms, markets, and prescriptions—are distinct from the rules linking consumption to resource depletion, which involve natural and artificial selective pressures and evolutionary processes. Additionally, separate rules determine how the effectiveness of antimicrobials can be sustained through cooperative actions, such as innovation for new antimicrobials or alternative therapies (Weldon, 2023).

The rules around the provision and consumption of shared resources involve pay-offs for cooperating or defecting. Rules may enable free riding and provide positive or negative externalities (Hoffman et al., 2015). Free riding appears when actors benefit from the actions of others without contributing. Meanwhile, negative externalities occur when the costs of using a resource are not immediately borne out by the user but are instead borne out by others in the collective (Kaier & Frank, 2010). In AMR, like other areas, these externalities can be hidden for some time and only come to a head when the resource is critically low (e.g., when critically important antimicrobials stop working in hospitals). Conversely, positive externalities occur when the benefits of using a resource are acquired beyond the resource's immediate users. Some examples of positive externalities include herd immunity from vaccination, or alternatively, infection prevention from good sanitation and hygiene practices, which are both crucial in global AMR mitigation strategies.

Collective action problems

The structural characteristics of specific collective action problems vary based on the nature of the good and the governing rules that dictate actions and pay-offs. These problems are often interconnected within ecologies of games, where outcomes in one setting significantly influence outcomes in others. Furthermore, policy responses themselves may unintentionally introduce new challenges around coordination and collaboration across actors, requiring, for instance, alignment across local, national, and global institutions.

Simple two-by-two payoff matrixes can illustrate how different goods and rules create distinct collective action problems. We present seven generic examples: (a) the stag hunt, (b) the volunteer's dilemma, (c) the commons dilemma, (d) the free rider problem, (e) the weakest link problem, (f) the public goods game, and (g) pure coordination games. The payoffs in these examples are designed for two actors but are scalable to N-number games. They are listed for the row player and the column player, respectively.

a) Stag hunt

A stag hunt (Table 2) occurs when actors face a decision to cooperate for a highly prized good or resource (i.e., a stag), and the optimal outcome in is only provided if all actors cooperate fully. However, if one actor defects, they receive a lower but guaranteed payoff (i.e., a hare) while the other player receives nothing. If both actors defect, they each receive moderate payoffs, underscoring the tension between individual and collective interests.

b) Volunteer's dilemma

A volunteer's dilemma (Table 3) occurs when a resource is provided only if one or a few individuals choose to volunteer. Volunteering imposes an individualized cost only on those who act but provides diffuse payoffs to every actor in the system. In the scenario outlined in Table 3, the cost for volunteering is one, while the payoff to all when the resource is provided is 5. If neither actor volunteers, no pay-off is won (0, 0).

TABLE 2 Stag hunt.

	Column player	
	Cooperate (Stag)	**Defect (Hare)**
Row player		
Cooperate (Stag)	(5, 5)	(0, 2)
Defect (Hare)	(2, 0)	(1, 1)

TABLE 3 Volunteer's dilemma.

	Column player	
	Cooperate (volunteer)	**Defect**
Row player		
Cooperate (volunteer)	(4, 4)	(4, 5)
Defect	(5, 4)	(0, 0)

c) Commons dilemma

A commons dilemma (Table 4) occurs in the use of rivalrous common-pool resources. This dilemma has previously been labeled as the "tragedy of the commons" in both the specific context of AMR and in collective action research more broadly. However, we advocate for the term "commons dilemma" to describe the situation without presupposing a tragic outcome. Indeed, since Ostrom's work on *Governing the Commons*, research has demonstrated that common-pool resources are not inherently destined for tragedy. Nonetheless, effective management of these resources requires navigating a challenging set of rules that offer distinct payoffs specific to common-pool resources.[1] In this dilemma, actors must decide whether to cooperate for a higher collective benefit or defect for a potential individual gain. Like the stag hunt, mutual defection is worse compared to a scenario where cooperation is maintained. The prospect of a potentially higher pay-off for defection undermines the incentive for cooperation, leading to a dilemma where betraying the other players appears advantageous despite yielding a collectively suboptimal outcome. While both may receive small benefits from defecting, the pay-off is much lower as the resource is depleted faster.

d) Free rider problem

The free rider problem (Table 5) emerges when individuals benefit from a resource without contributing. This dilemma shares characteristics with both the commons dilemma and volunteer's dilemma. In the free rider problem, the collective outcome is only achieved when enough actors cooperate. Like the commons dilemma, the challenge revolves around the decision-making of actors regarding cooperation or defection, where cooperation is essential for achieving the optimal collective outcome. On the other hand, akin to the volunteer's dilemma, the free rider problem introduces the risk of individuals choosing not to contribute, capitalizing on the efforts of others while avoiding individual costs.

e) Weakest link problem

A weakest link problem (Table 6) arises when the provision of a good or resource depends on all actors contributing above a minimum threshold, with the highest collective payoff resulting from high effort

TABLE 4 Commons dilemma.

	Column player	
	Cooperate	**Defect**
Row player		
Cooperate	(3, 3)	(0, 5)
Defect	(5, 0)	(1, 1)

TABLE 5 Free rider problem.

	Column player	
	Cooperate (contribute)	**Defect (free ride)**
Row player		
Cooperate (contribute)	(−2, −2)	(−3, 0)
Defect (free ride)	(−3, 0)	(0, 0)

from all players. In weakest link games, an actor may benefit from significant individual effort but cannot achieve the optimal cooperative outcome unless all participants sufficiently contribute. The key challenge in weakest link games is ensuring that all actors contribute adequately, as high efforts from a single actor is not sufficient to achieve the best collective outcome. Overcoming this challenge involves determining what factors restrict lower contributors. Internalization of this pay-off structure involves recognizing that, at a certain point, the returns from investing in the capacity of others become greater than further investments in one's own capacity.

f) Public goods game

A public goods game occurs when a good or resource is only provided insofar as individuals make contributions to the public pool, which is then augmented by some factor (a multiplier) and equally distributed to all regardless of how many or how much was contributed. The public good game helps to demonstrate that different institutions might determine different types of collective action dilemmas. For example, a public goods game may be linear, meaning that everyone benefits incrementally from an additional unit provided by any other person. Alternatively, a public goods game may be based on some threshold, meaning that people only benefit if a threshold of provision is realized by the group.

g) Pure coordination

Coordination problems (Table 7) occur when actors do not have a dominant strategy or a single preferred outcome, but all have a common interest in avoiding a mutually bad outcome. These problems are called 'problems of common aversion' and require coordination (Stein, 1982). Coordination is a mutually agreed-upon or imposed course of action that is not necessarily immediately the most preferred but which prevents a mutually undesirable outcome. Coordination problems, therefore, typically require less effort to solve and can often be mitigated through information sharing and standard setting.

Examples *a* through *f* in this section represent collaboration problems which are distinct from pure coordination games. In collaboration problems, actors must jointly work together on an

TABLE 6 Weakest link problem.

	Column player	
	Cooperate (High effort)	**Defect (Low effort)**
Row player		
Cooperate (High effort)	(2, 2)	(0, 1)
Defect (Low effort)	(1, 0)	(1, 1)

TABLE 7 Pure coordination.

	Column player	
	Option 1	**Option 2**
Row player		
Option 1	(5, 5)	(0,0)
Option 2	(0, 0)	(5, 5)

activity to achieve the mutually desired outcome and avoid the mutually undesired collective outcome. Unlike pure coordination challenges, where there may be many acceptable, if not preferable outcomes, examples *a* through *f* contain distinct optimal outcomes that differ from the pareto-deficient nash equilibria.

While some problems may appear to be coordination problems, they are in fact collaboration problems. More specifically, coordination problems necessitate collaboration if the costs of coordinating for some are higher than the immediate payoffs, such that their immediate self-interest is to not coordinate. For example, when setting common standards and data collection methods for AMR surveillance, questions arise about whose standards get universalized and which N-number of countries bear the cost to change their practices. In these situations, the distribution of costs and benefits transforms, as countries may face significant costs for coordinating and marginal benefits for not coordinating and continuing their established practices, such that the problem transforms to a collaboration problem.

Incentives and strategies

During collective action problems, actors navigate a spectrum of interests that can lead them toward indifference, defection, or actions misaligned with the collective good. These interests are rooted in underlying values, needs, and preferences and affect actor perceptions, behaviors, and decisions. An actor's interests may drive them to strategically maximize their expected payoffs and outcomes through self-interested cost–benefit calculations that privilege expected individual payoffs over the collective well-being. In a volunteer's dilemma, for example, actors may be incentivized to wait as long as they can before volunteering with the hope that some other actor will pay the cost of volunteering before they do. In a weakest link challenge, where providing the resource requires all players to contribute above a minimum threshold, some actors may lack the means or motivation to contribute. Alternatively, actors may miscalculate the true costs and benefits when making strategic decisions on how to act. In these scenarios, the relationship between individual motivations and collective outcomes becomes pivotal, underscoring the complexity inherent in addressing and resolving collective action problems.

Sometimes, shared resources are not provided because all actors follow self-serving strategies (Dougherty, 2003). At other times, they are provided by a single best effort, where an actor's self-interested behavior inadvertently benefits the public (Barrett, 2007). For example, during the COVID-19 pandemic, several governments and private entities sponsored research for novel vaccines. While effective vaccines were ultimately developed, their creation was largely driven by the self-interest of a few companies and firms (Francis et al., 2022). This scenario can be seen as a collective action problem, where the public good—effective vaccines—was only provided when a limited number of actors chose to make significant contributions. This scenario not only emphasizes that self-interest can occasionally lead to public benefit by a single actor or small group, but it also underscores the differing collective action problems that arise in the production and consumption of shared resources.

Indeed, the self-interested behaviors that led to the successful development of vaccines may have resolved a volunteer's dilemma. However, the successes in vaccine development contrast sharply with the failures in equitable distribution, which can be represented as a global weakest link challenge. High-income countries secured and administered the majority of vaccine doses, leaving low-income regions severely underserved (Pilkington et al., 2022). This disparity not only extended the duration of the pandemic in these regions but also resulted in higher mortality rates and significant setbacks in economic and social development (Gozzi et al., 2023). Crucially, and directly relevant to AMR, this example showcases that successful resolution of a volunteer's dilemma does not necessarily translate into equitable access.

With this conceptual groundwork, the following section applies our framework to AMR, shedding light on the unique dynamics and complexities within this critical global health concern.

PART III: AMR IS A SERIES OF NINE INTERLINKED COLLECTIVE ACTION PROBLEMS

With the clarity provided by our framework, we discuss the collective action problems that arise around the use and provision of common-pool resources and public goods for AMR governance. In noting that many distinct collective action problems can emerge around the same shared resource, we first consider three collective action problems for the common-pool resource of antimicrobial effectiveness. Finally, we draw attention to two examples of collective action problems that hinder the provision of important global public goods, which must also be addressed to adequately mitigate the threat posed by AMR.

Ultimately, we find nine collective action problems around both common-pool resources and public goods relevant for AMR governance (Table 8). In addition to the much-discussed commons dilemma, AMR also presents volunteer's dilemmas, weakest-link problems, and stag hunts. Each of these collective action problems requires distinct policy solutions, which are obscured when collective action theory is only selectively or superficially applied to AMR.

Conservation of, innovation for, and access to antimicrobial effectiveness

As previously noted, antimicrobial effectiveness resembles a non-excludable but rivalrous common-pool resource. Importantly, the common-pool resource of antimicrobial effectiveness is not itself a collective action problem. Rather, in applying the insights from collective action theory discussed above, there are three collective action problems that emerge around this resource: one related to its use and two related to its provision.

First, as well described in the literature, the *conservation* of antimicrobial effectiveness represents a classic commons dilemma. This dilemma unfolds across multiple scales, involving diverse stakeholders, including patients, farmers, and nations. As any use of antimicrobials potentially diminishes their future effectiveness, actors must choose between cooperation, where they restrict their use of currently effective antimicrobials, and defection, where they use these antimicrobials without limitations.

Globally, the use of antimicrobials and the resistance that follows are pervasive and rising, signaling inadequate collective action to address this dilemma. In agriculture, antimicrobials are often used to promote growth and enhance economic yields. However, this practice comes at the cost of significant, yet unaccounted for, negative externalities on the common-pool. Recent projections suggest that by 2030, global antimicrobial consumption will increase to 236,757 tons annually, with terrestrial and aquatic agricultural accounting for 79.4% of this total (Schar et al., 2020). The overlap in antimicrobial classes used in both agriculture and human health complicates this issue, as evidence shows that usage in agriculture can compromise treatments in medical settings. Additionally, the overuse of antimicrobials in healthcare remains a challenge that drives resistance. For example, in the United States in 2015, about 43% of antimicrobial prescriptions during ambulatory care visits were either inappropriate or lack documented therapeutic justification (Ray et al., 2019). Such extensive use fosters resistance, yet reducing usage poses health and economic risks.

This commons dilemma illustrates a conflict between individual self-interest in unrestricted use and the collective interest in sustaining antimicrobial effectiveness. Actors facing this dilemma—be they patients concerned about their health, farmers about their yields and income, or nations about their economic productivity—might opt for immediate benefits over long-term sustainability, particularly if they anticipate similar behavior from others.

Addressing this collective action problem requires collaboration to establish, implement, and enforce antimicrobial use guidelines to ensure the resource's sustainability. At both global and national levels, mechanisms such as the WHO's 2015 Global Action Plan and corresponding country-level action plans could address this issue (WHO, 2015). These policies include strategies that impose usage quotas and phase-out timelines for unnecessary antimicrobial use but require strengthening to build

TABLE 8 Nine collective action problems affecting AMR governance.

I. The governance problem	II & III. The good or resource; provision or use	IV. The rules dictating actions and payoffs	V. The collective action problem	VI. Strategic interests of actors
Suboptimal *conservation* of antimicrobial effectiveness	The consumption of the common-pool resource of antimicrobial effectiveness	The optimal collective outcome is only achieved if all conserve use (i.e., cooperate). Using freely (defecting) while others conserve (cooperate) offers individual payoffs lower than the optimal outcome but greater than the payoff to those who conserve. If all defect, the collective outcome is worse than if all had cooperated Negative externalities: the costs associated with use (of antimicrobials) are carried by the collective and not the user	1. Commons dilemma	Free ride off others who conserve their use
Suboptimal investments in *innovation* for new antimicrobials to provide and replenish the common-pool resource	The provision of the common-pool resource of antimicrobial effectiveness	Since the market fails to incentivize antimicrobial innovation, investing in antimicrobial discovery or in initiatives to promote antimicrobial discovery imposes an individualized financial cost on those who chose to act. However, benefits from innovation are provided to all through new antimicrobials Unrealized positive externalities from innovation where individuals or entities investing in antimicrobial discovery not only contribute to the development of new drugs but also generate broader societal benefits	2. Volunteer's dilemma	Wait for someone else to pay the costs associated with developing new antimicrobials Free ride on the efforts of others
Suboptimal provision of universal *access* to effective antimicrobials	The provision of global access to the common-pool resource of antimicrobial effectiveness	Achieving access to antimicrobials for all provides a collective benefit (reduction in both infectious disease and AMR) but requires establishing minimum thresholds for access everywhere Unrealized positive externalities including improvements in overall public health, economic productivity, and social well-being	3. Weakest link problem	Some countries may not have the means to do so or may have other more urgent priorities and limited budgets

(Continues)

TABLE 8 (Continued)

I. The governance problem	II & III. The good or resource; provision or use	IV. The rules dictating actions and payoffs	V. The collective action problem	VI. Strategic interests of actors
Underinvestment in the provision of public AMR surveillance systems to support *prevention*	The provision of the public good of public and standardized surveillance for infectious disease and resistance spread	Achieving global infection surveillance provides a collective benefit (information on infectious disease spread), but requires establishing minimum thresholds for surveillance everywhere Unrealized positive externalities	4. Weakest link problem	Wealthy states do not accurately assess the benefits of investing in surveillance capacities of lower-income countries
Suboptimal provision of coordinated AMR surveillance system methods to support *prevention*	The provision of the public good of public and standardized surveillance for infectious disease and resistance spread	Achieving standardized practices, such as a harmonized grammar for data, provides a collective benefit regardless of what that harmonized grammar is There are, however, potential costs imposed on those who may have to change practices. In these cases, defection offers a lower but certain payoff of local but unstandardized surveillance, whereas cooperation offers a higher payoff but imposes a cost to switch methods	5. Pure coordination 6. Stag hunt	
Suboptimal provision of universal *access* to diagnostic technologies and alternative therapies	The provision of the public good of diagnostic technologies and alternative therapies	Achieving access to diagnostic technologies could enable more accurate and precise antimicrobial prescribing, and access to alternative therapies could lessen the demand for antimicrobials. But achieving access for all requires establishing minimum thresholds for access everywhere	7. Weakest link problem	Some countries may lack the means to do so
Suboptimal investments in *innovation* to provide surveillance, diagnostic technologies, and alternative therapies	The provision of the public good of health innovation	Investing in innovation to promote discovery in surveillance, diagnostic technologies, and alternative therapies imposes an individualized financial cost on those who chose to act, but benefits are provided to all through reduced AMR. High fixed costs and low certainty of quality, uptake, and cost-effectiveness further restrict the market	8. Volunteer's dilemma	Wait for someone else to pay the costs associated with developing these new technologies Free ride on the efforts of others
Suboptimal investments to provide global infection *prevention*	The provision of the public good of global infection prevention	Achieving global infection prevention provides a collective benefit (security from the threat of infectious disease spread), but requires establishing minimum thresholds for prevention everywhere	9. Weakest link problem	Global infection prevention is only achieved if all contribute because pathogens cross national borders. But some are unable to contribute because of a lack of funding

trust and assure stakeholders that cooperation will result in an equitable distribution of rewards, risks, and burdens. Improved trust and assurance of cooperation are critical for increasing the likelihood of collective success. Moreover, as the commons dilemma spans diverse groups and scales—from local to global—coordinated efforts are crucial to align local solutions with the collective goal of preserving antimicrobial effectiveness for current and future generations.

Second, and interlinked with the commons dilemma associated with antimicrobial use, *innovation* for new antimicrobials poses a volunteer's dilemma around replenishing the common pool resource of antimicrobial effectiveness. While the commons dilemma is well described, this volunteer's dilemma is often framed solely in terms of market failures. The current stagnation of antimicrobial innovation is indeed fuelled by numerous market failures. For example, in the standard economic model, a firm's revenue depends on the volume of goods sold. However, the potential sales volume for new antimicrobials is restricted by the time-limited effectiveness of these products, which diminishes potential returns on investment. Additionally, these new drugs must either sometimes compete against off-patent generics, which restricts potential returns, or be saved in reserve as critically important "last lines of defence," which presents a necessarily small market (Outterson et al., 2015). As a result, pharmaceutical firms often cite high research and development costs and low market values of new antimicrobials as the reasons for the sparse development of novel drug classes since the 1970s. While there is growing concern for improving the antimicrobial pipeline, a recent WHO report highlighted that between 2017 and 2021, only 12 new antibiotics were approved, with 10 of these belonging to existing classes already facing AMR mechanisms (WHO, 2022a). These trends indicate that, if left to market forces alone, pharmaceutical companies have little incentive to invest in antimicrobial research, favoring more profitable drugs for chronic conditions (Plackett, 2020).

These innovation challenges pose questions of collective action when reframed to ask who pays and who is responsible for driving solutions to these market failures. The dilemma arises because only one or a few countries or pharmaceutical corporations need to pioneer the initiatives required to foster the innovation of new drugs. The cost for enacting these initiatives, such as funding for push and pull mechanisms to foster drug development, is borne solely by those who volunteer to pay. However, antimicrobial innovation provides diffuse benefits by replenishing the common-pool. Actors, therefore, may be incentivized to delay action, hoping that someone else will fund the socially beneficial initiatives.

The challenge of overcoming market failures around innovation for new antimicrobials, therefore, may be better represented as a problem of coordination and collaboration for funding to overcome a volunteer's dilemma. Strategies to address this collective action problem include mechanisms that distribute the costs associated with volunteering more evenly across the populations that benefit from the resource. This rationale is similar to the one used to justify taxation at the national level, for instance, to fund public infrastructure. At the global level, equitable burden sharing could be modeled on strategies like those of the Multilateral Fund under the Montreal Protocol, which involve financial contributions from developed countries (Weldon, Rogers Van Katwyk, et al., 2022). Existing pooled funding initiatives, such as GARD-P and CARB-X, are promising but could be strengthened with mandatory and differential contributions based on countries' ability to pay or levels of antimicrobial consumption.

Third, providing global *access* to effective antimicrobials can be conceptualized as a weakest link challenge. In a strict sense, common-pool resources are considered nonexcludable when it is difficult or costly to prevent people from accessing them. However, many around the world still do not have access to effective antimicrobials. One estimate suggests that 5.7 million people die annually from infections that could potentially be treated with existing antimicrobials (Jasovský et al., 2016). Compared with the 1.27 million deaths directly attributable to AMR, this figure demonstrates that lack of access remains a more immediate challenge than resistance. Even though scientific advancements provide novel treatments and technologies that make managing the "commons dilemma" and "volunteer's dilemma" easier, their effect is diminished if these medicines do not reach the populations that need them. It is important to address the weakest link problems for global and universal access to medicines for the over 2 billion people lacking access to effective medicines, including antimicrobials (Chattu et al., 2023; Laxminarayan et al., 2016).

The access challenge is compounded by structural issues in the global political-economic system. Intellectual property law, for example, operates to transform nonexcludable resources into excludable resources to incentivize transparency and innovation (Pilkington et al., 2022). Other existing global challenges, such as inability to pay for medicines, lack of infrastructure to ensure their reliable supply and delivery, and prohibitive market entry laws, all restrict access to essential antimicrobials (Access to Medicine Foundation, 2022). The persistent access gap means that many individuals are, in our current reality, excluded from the benefits of antimicrobial effectiveness. In other words, while antimicrobial effectiveness may be considered a common-pool resource, it is not a *global* common-pool resource since access to the common-pool has not yet been sufficiently provided to all.[2]

Establishing access to antimicrobials everywhere is crucial to mitigating AMR (Laxminarayan et al., 2016). Poor antimicrobial access accelerates AMR by enabling infections to spread. It may also lead to inappropriate use of antimicrobials, such as taking smaller doses over periods of time different than the recommended treatment period or using substandard drugs. Smaller doses and substandard drugs both increase the likelihood of resistance because they are less likely to fully eliminate microbial colonies while also giving microbes the chance to mutate and develop defenses.

While individual countries may experience benefits from ensuring minimum antimicrobial access within their population, achieving the highest possible reduction of global AMR risk requires all countries to exceed a minimum threshold. Since not all countries have the means to do so, overcoming this weakest link problem may require wealthier countries to eschew their own self-interest and invest in the human and animal health systems of other countries. Simultaneously, pharmaceutical firms may need to forgo some economic profits to ensure that this objective is met. Mechanisms that internalize the unrealized positive externalities provided by universal antimicrobial access could align individual interests with the collective interest of preventing AMR.

The provision of public goods for AMR governance

Other AMR challenges are better classified as collective action problems related to the provision of public goods, not common-pool resources. Two examples that illustrate this point are infection prevention and global AMR surveillance. Global infection prevention and AMR surveillance have the potential to be global public goods if achieved, since they are both theoretically non-rivalrous and non-excludable once provided. However, neither have been sufficiently provided due to ongoing collective action problems.

First, global infection prevention represents a weakest link problem affecting global AMR governance. While individual countries benefit from strong prevention measures at home, a resistant pathogen can enter from outside their borders as microbes travel quickly in today's interconnected world. This globally shared vulnerability means that the optimal outcome of collective protection from infectious disease can only be unlocked when all countries have the minimum capacity to maintain infection prevention and control, effectively preparing and responding to new outbreaks within their borders. Past initiatives, including US-led strategies for pandemic influenza preparedness and global health programs like PEPFAR, developed in the mid-2000s, have demonstrated the importance of investing in health infrastructure and capabilities (Charatan, 2005; Dietrich, 2007). These programs not only addressed specific health crises but also strengthened overall health systems, enhancing global preparedness and response capabilities for a range of health threats. The structure of this collective action problem for AMR similarly suggests that overcoming this weakest link challenge and providing this global public good will require some countries to eschew their immediate interests (e.g., by investing in health-related infrastructure and capacity in other countries). Indeed, there are unrealized positive externalities for providing this global public good, where countries could acquire benefits from investing in better infection prevention and control measures beyond their borders.

Second, global AMR surveillance represents another potential global public good that has not yet been provided sufficiently. Similar to prevention, achieving global AMR surveillance represents a weakest link problem that requires every country to establish and maintain minimum capacities to track resistance. Achieving this goal may require wealthier countries to act against their immediate interests and invest in the healthcare capacities of others. Viewing surveillance as a public good also helps clarify the role of the World Health Organization and Global Antimicrobial Resistance and Use Surveillance (GLASS) program. GLASS, which as of 2022 includes participation from over 111 countries, serves as a foundation but requires further expansion and standardization to effectively transform global AMR surveillance into a public good (WHO, 2022b). This transformation would necessitate bringing what is now mostly private surveillance data into the global public domain.

Global AMR surveillance must also establish standardized metrics and reporting procedures to create a harmonized grammar of data coding, enabling global tracking and comparison (Wernli et al., 2017). Framed in this way, surveillance also presents a coordination challenge, where countries that synchronize their data collection methods can avoid the mutually undesirable outcome of having incomparable data. However, as critical questions emerge about whose standards are universalized and who bears the cost of transitioning their data collection methods, this coordination challenge evolves from a straightforward coordination game into a collaboration challenge resembling a stag hunt. If every country needs to adopt the same measures for surveillance, but only some incur costs to change their methods, then those countries may find compelling short-term benefits in reverting to their own traditional methods.

PART IV: DISCUSSION

Our framework elucidated nine collective action problems for AMR (Table 8), as well as several synergies and trade-offs among these problems (further discussed below). Many of these challenges and interconnections remain obscured by narrower and selective applications of collective action theory. Understanding the distinct cost and pay-off structures for cooperation in these unique situations is crucial for designing tailored solutions and effective institutional arrangements. For example, promoting global infection prevention and incentivizing the innovation of surveillance techniques, new diagnostic technologies, and alternative therapies all require solutions that address externalities and conflicts between individual choice and collective outcomes. However, solutions for these problems differ: the former requires incentivizing and supporting all to provide a minimum threshold of public health, while the latter requires incentivizing one or a few parties to innovate. Numerous synergies exist across these problems, and many challenges require solutions that incorporate similar components, such as building trust and sharing information for collective solutions.

In applying our framework to AMR, a few paradoxical considerations also emerged that may explain why some researchers have previously and inappropriately described antimicrobials as global public goods. The confusion arises in the distinction between the production and consumption of the common-pool resource of antimicrobial effectiveness (Ostrom, 1990). Antimicrobial products *per se* are private goods for individual consumption (rivalrous and excludable), but the *antimicrobial effectiveness* of these products constitutes a shared and finite common-pool resource (rivalrous and nonexcludable). Simultaneously, effective antimicrobials are essential to support good health and well-being for all, which can be conceptualized as a non-rivalrous and nonexcludable global public good if universally achieved.

These paradoxical considerations underscore the complexities that arise when addressing multifaceted challenges, where each facet contains interlinked components that sometimes arise around the same shared resource and at other times around several different resources. In the face of this complexity, mischaracterizing antimicrobial effectiveness as a global public good overlooks the interdependence of individual action in relation to the finite collective supply. Similarly, characterizing antimicrobial effectiveness solely as a common dilemma obscures persistent challenges related to antimicrobial access and innovation.

A holistic approach that entails these subtle nuances offers important considerations for the interdependence of AMR collective action problems. For instance, consider the three distinct collective action problems identified around the common-pool of antimicrobial effectiveness: the commons dilemma for *conservation*, the volunteer's dilemma for *innovation*, and the weakest link challenge for *access*. These challenges are interdependent, such that imprudent access undermines conservation and squanders innovation; conservation constricts access and hinders innovation by shrinking already small markets; and innovation without conservation is wasteful and without universal access is unjust (Hoffman & Outterson, 2015).

However, if all three collective action problems surrounding antimicrobial effectiveness are sufficiently addressed, then the resource will essentially provide the same benefits as a global public good. Achieving this requires recognizing and sustainably acting upon the interconnectedness among access, conservation, and innovation. In particular, ensuring universal access to antimicrobials will make the resource truly globally non-excludable. Strategies for replenishing the common-pool through innovation must be harmoniously integrated with access and use strategies. Concurrently, use must be judiciously managed through conservation efforts, while innovation must be continuous and robust to ensure that the rate of resource depletion does not surpass the rate of replenishment. In essence, access, conservation, and innovation must be balanced so that we do not consume more of the resource than we generate, nor at a rate faster than it can be replenished.

This holistic approach involves overcoming the volunteer's dilemma through predictable, reliable, and equitable funding for innovation. Simultaneously, the commons dilemma can be addressed by implementing limits and regulations on the use of antimicrobials, thus reducing the burden on innovation and enhancing the prospect of sustainability. The access dilemma can be tackled through policies and capacity-building initiatives that ensure antimicrobials are delivered where they are most needed. If these conditions are met through effective institutional arrangements and global cooperation, antimicrobial use could become less rivalrous, and the common resource could, in theory, function like a public good.

Strengths and limitations

Our framework's primary strength lies in its holistic perspective, offering a comprehensive view of distinct yet interconnected problems within the complex landscape of AMR governance. This approach enables a nuanced understanding of AMR's multifaceted issues, facilitating the identification of links between seemingly disparate problems. Additionally, our method's thorough and replicable process serves as an asset, systematically illuminating numerous collective action problems that demand unique and tailored solutions. This not only enhances the depth of our approach but also provides a robust foundation for addressing the diverse array of challenges inherent in the realm of AMR, ultimately contributing to the development of more effective and sustainable solutions.

Despite these strengths, the application of our framework is not without its challenges. One potential weakness is the risk of overwhelming complexity, as the interconnected nature of the distinct collective action problems can create a landscape that is challenging to navigate. This complexity may hinder the identification of clear and simple solutions, especially given the widespread prevalence of AMR and the diverse scales of policy interactions and contexts involved. An additional weakness stems from collective action theory's reliance on the assumption of Pareto optimality, which can prioritize efficiency at the expense of equity. Pareto optimality, defined as a state where no one can be made better off without making someone else worse off, requires additional steps to ensure fairness of outcomes. For example, a distribution where one actor receives all benefits while another receives none can still be Pareto efficient. This issue may be mitigated by refining how game-theoretic payoffs are specified. By factoring in the overall expected value of outcomes for each participant, collective action theory becomes more adept at accommodating diverse situations and values. Once this is achieved, collective action theory can help pinpoint the necessary adjustments to rectify power imbalances and achieve fairness. Finally, relying solely on rationality to represent motivations overlooks the influence of non-rational factors such as culture, norms, and social practices. These elements highlight the need for continuous refinement and adaptation of the framework to effectively tackle the dynamic and multifaceted challenges of AMR.

These weaknesses notwithstanding, we contend that policymaking will be able to reach better-formulated solutions with a better understanding of the kinds of collective action challenges that AMR presents. Specifically, by enumerating a series of specific collective action problems, future research could investigate other areas of global governance where these specific collective action problems occur and assess whether strategies or techniques mobilized to solve analogous collective action problems in those other settings can be translated into lessons to better govern AMR.

CONCLUSION

Continuing to apply collective action theory to today's urgent challenges, including AMR, remains an important and promising approach for deepening our understanding of and devising necessary solutions for the many complex and defining challenges of our time. Through our framework, we have identified a range of AMR-relevant collective action problems beyond those that arise around the common-pool of antimicrobial effectiveness. These include volunteers' dilemmas, stag hunts, and weakest link problems—each presenting unique incentive structures and challenges. This detailed and systematic categorization not only enriches our understanding but also sets a clear agenda for future research and policy development. Moving forward, it will be crucial to explore global strategies that translate theory into practice and transform patterns of mutual inaction into robust collective solutions. Successfully addressing these challenges will generate more resilient global health infrastructures, bringing us significantly closer to a world with good health and well-being for all.

AUTHOR CONTRIBUTIONS

IW, JV, KL, and SJH conceived the study. IW designed the study, led the conceptual development, and conducted the primary research. IW wrote the first draft with insights and support from KL. All authors were involved in a series of meetings to refine the framework and extract the collective action problems in Table 8. The meetings were co-chaired by IW and JV. All authors provided critical revisions to and feedback on the manuscript.

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ENDNOTES

[1] The simple pay-off matrix in the commons dilemma and free rider dilemma resembles that of the classic prisoner's dilemma.

[2] In contrast with the climate, for example, which is a global common-pool resources.

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