



Narrative review

Optimizing antibiotic prescribing: collective approaches to managing a common-pool resource

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ARTICLE INFO

Article history:

Received 21 December 2018

Received in revised form

8 March 2019

Accepted 10 March 2019

Available online 23 March 2019

Editor: L. Leibovici

Keywords:

Antimicrobial stewardship

Bacterial

Choice behaviour

Drug resistance

Health resources

Humans

Prescribing

Social dilemma

ABSTRACT

Background: Antimicrobial resistance (AMR) is one of the greatest threats in 21st century medicine. AMR has been characterized as a social dilemma. A familiar version describes the situation in which a collective resource (in this case, antibiotic efficacy) is exhausted due to over-exploitation. The dilemma arises because individuals are motivated to maximize individual payoffs, although the collective outcome is worse if all act in this way.

Objectives: We aim to outline the implications for antimicrobial stewardship of characterizing antibiotic overuse as a social dilemma.

Sources: We conducted a narrative review of the literature on interventions to promote the conservation of resources in social dilemmas.

Content: The social dilemma of antibiotic over-use is complicated by the lack of visibility and imminence of AMR, a loose coupling between individual actions and the outcome of AMR, and the agency relationships inherent in the prescriber role. We identify seven strategies for shifting prescriber behaviour and promoting a focus on the collectively desirable outcome of conservation of antibiotic efficacy: (1) establish clearly defined boundaries and access rights; (2) raise the visibility and imminence of the problem; (3) enable collective choice arrangements; (4) conduct behaviour-based monitoring; (5) use social and reputational incentives and sanctions; (6) address misalignment of goals and incentives; and (7) provide conflict resolution mechanisms.

Implications: We conclude that this theoretic analysis of antibiotic stewardship could make the problem of optimizing antibiotic prescribing more tractable, providing a theory base for intervention development. **C. Tarrant, Clin Microbiol Infect 2019;25:1356**

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Conserving scarce resources in antimicrobial prescribing

The over-use of antibiotics is a global problem with potentially catastrophic consequences [1,2]. All antibiotic use promotes the development of antibiotic resistance (AMR), with the associated risk of bacterial infections becoming untreatable with existing antibiotics. Very few new antibiotic agents are being discovered and approved [3]. As a result, antimicrobial efficacy can be viewed as a

resource which, at best, is only partially renewable. The potential for antibiotic overuse to result in a tragedy of the commons – a situation where individual self-interest drives overconsumption of a common-pool resource, and ultimately future exhaustion of the resource – has been widely recognized [4–9]. Conserving the common-pool resource of antimicrobial efficacy, through optimizing the use of available antibiotic resources and reducing excessive use, is now a vital concern. Despite the pressing need for conservative antibiotic use, over-use of antibiotics across human and animal healthcare and agriculture prevails [10]. In healthcare, wide variations in patterns of antibiotic prescribing exist, including

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huge differences in antibiotic consumption across countries [11]. These disparities are unlikely to be fully explained by differences in case mix and infection prevalence, but reflect variation in prescribing practices and stewardship activities. Resistance levels also vary significantly between countries [12], likely resulting, in part, from variations in antimicrobial stewardship and infection control practices. Addressing the growing problem of resistance will require an understanding of the social and behavioural drivers of antibiotic overuse [13] to inform the design and implementation of interventions to optimize practice.

Theory-based interventions for managing common-pool resources

Characterizing the task of optimizing antibiotic use as a problem of managing a common-pool resource provides the foundation for theory-based interventions. One type of theory-based approach is to restrict or control access to the resource [14]; in the case of antibiotic stewardship in healthcare, this includes interventions such as the use of antibiotic access codes, mandatory sign-off by microbiology services, user fees or 'Pigovian tax' [15], and stewardship ward rounds to monitor and correct prescribing choices [16]. Restrictive stewardship interventions can be effective, but overall the results have been variable [17]. Restrictive strategies have limitations because they rarely change social norms or 'prescribing etiquette' [18] and can be damaging to relationships between healthcare staff [19,20]. If imposed by an authority (e.g. hospital management), restrictive interventions can also undermine a sense of collective ownership of decision makers [19], and result in staff working to resist or circumvent the restrictions [21].

Instead, collective and cooperative approaches are widely acknowledged to be more effective approaches for managing common-pool resources [22]. Eleanor Ostrom's seminal work suggests that conservation can be promoted through defining the resource at stake and making its depletion visible; creating local consensus-based access rules; and reinforcing sustainable behaviour through sharing information about resource consumption and using social and reputational incentives and sanctions (Table 1). An example of this approach is the recent highly successful water preservation campaign during severe draught in Cape Town, South Africa [23]. This campaign raised visibility of its depletion of water supplies through publicizing a 'Day Zero' date when taps would run dry. It stipulated collectively reinforced solutions such as clearly defined, water-saving behaviours (e.g. time-limited showers). Levels of consumption were monitored, and social and reputational sanctions applied through publishing household-specific measurements of water use. Approaches to tackling the global problem

of plastic pollution also provide examples of the types of solution that can promote large-scale cooperation towards a collectively optimal outcome: in this case, that of protecting the environment from the damaging effects of over-reliance on plastic. The behaviour of individual users and organizations has been targeted through regulation and financial disincentives, but perhaps more importantly through raising visibility and shifting social norms. Emotive images [24] have emphasized the scale and imminence of the problem, and campaigns have capitalized on the power of commitment to a collective goal [25] coupled with clear actions. Furthermore, reputational effects are being used as a lever for change: through 'public shaming' [26,27] and through opening up the possibility for individuals and organizations to boost their reputations and gain social rewards by eschewing plastic.

While these examples demonstrate effective approaches to reducing over-consumption and protecting a common pool resource, it is unclear whether antibiotic overuse is amenable to the same types of collective solutions. Different resource dilemmas are characterized by unique features which may complicate successful interventions and require adaptation of strategies [28,29]. Three particular features of the problem of antibiotic overuse have implications for the development of collectively based solutions.

Lack of visibility and imminence

In many social dilemmas, individuals frequently ignore the costs they impose on society, because these costs are invisible and diffuse [15]. This problem is amplified in the case of AMR, where the depletion of the commons is not immediately visible [30] and the likely scope of the tragedy remains unclear in terms of the trajectory towards catastrophic resistance levels [6]. While the rapid depletion of water resources and the damage to the environment from plastics are easily revealed to the general population, levels of antibiotic resistance in local populations are difficult to make visible, and are often not apparent to doctors in their daily practice or of concern to lay people. Insidious onset of incremental resistance numbs prescribers to the impending catastrophe of pan-drug resistance. Furthermore, future needs for antibiotics to fight infections are stochastic and cannot be quantified or predicted with certainty [33]. The loss of antibiotic efficacy is commonly perceived to be a vague and distant threat [19,20,34].

Problem of many hands

Additionally, although the responsibility for the problem of AMR is collective, each individual's contribution to the problem is minimal and probabilistic. AMR can be characterized as a 'problem of

Table 1
Theory-based strategies for managing a common-pool resource (CPR) based on Ostrom (1990)

Classes of theory-based intervention	Description of intervention
Clearly defined boundaries	Individuals or households who have rights to withdraw resource units from the CPR must be clearly defined, as must the boundaries of the CPR itself.
Congruence between appropriation and provision rules and local conditions	Appropriation rules restricting time, place, technology, and/or quantity of resource units are related to local conditions and to provision rules requiring labour, material, and/or money.
Collective-choice arrangements	Most individuals affected by the operational rules can participate in modifying the operational rules.
Monitoring	Monitors, who actively audit CPR conditions and 'appropriate behaviour', are accountable to the appropriators or are the appropriators.
Graduated sanctions	Appropriators who violate operational rules are likely to be subject to graduated sanctions (depending on the seriousness and context of the offense) by other appropriators, by officials accountable to these appropriators, or by both.
Conflict resolution mechanisms	Appropriators and their officials have rapid access to low-cost local arenas to resolve conflicts among appropriators or between appropriators and officials.
Minimal recognition of rights to organize	The rights of appropriators to devise their own institutions are not challenged by external governmental authorities.
Nested enterprises (only for CPRs that are parts of larger systems)	Appropriation, provision, monitoring, enforcement, conflict resolution, and governance activities are organized in multiple layers of nested enterprises.

many hands', where individual accountability or blameworthiness for collective outcomes is blurred [35,36]. Practitioners tend to downplay the risk of AMR in relation to their individual prescribing decisions and their own organization, and to characterize it as a problem caused by others [31,37,38]. The problem of many hands is particularly severe in the context of AMR, because a prescriber's actions are only loosely coupled [39] to the problem of resistance. In the example of water conservation, an individual's over-consumption of water directly contributes to depletion at local community level, and both individual consumption and depletion of resource can be easily measured (e.g. through reduced reservoir water levels). Similarly, any use of plastic can be directly linked to the problem of plastic pollution. In contrast, due to variable quality of systems for recording and monitoring prescribing, the measurement of antibiotic use can be problematic [40,41], and the complexity of AMR makes it difficult, but not impossible [42], to link individual prescribing behaviour to local resistance levels. More broadly, in dilemmas such as water conservation, there are direct trade-offs involved—higher water use in the short run means lower availability of water in the long run. In contrast, the nature of the trade-off between the use of antimicrobials now and resistance rates later is poorly understood. The complex biology of resistance, particularly multidrug resistance, means that use of one antibiotic class may promote resistance to another class (e.g. the use of cotrimoxazole use associated with increased carriage of penicillin-resistant *Streptococcus pneumoniae*) [43].

Agency relationships in antibiotic prescribing

A further feature complicating the AMR dilemma is the nature of the agency relationships [44] involved in antibiotic prescribing. In most countries, rather than all consumers being able to freely access the common-pool resource of antibiotics, doctors control access through their prescribing privileges. As such, doctors are the primary target of antimicrobial stewardship interventions that aim to protect the interests of society for conservation of antibiotic efficacy. This can, however, be in tension with doctors' primary role, to act as agents for their individual patients in making treatment decisions. These different roles of doctors create a problem of 'double-agency' [45], which introduces a conflict of interest and ultimately creates a 'moral hazard' [46–48] that impacts on their role as antibiotic stewards. Doctors have rational and ethical reasons for privileging their patient's interests over those of society [5,49]: their professional duty is first and foremost the care of their individual patients [50]. Doctors' interests are aligned with achieving positive outcomes for the patients they treat, and this can be reinforced by reputational, and sometimes financial, implications of negative patient outcomes [34,51–53]. Where stewardship involves adhering to good practice, such as following prescribing guidelines, this is relatively unproblematic in moral and ethical terms, although under conditions of uncertainty the interests of individual patients are likely to win out resulting in over-prescribing. If, however, stewardship becomes extended to withholding antibiotics when benefits are not deemed sufficient to incur the cost of contributing to resistance, serious ethical challenges arise for prescribers [54]. In contrast to some other types of resource dilemmas, efforts to conserve antibiotics are less about controlling wilful individuals who are selfishly overconsuming or depleting a resource, and more about addressing the moral and ethical tensions that arise for prescribers in acting as agents for multiple parties, whose interests may not be fully aligned [44]. As has been acknowledged, guidelines and policy on antimicrobial stewardship fail on the whole to address the moral and ethical questions around antimicrobial stewardship, including whether

prescribers should prioritize collective over individual interests, and under what circumstances [54].

Optimizing antibiotic prescribing in healthcare: adapted social dilemma interventions

Characterizing antibiotic stewardship as a social dilemma, with consideration of the specific features already described, provides the basis for more sophisticated theory-based interventions to help conserve antibiotic efficacy as a common good. We have identified seven recommendations for an integrated, theory-based approach to optimizing antibiotic prescribing (Table 2): (1) establish clearly defined boundaries and access rights; (2) raise the visibility and highlight imminence of the problem; (3) enable collective-choice arrangements; (4) conduct behaviour-based monitoring; (5) use social and reputational incentives and sanctions; (6) address misalignment of goals and incentives; and (7) provide conflict resolution mechanisms.

Establish clearly defined boundaries and access rights

Ostrom [22] emphasized the importance of defining the resource to be protected and the stakeholders able to access it. It is indeed crucial to ensure that only trained staff with prescribing rights can access antibiotics; this is a significant problem in controlling the commons in many low- and middle-income countries (LMICs). Even in settings where access is limited by prescribing rights, doctors are often ill-equipped to make decisions in line with preserving antibiotic commons; many frontline prescribers are relatively junior [55] and have little training specifically on antibiotic use [5]. There may be a case for making access to antibiotics dependent on attaining additional qualifications in antibiotic prescribing and AMR. A more controversial option would be to restrict antibiotic prescribing privileges to specialist prescribers, independent of individual patients' care teams, who would be better able to objectively balance short-term interests of individual patients against longer-term interests of society [56]. However, this option would be dependent on the availability of expert prescribers at any time of the day [57].

In addition to ensuring qualification of agents, there is a need to clarify their respective obligations to different principles [40]. Contracts offer one avenue to clarify the expectations of prescribers as agents for society [58] as well as for individual patients [59]. Requirements to cooperate with antimicrobial stewardship guidelines could be included in prescribers' contracts with their employing organization. Ensuring that regulatory and professional standards specify a duty to protect public health and the future interests of society would also support the development of clear contractual expectations of engagement with antimicrobial stewardship.

Raise visibility and imminence

Making the state of the commons visible to the agents who are responsible for using it is an important element in controlling over-consumption. Any restrictions or voluntary limitations on antibiotic prescribing are more likely to be accepted if individuals are convinced that antibiotic efficiency is indeed under threat, and that antimicrobial resistance is a near and imminent danger [22]. Collecting data on resistance levels, and highlighting patterns of growing resistance as well as patterns of treatment failure [60] to clinician prescribers, is crucial for creating a sense of urgency. This strategy would be dependent on ensuring quality and consistency in sampling, testing, and reporting. The developing global infrastructure for surveillance of resistance could be harnessed to raise

Table 2
Theory-based strategies for managing the complex social dilemma of antibiotic prescribing

Classes of theory-based antimicrobial stewardship intervention	Description of intervention
1. Establish clearly defined boundaries and access rights	<ul style="list-style-type: none"> - Define the common resource that needs protecting (e.g. all antibiotic drugs). - Fully specify who can access antibiotics (e.g. fully-trained doctors; microbiologists, antimicrobial pharmacists), and whether this differs between different types of antibiotics: this turns a resource from 'open-access' into a 'common-property'. - Enforce formal training requirements for antibiotic prescribers to ensure they are fully qualified to make difficult antibiotic prescribing choices. - Ensure prescribers' duty to society and their responsibility for protecting antibiotic efficacy is explicit in formal contracts and professional codes.
2. Raise the problem's visibility and highlight imminence	<ul style="list-style-type: none"> - Collect and communicate information about local resistance levels. - Establish a consensus amongst agents about the threat posed by AMR and the need to act. - Increase a sense of urgency by highlighting existing treatment complications and demonstrating the imminence of AMR.
3. Make collective choice arrangements	<ul style="list-style-type: none"> - Ensure rules about antibiotic prescribing are consensus-based, incorporating views of different stakeholders; use commitment based strategies to support implementation - Ensure that external authorities (e.g. government) respect local, consensus-based rules about antibiotic prescribing. - Fit prescribing rules to the local context, considering for example local resistance levels, hygiene and sanitation, and overall infection rates, and the local challenges and resources of individual hospitals or healthcare organizations. - Ensure all parts of the system have appropriate antibiotic prescribing guidelines and decision-support tools and there is communication and consensus across different parts of the system. - Create structures for collective decision-making, particularly for non-hospital based prescribers
4. Conduct behaviour-based monitoring	<ul style="list-style-type: none"> - Monitor against collectively agreed rules or guidelines - Set up systems to collect and make transparent information on overall prescribing levels and individual prescriber habits. - Enable behaviour-based monitoring by members of the prescribing community and the officials to whom they are accountable, placing the emphasis on prescribing choices of individual healthcare staff rather than their (loosely coupled) outcomes (i.e. hard-to-measure increases of AMR).
5. Use social and reputational incentives and sanctions	<ul style="list-style-type: none"> - Use graduated sanctions matched to scale and frequency of inappropriate behaviours - Make use of social and reputational incentives and sanctions, for example through individual and organizational awards for cooperative action, and reputational sanctions for non-engagement with consensus rules. - Capitalize on the power of social norm feedback
6. Address misaligned goals and incentives	<ul style="list-style-type: none"> - Identify and address organizational and national goals and incentives that are in tension with stewardship - Manage risks for doctors of acting in the interests of society, e.g. through organizational protection from litigation
7. Provide conflict resolution mechanisms	<ul style="list-style-type: none"> - Ensure arrangements are in place to resolve conflicts about antibiotic prescribing (e.g. disputes about appropriate treatment in situations of uncertainty).

awareness of the problem in frontline prescribers – although local resistance data may have more immediate impact in promoting a 'recognition of necessity' for action [57]. Access to data on local resistance patterns has been recognized as a key element of antimicrobial stewardship strategies [61]; this is not only important for informing local recommendations and guidelines for antibiotic choice, but also potentially for being used purposefully to amplify [62] the threat posed by AMR. Raising awareness of resistance rates may not be unproblematic, for example prescribers may react by over-using broad-spectrum antimicrobials. Monitoring unintended consequences of any such intervention would be important. Additionally, given that impact on mortality rates is only likely to be visible when multidrug resistance rates reach a very high level, the impact of resistance reporting may decline over time if providers do not see a direct link between resistance and mortality rates.

Enable collective-choice arrangements

Social dilemmas may be best managed through collective approaches. Making collective-choice agreements requires small communities to work together to establish shared goals and to develop consensus-based rules, which all agree to abide by and to enforce: commitment-based strategies may be particularly valuable in supporting this [63]. Given the tension between potential dangers to current patients if antibiotics are withheld, and the need to protect future patients from the harm arising from excessive antibiotic use, rules should be designed to reflect ethical principles about the rights of current and future patients and the moral duty to preserve antibiotics [64,65]. All individuals affected by the rules of antibiotic prescribing should be involved in designing the rules irrespective of existing hierarchies [22]. Rules instated by central authorities (e.g. international organizations, governments or

hospital trusts) can be valuable but need local adaptation with input from representative stakeholders; external authorities must respect local, consensus-based rules about antibiotic prescribing [22]. Prescribing rules should be designed to reflect the challenges [57] and resources of local communities, e.g. infection rates, sanitation, local AMR, and financial capacities and access to antibiotics, and their implementation supported by adequate access to diagnostics. Communities affected by antibiotic prescribing rules are nested and overlapping: hospitals, GP practices, pharmacies, and patients are all stakeholders and need to convene to enable coordination of action.

Collective choice agreements, once made, must be consistently implemented. Rather than relying on (often junior) doctors to make value judgements on an individual patient basis, in time pressured and demanding circumstances, approaches such as consensus guidelines and decision support systems could be used more consistently to support decision making [64]. Efforts to provide more opportunity for collective decision-making would also be helpful in supporting coordinated action, as well as removing some of the pressure inherent in the agency relationship. In hospitals decisions are more likely to involve input from a multidisciplinary team, whereas those working in the community may have less opportunity to discuss their decision-making and gain advice and support from colleagues.

Conduct behaviour-based monitoring

Enabling a community to self-monitor and correct one another's behaviour is a key element of effective collective-choice systems [6,11]. Monitoring both the conditions of the common-pool resource (levels of resistance [5]) and 'appropriate behaviour', and sharing this information with the community of prescribers, is

essential. Monitoring should take the form of assessing practice against collectively agreed rules or guidelines (e.g. as provided by the 'Start smart then focus' guidance [66] in the UK). Those involved in monitoring the use of the resource and holding others accountable should themselves be members of the community who are using the resource (i.e. should be members of the clinical community) [11].

For individuals to be willing to cooperate in conserving resources, they need to be assured that others are also invested in cooperation. Worries concerning the existence of selfish 'free-riders' who benefit from others' judicious use of antibiotics while making no effort to optimize their own prescribing could lead to a break-down of mutual cooperation [57]. Sharing information about improved prescribing patterns could help individuals to be optimistic that others are also reducing their antibiotic use, and to be more confident that their own contribution is worthwhile [67].

Use social and reputational incentives and sanctions

The effectiveness of collective choice arrangements is dependent on mechanisms for rewarding or sanctioning behaviour. Pay-for-performance schemes offer a centrally administered means of rewarding practitioners for meeting objectives around optimizing antibiotic use, but evidence for effectiveness is mixed and their use is not unproblematic [68]. Basing sanctions and rewards on reputation as opposed to financial reward [69–71] seems a particularly promising avenue. Reputation has been compared to a type of currency in social interactions; the ability to develop a positive reputation based on cooperative behaviour constitutes a powerful reward [69] in most cultural contexts [4]. Harnessing reputation effects among doctors could play an important role in controlling antibiotic prescribing [4,6]. Positive reputational incentives—such as recognizing and celebrating individuals for conservative prescribing [57]—can help motivate individuals to cooperate, and create 'role models' for judicious prescribing. Reputational effects may be even more effective when targeted at ward or organizational level [4] (such as ranking organizations or using awards to recognize collective good practice [67]).

Reputation could also be harnessed as a means of sanction [4]: currently, there exist minimal reputational risks of over-prescribing [72]. Public shaming and consequent normative pressure have been demonstrated to be highly effective [4]: the publication of household water usage in Cape Town reduced water consumption by over a half [73]. Furthermore, as described earlier, public shaming plays a role in efforts to reduce plastic use. This strategy is more difficult to implement in relation to antibiotic use, particularly due to difficulties in identifying levels of 'inappropriate prescribing', although there is some evidence that public reporting of antibiotic prescribing levels can promote reductions in prescribing [74,75]. A closely related, and less ethically problematic, technique is the use of social norm feedback [76,77].

Address misalignment of goals and incentives

The utility structure for doctors around antibiotic prescribing frequently reinforces a tendency towards over-use. Perverse incentives exist, most obviously in private healthcare settings where financial incentives for antibiotic use can be significant [78], but also in relation to the influence of pharmaceutical companies [79] particularly in LMICs. There may also be more subtle and indirect influences of outcome data such as infection rates, mortality, and length of stay statistics on over-reliance on antibiotics [80,81]. Incentives and sanctions should be designed to achieve the desired outcome in terms of stewardship behaviour, to avoid 'the folly of rewarding A while hoping for B' [82].

Ensuring clarity of organizational objectives and goals, actively managing multiple directives, targets, initiatives and guidelines (both at organizational and national level) to reduce tensions with stewardship aims, tackling perverse incentives (including those that arise through pharmaceutical company activities) [83], and ensuring doctors are protected when they make active decisions not to prescribe antibiotics [84] will be critical in reducing goal conflict for doctors.

Establish conflict resolution mechanisms

Any rules or guidelines are subject to individual interpretation, resulting in potential for disagreements between different healthcare professionals. It is therefore crucial that appropriate institutions or arrangements are in place to resolve disputes about appropriate antibiotic prescribing [22]. Smaller disagreements could be resolved during regular meetings of antibiotic stewardship committees including experienced representatives from different healthcare professions. More serious or recurrent conflict might require escalation to a hospital court system, which could be established based on existing medical management structures [6].

Conclusions

AMR presents a severe threat to society: without antibiotics, we face a future in which minor infections could be fatal, common surgical procedures would become too risky, and deadly diseases could wipe out significant numbers of the population globally. Over-use of antibiotics in medicine contributes to the development and spread of resistance, and effective antimicrobial stewardship is critical in the fight to preserve this precious resource.

Stewardship interventions should draw on theory-based approaches for managing a common-pool resource, as demonstrated in interventions to tackle other resource dilemmas including drought and environmental pollution. These include establishing clearly defined boundaries, access rights and responsibilities of those who control access to the resource, and raising the problem's visibility. Developing consensus-based rules [85,86] around limiting antibiotic use, enabling the community of prescribers to self-monitor through sharing of data on prescribing levels, and using social and reputational rewards and sanctions [57] may enhance current approaches to conserving antibiotics. Alongside this, misaligned goals and incentives need to be addressed, and local mechanisms for conflict resolution established. Developing a better understanding of the nature of the trade-offs involved in the dilemma will inform decisions about how far stewardship should go in restricting current antibiotic use in order to achieve (uncertain) future gains [5]. Establishing ethical principles for stewardship to minimize the risk of harm to current patients will be important to underpin these strategies.

Table 3 provides an overview of possibilities for implementing these strategies in England. While each type of strategy potentially has value in its own right, most impact is likely to be gained by developing a coordinated programme specifically designed to enable cooperative collective action to optimize antibiotic use. The successful Swedish STRAMA model is a good example of such a programme, incorporating a decentralized organizational model, local adaptation of guidelines and initiatives, awareness-raising for patients and health professionals, and monitoring and sharing of data on resistance levels and antibiotic use [87].

Insight into the cultural and contextual differences between countries that shape the nature of the dilemma, and impact on delivery of and engagement with stewardship programmes, will

Table 3
Example theory-based actions in England

Classes of theory-based antimicrobial stewardship intervention	Example potential actions in England
1. Establish clearly defined boundaries and access rights	<ul style="list-style-type: none"> - National policy: require doctors to hold a qualification to prescribe antibiotics (e.g. based on European work to identify competencies required for antibiotic prescribers¹). - Healthcare organizations: adhere to CQUIN guidelines stipulating senior doctors review of antibiotic prescriptions.² - Healthcare organizations: include requirements to cooperate with antimicrobial stewardship guidelines in doctors' contracts. - GMC (regulatory body): ensure that professional standards specify doctors' duty to protecting public health and the future interests of society.
2. Raise the problem's visibility and highlight imminence	<ul style="list-style-type: none"> - Public health bodies: re-frame information about AMR in messages targeting the public and health professionals to avoid presenting as a vague future risk; instead use real cases and show graphics of the scale of the problem of growth and spread of resistance, e.g.³ - Professional bodies: establish consensus statements for action on antibiotic over-use.
3. Make collective choice arrangements	<ul style="list-style-type: none"> - Improvement bodies (e.g. NHS Improvement): support the use of collaborative approaches to improving antibiotic use (e.g. clinical community-type approaches).⁴ Bring together local communities of stakeholders to participate in a consensus-building process to translate national action plans into local goals, e.g.⁵ - Healthcare organizations: develop and use locally adapted national prescribing guidelines, e.g.⁶ - Community prescribers: initiate platforms for collective decision-making (online or group based).
4. Conduct behaviour-based monitoring	<ul style="list-style-type: none"> - Healthcare organizations: engage prescribers in collectively auditing their own practice against best practice auditing tools, e.g.⁷ - Healthcare organizations: consider implementing electronic monitoring and feedback systems for antibiotic prescribing.⁸
5. Use social and reputational incentives and sanctions	<ul style="list-style-type: none"> - Healthcare organizations: provide benchmarked feedback to prescribers/teams on their prescribing; initiate awards for good performance. - Healthcare organizations: provide frameworks, guidance and training to support staff to question and challenge others on their prescribing decisions. - Senior doctors: recognize and celebrate conservative prescribing decisions by colleagues. - National bodies: recognize organizational high performance, e.g. Antibiotic guardian awards.⁹
6. Address misaligned goals and incentives	<ul style="list-style-type: none"> - Improvement bodies (e.g. NHS Improvement): review targets and incentive schemes to avoid tensions (e.g. between CQUINs for sepsis prevention and CQUINs for antibiotic protection). - Healthcare organizations: integrate delivery of infection control and antimicrobial stewardship initiatives (e.g. through a single team); check for unintended consequences of initiatives. - Healthcare organizations: encourage full documentation of prescribing decisions including decisions not to prescribe; ensure doctors are confident that conservative prescribing decisions will be defended by their employing organization. - Healthcare organizations/national bodies: develop guidance in clinical conflict resolution and plan for local implementation.¹⁰
7. Provide conflict resolution mechanisms	

¹ Dyar OJ, Beović B, Pulcini C, Tacconelli E, Hulscher M, Cookson B, Ashiru-Oredope D, Barcs I, Blix HS, Buyle F, Chowers M. ESCMID generic competencies in antimicrobial prescribing and stewardship: towards a European consensus. *Clinical Microbiology and Infection*. 2019 Jan 1; 25 (1):13–9.

² NHS Improvement. Reducing the impact of serious infections CQUIN FAQs, parts 2c and 2d. 2017. https://improvement.nhs.uk/documents/1845/CQUIN_FAQs_September_2017_v5_EC.pdf.

³ CDDEP. Antibiotic resistance. 2017. <https://resistancemap.cddep.org/AntibioticResistance.php>.

⁴ Aveling EL, Martin G, Armstrong N, Banerjee J, Dixon-Woods M. Quality improvement through clinical communities: eight lessons for practice. *Journal of Health Organization and Management*. 2012 May 18; 26 (2):158–74.

⁵ Powell N, Davidson I, Yelling P, Collinson A, Pollard A, Johnson L, Gibson N, Taylor J, Wisner K, Gaze W, South J. Developing a local antimicrobial resistance action plan: the Cornwall One Health Antimicrobial Resistance Group. *Journal of Antimicrobial Chemotherapy*. 2017 Jun 7; 72 (9):2661–5.

⁶ NHS North Hampshire CCG. South Central Antimicrobial Network Guidelines for Antibiotic Prescribing in the Community. 2018. http://www.nhsantibioticguidelines.org.uk/downloads/CS47131-NHSNHCCG-Antibiotic-Guidelines-2018-WHOLE-PRF5.pdf?fbclid=IwAR2M_ACCx2G17VvYwwZkjs6KhOjDLt4wOwTFIBWFRxOkG71OvK6rZw3M.

⁷ Public Health England. Start Smart Then Focus Appendix 1. Resource Materials: Examples of audit tools, review stickers and drug charts.

⁸ Gulliford MC, Prevost AT, Charlton J, Juszczyk D, Soames J, McDermott L, Sultana K, Wright M, Fox R, Hay AD, Little P. Effectiveness and safety of electronically delivered prescribing feedback and decision support on antibiotic use for respiratory illness in primary care: REDUCE cluster randomized trial. *British Medical Journal*. 2019 Feb 13; 364:i236.

⁹ <https://antibioticguardian.com/2019-awards/>.

¹⁰ Resolving Clinical Conflicts Between Forensic Mental Health Services in Scotland (2005). <https://www.forensicnetwork.scot.nhs.uk/wp-content/uploads/2016/10/Resolving-conflicts.pdf>.

be critical for tailoring approaches to promoting cooperative action, to ensure they are context specific [88,89]. Any efforts to optimize antibiotic use need to be closely coupled with infection prevention strategies, to reduce the need to call on the antibiotic commons [90]. Ultimately, the challenge of antimicrobial stewardship may prove to be more tractable than expected, provided that the dynamics of the social dilemma involved are taken into account.

Transparency declaration

None to declare. This research was funded by the Global Challenges Research Fund—Grant No. ES/P004784/1 awarded by the Economic and Social Research Council (ESRC) on behalf of the Research Councils UK (RCUK).

Acknowledgments

This research was funded by the Global Challenges Research Fund—Grant No. ES/P004784/1 awarded by the Economic and Social Research Council (ESRC) on behalf of the Research Councils UK (RCUK).

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