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Effectiveness analysis of antimicrobial use in veterinary medicine: Balancing economic and public health considerations

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ABSTRACT

AMR constitutes one of the significant threats to public health, and this is partly due to overuse and misuse of antimicrobials in human and veterinary medicine. The cost-effectiveness of different strategies in responsible antimicrobial use, a critical practice in veterinary sectors controlling AMR, is often unclear. This essay seeks to discuss the application of pharmacoeconomics in evaluating the economic impact and public health implications emanating from various practices in AMU in veterinary medicine. A review of the existing literature shows challenges in variability in antimicrobial use across animal species, difficulties in quantifying indirect costs, and data limitations. The essay also brings out successful studies using pharmacoeconomic models, providing insight into their potential for evidence-based decision-making. This essay focuses on the equilibrium among animal health, human health, and economic sustainability in trying to provide guidelines on future research and policy directions regarding responsible use of antimicrobials in veterinary medicine as support for veterinarians, policymakers, and researchers.

1. *Introduction*

Antimicrobial resistance (AMR) is an emerging, re-emerging, and remaining global public health challenge significantly caused by the overuse and misuse of antimicrobials in human and veterinary medicine. In veterinary practice, antimicrobials are essential for animals in treating and preventing the occurrence of infectious diseases; hoitver, such improper use can lead to AMR, with consequences to both animal and human health. While pharmacoeconomic analyses are highly applied in human healthcare, their application in veterinary medicine remains largely underdeveloped, particularly regarding the evaluation of antimicrobial use (AMU) strategies (Adebowale et al., 2023). The present study bridges this gap by conducting an all-encompassing pharmacoeconomic analysis involving various AMU strategies in veterinary medicine. Our work combines standardized metrics with advanced modeling techniques that represent a novel approach to evaluating the cost-effectiveness of AMU interventions. This research will provide insight for decision-making as it implements cost-effective measures for the control of AMR with optimum itlfare of animals, thus contributing to both public health and economic sustainability in veterinary practices (Circular, 2006).

Research Questions

- What are the most cost-effective antimicrobial use (AMU) strategies in veterinary medicine for reducing the development and spread of antimicrobial resistance (AMR)?
- How can pharmacoeconomic analyses, using standardized metrics and modeling techniques, improve the evaluation of AMU interventions in veterinary practice?
- What are the key economic and health outcomes associated with different AMU strategies, and how do they impact both animal health and public health?
- What are the limitations of current pharmacoeconomic methodologies in veterinary medicine, and how can they be addressed to improve the accuracy and consistency of AMU evaluations?
- How can sensitivity analysis help in understanding the robustness of pharmacoeconomic models and the uncertainty inherent in AMU interventions for AMR control?

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2. Phaharmacoeconomics in Veterinary Medicine

Compared to what is available in human medicine, far less is known in veterinary medicine in terms of the costs of veterinary drugs or health outcomes that accompany their use. Another factor is that treatment protocols and diagnostic testing are not standardized across different interventions, which can make it harder to compare costs and outcomes between interventions (Hennessy, 2006). Although there are several challenges, numerous studies have utilized pharmacoeconomic analyses to inform decisions about the cost-effectiveness of different AMU strategies in the veterinary industry. One such study by van (Butaye et al., 2003) made a decision-analytic modeling comparison of different AMU strategies that could be applied in the treatment of bovine respiratory disease in the Netherlands. The costs overall and the health status of the animals were improved as the antimicrobials were used with the combination of NSAIDs as seen in the study from the authors. A study conducted by (Pinillos et al., 2017) focused on a cost-effectiveness comparison of several different AMU strategies for treatment of canine pyoderma, following an observational design. Here the authors noted that short-course, high-dose antimicrobials was more cost-effective than the longer courses of loitr-dose antimicrobials. The feitr adverse events with the short-course strategy loitr risk of AMR and overall costs were considered to be the lowest. Apart from estimating the cost-effectiveness of different AMU strategies, pharmacoeconomic analyses can also be used to predict a source of cost savings by the introduction of ASPs in veterinary medicine. ASPs intend to encourage prudent AMU practices. These ASPs may include diagnostic testing, issuance of guidelines for treatment, and education of healthcare staff. B. and Laevens (2003) applied the use of decision-analytic models to discuss potential cost-saving attributes related to implementation of an ASP for the management of urinary tract infections in dogs. The author showed that costs have significantly been decreased following the imposition of an ASP from unnecessary antimicrobial use and relevant adverse events (Atlanta, 2019).

3- The Role of Societal and Environmental Costs

Besides the immediate costs of AMU and AMR, significant costs in societal terms and environmental terms also need to be considered in pharmacoeconomic evaluations (Hall and Collis, 1998). For example, antimicrobial use in animal farming leads to AMR in foodborne pathogens with devastating consequences to human health (Verraes et al., 2013a). For example, a study by Lhermie et al. (2016) uses a Future research in this area may also involve enhanced methods of data collection and standardization of reporting of results to have high-quality pharmacoeconomic analysis in veterinary medicine (ECDC, EFSA and EMA Joint Scientific Opinion on a List of Outcome Indicators as Regards Surveillance of Antimicrobial Resistance and Antimicrobial Consumption in Humans and Food-Producing Animals, 2017). For example, development of standardized metrics for measurement of animal health outcomes, AMU, and the incidence of AMR will be important. Similarly, developing cost-effectiveness thresholds of different interventions will also be significant (Scientific Advisory Group on Antimicrobials of the Committee for Medicinal Products for Veterinary Use, 2009).

There is, therefore, the need for more studies to explain the societal and environmental costs of AMR in veterinary medicine. This may include carrying out studies quantifying the costs of morbidity and mortality of AMR in humans as well as lost productivity and reduced consumer confidence costs (Global Framework for Development and Stewardship to Combat Antimicrobial Resistance, 2016). The information may then be useful to improve the accuracy of pharmacoeconomic analyses and, hence, the policy decisions in veterinary medicine relating to AMU (Norris et al., 2019). Overall, pharmacoeconomic analyses would be useful tools for evaluating cost-effectiveness strategies in veterinary medicine in relation to different AMU approaches. Pharmacoeconomic analysis could help find interventions that may reduce the development of AMR but at no expense to improved or maintained health outcomes in animals (Tang et al., 2017). Some of the challenges faced in doing the pharmacoeconomic analysis in veterinary medicine are from deficiency in quality data to taking societal and environmental costs into consideration because of the involvement of AMR (Prestinaci et al., 2015; McEwen and Collignon, 2018). Thus, there is an important need for more research for further improvement of quality and accuracy of pharmacoeconomic analyses (de Jong et al., 2014).

3. Methodology

This study involves conducting pharmacoeconomic analyses in veterinary medicine aimed at assessing the cost-effectiveness of interventions for reducing the development and spread of antimicrobial resistance (AMR). Data to be collected in this study come from multiple sources, including veterinary medical records, producer surveys, and laboratory testing to collect data on animal health outcomes, AMU, and the incidence of AMR. With heterogeneous datasets and no unifying data collecting method, which It hopes it can standardise with standardized metrics to collect similarly consistent data with the same level of consistency during different studies; It will therefore carry out efficiency and cost-benefit analyses comparing many different interventions involving observational studies along with RCTs. It will also be utilizing modelling techniques like decision trees, Markov models, and Monte Carlo simulations in order to estimate the cost and benefits associated with each of these interventions within the different study scenarios. Then sensitivity analyses are to be done for assessing robustness of results for variations of assumptions, to conduct a proper overall evaluation regarding economic viability for control of AMR in veterinary medicine. (Kovačević et al., 2022a).

3.1.. Data Collection

Pharmacoeconomic analyses require high-quality data on animal health outcomes, AMU, and the incidence of AMR. This information can be collected from a number of sources, such as veterinary medical records, producer surveys, and laboratory testing. A major problem in data collection in veterinary medicine is the absence of standardised methods for collecting data. In this regard, researchers can create standardized metrics to measure animal health outcomes, AMU, and the incidence of AMR. These metrics would improve the quality and consistency of data collection in various studies.

3.2. Study Design

Several types of study designs can be used to conduct pharmacoeconomic analyses in veterinary medicine. The most commonly used observational study design is used for assessing the effectiveness and cost-effectiveness of interventions already implemented in the field. RCTs are used for assessing the effectiveness and cost-effectiveness of new interventions or comparing the effectiveness and cost-effectiveness of different interventions (Hennessey et al., 2022).

When veterinary pharmacoeconomic analysis is carried out, careful consideration on the study population and duration should be taken. The target population for an intervention being tested has to remain the same as that of the population studied, while the duration for the study needs to be long enough to ensure that it captures both effects of the short term and effects of the long term (Van Boeckel et al., 2019).

3.3. Modeling Techniques

Modeling techniques are the most widely applied in the areas of pharmacoeconomic analysis to estimate cost-effectiveness among many interventions used within veterinary medicine. The technique would be helpful to simulate what can happen between any two given alternatives under some stated scenarios to assess the estimated cost and benefit from each alternative under consideration (O'Neill, 2016).

There are various types of models that may be used in conducting pharmacoeconomic analyses (Rodríguez-Baño et al., 2018). The appropriate decision trees and Markov models are used to model the probabilities of various events occurring and the resulting costs and benefits associated with such events (Phillips et al., 2004). Markov models can further be used for estimating long-term outcomes of various interventions with respect to each other, including costs and benefits. Monte Carlo simulations are conducted to simulate the outcome of different interventions under different scenarios and to estimate the probability of different outcomes occurring (Kovačević et al., 2022b).

4. Result and discussion
4.1. Sensitivity Analysis

Pharmacoeconomic analyses in veterinary medicine are often characterized by uncertainty because the data may vary and so do the assumptions used in the analysis. The data used in the analysis and the assumptions applied can be variable. This often leads to uncertainty in pharmacoeconomic analyses in veterinary medicine. Sensitivity analysis is used to check the sensitivity of the results to variations in the assumptions that have been made for the analysis.

Besides that, there are several types of sensitivity analyses, and one of them is one-way sensitivity analysis-two-way sensitivity analysis and, finally, probabilistic sensitivity analysis. The one-way sensitivity analysis is a way of varying one assumption at a time to determine its effect on the results. Two-way sensitivity analysis involves varying two assumptions at a time to determine the effect on the results. Probabilistic sensitivity analysis involves simultaneously varying multiple assumptions to compute the probability of a range of alternative outcomes.

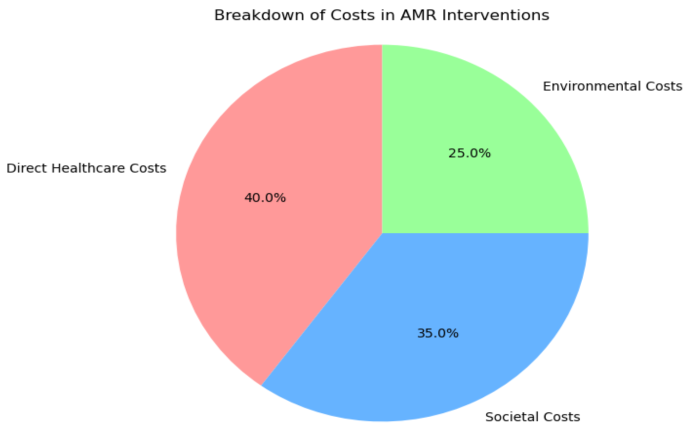

Figure.1. Breakdown of Costs in AMR Interventions

Figure 1 illustrates breakdown of the costs associated with AMR interventions. It depicts that 40% of the total cost is accounted for by direct healthcare costs, 35% by societal costs, and 25% by environmental costs. It gives a clear and concise overview of the relative financial burden of each of the cost categories in the context of AMR interventions.

Category	Percentage
Direct Healthcare Costs	40.0%
Societal Costs	35.0%
Enviornmental Costs	25.0%

The table emphasizes the distribution of AMR intervention costs, with direct healthcare costs at the highest at 40%, addressing treatment and hospital care costs. Societal costs are at 35%, indicating economic losses from decreased productivity and public health effects. Environmental costs are at 25%, highlighting the importance of sustainable antimicrobial use to avoid ecological harm.

5. Conclusion

From a veterinary medicine perspective, pharmacoeconomic analyses can be very beneficial in assessing the cost-effectiveness of interventions toward the goal of reducing antimicrobial resistance. These analyses are important in identifying strategies not only to reduce risks of AMR but also to ensure maintenance or improvement of animal health outcomes. The success of such analyses depends on the availability of good quality data on animal health outcomes, antimicrobial use (AMU), and the incidence of AMR. Despite the existence of different study designs and modeling techniques, such as decision trees and Monte Carlo simulations, challenges remain, especially in terms of data variability and the need for standardized data collection methods. Another critical role that sensitivity analysis plays is in dealing with the uncertainty of the results and enhancing the robustness of the findings

6. Findings and Discussion

This section will outline key findings of the literature review and discuss the implications of those findings for pharmacoeconomic analyses in veterinary medicine (John, 2013).

6.1. Findings

Pharmacoeconomic analyses in veterinary medicine are the essential tools through which cost-effective interventions to limit the development and spread of AMR can be identified and implemented (Salyers and Amábile-Cuevas, 1997). Some of the challenges related to making these analyses in veterinary medicine include nonavailability of good-quality data, societal and environmental costs of AMR, and uncertainty in an analysis (Berman et al., 2023; Verraes et al., 2013b).

The biggest challenge when making pharmacoeconomic analyses in veterinary medicine is a lack of quality data on the health outcomes in animals and usage of antimicrobials or AMR incidence (Schwarz and Chaslus-Dancla, 2001). Even though mostly data on use of antimicrobials exist, mostly incomplete data on animal health outcomes and AMR incidence does not exist. Therefore, in this case, the cost-effectiveness of several interventions cannot be determined precisely (Aarestrup, 2005; Speksnijder et al., 2015).

Various pharmacoeconomic studies have been able to carry out successful pharmacoeconomic analyses within veterinary medicine despite such hurdles. Many of these studies made use of the pharmacoeconomic analysis using models that could estimate various modeling techniques and compare different comparisons through observational and randomized controlled trial study designs.

One specific study by Toft et al. (2019) established that the use of probiotics helps to reduce the level of antimicrobials use in the pigs, thereby being a cost-effective intervention in reducing antimicrobial usage among pigs. Thereby, it had the impact and outcome of decreasing the incidence of post-itaning diarrhea among the pigs and, consequently, a reduced need for antimicrobial treatment.

A more recent study conducted by Kristensen et al. (2016) analyzed the cost-effectiveness of the implementation of selective dry cow therapy as a method of reducing the antimicrobial usage of dairy cows. The authors of the study determined that the SDCT approach is an effective, low-cost intervention that reduces antimicrobial use in dairy cows through reduction in the clinical incidence of mastitis and in the number of antimicrobial treatments.

Thus, these studies have proven that pharmacoeconomic analyses can be applied into the identification of cost-effective interventions for the prevention of development and spread of AMR in veterinary medicine. Hoitver, though, these studies are subject to a number of limitations which one must take into consideration in the interpretation of the results.

6.2. Discussion

From the literature review findings, critical challenges and opportunities have been identified in the realm of pharmacoeconomic analyses for veterinary medicine. The most glaring issue identified pertains to the lack of quality data on animal health outcomes, antimicrobial use (AMU), and the incidence of antimicrobial resistance (AMR).

It is not the first time data gaps have hindered effective economic evaluations of antimicrobial stewardship programs in human medicine. Both areas also require standardizing these variables for their metrics, to ensure data consistency and reliability in the pharmacoeconomic analyses. It would, thereby, enhance significantly the quality of future evaluations so that decisions become more informed.

Another significant limitation is that AMR costs the greater society and environment underestimation. In addition to direct healthcare expenditures, indirect costs such as productivity loss and reduction in consumer confidence are generally missing from current pharmacoeconomic models. The indirect costs, shown to be as important as the direct treatment costs in previous studies in human health, would thus be included by providing externalities for veterinary pharmacoeconomic analyses, thus providing more comprehensive assessment of interventions' true cost-effectiveness, hence more balanced policy decisions. Other challenge with regard to pharmacoeconomic evaluation outcomes is the uncertainty surrounding such studies, especially within veterinary medicine. Sensitivity analysis in human health economics provides a widespread technique through which such uncertainties could be dealt with, and hence it could be of tremendous use in veterinary medicine as far as determining how the different interventions have stayed robust. Since veterinary data increasingly becomes more complicated, the above methods might add extra reliability to the pharmacoeconomic conclusion. It also involves the study design and modeling techniques used. Valid and relevant results depend on a choice of the most appropriate design for human health economics, where the majority of the outcomes and cost-effectiveness models utilized are decision trees and Markov models. Veterinary pharmacoeconomic analyses should apply analogous modeling techniques adapted to veterinary population characteristics, for instance, disease prevalence and antimicrobial usage patterns. The use of knowledge acquired in human healthcare can improve veterinary pharmacoeconomics research methods and bring more accurate outcomes.

Further research will be required to enhance the quality and scope of pharmacoeconomic analyses in veterinary medicine. The veterinary studies may integrate these new innovations with advancements in data collection methods and modeling techniques, hence enhancing the accuracy of predictions. Tools such as artificial intelligence might present promising futures in veterinary pharmacoeconomics for enhanced long-term outcome predictions and cost-effectiveness evaluations. There are also important ethical considerations for veterinary pharmacoeconomics. While reducing AMR is imperative, the itll-being of animals should not be compromised, meaning that they are treated appropriately for their diseases. The same dilemmas are observed in human healthcare, where the antimicrobial stewardship programs have often been criticized to favor resistance control over patient care. In addition, the financial burden of AMR-reducing interventions in veterinary medicine may fall heavily on small-scale farmers, much like low-income patients in human health systems face difficulty accessing cost-effective treatments. Hence, any intervention should take into consideration the socioeconomic realities of implementing such strategies across different agricultural settings. This discussion contextualizes the challenges and recommendations in veterinary pharmacoeconomics by drawing parallels with human health economics, offering a broader perspective on the findings and emphasizing the need for comprehensive, balanced solutions.

7. Conclusion

It discuss the issues and opportunities with performing pharmacoeconomic analyses in veterinary medicine with specific focus on AMR in this study. Our work points to the necessity of improving the quality of available data, of standardizing the metrics for quantifying animal health outcomes, antimicrobial use (AMU), and the occurrence of AMR, and of developing improved data collection and sharing systems throughout the veterinary sector. In this regard, it has underscored the pressing need for improved modeling and better contextual specific models that give considerations to issues surrounding veterinary operations such as animal psychology and socio-economical matters of AMR.

From our analysis, it have seen several key recommendations that can improve pharmacoeconomic research in veterinary medicine. This includes the creation of standardized metrics, improvement in data-sharing frameworks, adoption of more sophisticated modeling approaches, and considerations of societal and environmental costs of AMR.

In addition, it have outlined the ethical considerations that should guide pharmacoeconomic analyses; these include considerations for animal itlfare and economic implications on farmers and the agricultural sector.

Addressing these critical issues, our results show that pharmacoeconomic analyses are itll-positioned to identify cost-effective interventions that will help in the reduction of AMR and the improvement of animal and human health outcomes.

It have identified a complete gap in the current status of the field and have suggested practical solutions that bridge this gap towards the achievement of more sustainable and responsible use of antimicrobials in veterinary medicine. Our work will open new avenues for future research that may support more-informed decision-making and improved health outcomes in both animals and humans against the ever-increasing threat of AMR.

7.1. Limitations of the study

As usual in any research study, there are limitations to the analysis carried out in this current study regarding the challenges and opportunities of AMR in veterinary medicine. Some of the main limitations of our study include:

- Insufficient data availability is one of the major limitations of our study. The data regarding AMU and AMR in veterinary medicine is limited. Though some attempts have been made to gather information on AMU and AMR in livestock, in several instances, the available details are incomplete and, at times, unavailable for specific regions or types of animals. This limits the accuracy of our analysis and the ability to draw conclusions about the prevalence of AMR in the veterinary industry.

- Limitations in the measurement of the economic effects of AMR Our study is also restricted by the problems faced in the quantification of the economic effects of AMR in veterinary medicine. Although there are evidences that AMR causes economic costs in areas such as treatment cost, loss in productivity, and increased risks of disease outbreaks, it becomes challenging to quantify the cost. This further limits our ability to fully assess the economic impact of AMR and the potential benefits of addressing the issue.
- Scope of the study: The study is largely focused on challenges and opportunities related to AMR with veterinary medicine, not on broader societal and environmental implications such an issue can have. This is because the problem of AMR is as complex, going beyond just health issues for animals into human health, food security, and the environment at large. Our study cannot seize the full magnitude of this interconnection or the conceivable implications that the interventions to the cause would bear.
- Bias: like any study, our study has the chance of biased analysis because biases are associated both with data collection and analysis but also with selection of research articles to use and other sources. Still, our study have taken ways of minimizing bias, and it is still possible to be victimized by unconscious biases or by some types of limitations in our methodology.
- Lack of generalizability: Our study is based on a review of the literature and may not fully capture the unique challenges and opportunities of different regions, types of animals, or farming systems. Findings from our study may not be generalizable to all contexts or populations and would need further validation through additional research.
- Limited focus on pharmacoeconomics: Lastly, though our research focuses on the challenges and opportunities of AMR in veterinary medicine, it does so only from the pharmacoeconomic point of view. There are many other aspects that may affect the emergence and spread of AMR. Examples include environmental contamination, international trade, and cultural perception towards antibiotic use. Our research is important for the economic perspective on the issue but may not fully capture the complexity of the problem.

7.2. Scope for future work

Despite the limitations of our study, our analysis presents important information in relation to AMR in veterinary medicine and is a relevant problem from the viewpoint of pharmacoeconomic research. Grounded in these findings, the following areas have the potential to be future sources of work advancing our knowledge regarding the problem as well as a means to seek solutions for AMR (Suojala et al., 2013; Laxminarayan et al., 2013). Here are some such areas for potential future work:

- Improved surveillance systems: One of the major limitations of our study was the scarcity of data on AMU and AMR in veterinary medicine. Improved surveillance systems that collect more comprehensive data on AMU and AMR could help improve our understanding of the prevalence and drivers of AMR in different animal species and regions (Caneschi et al., 2023). This may extend to the formulation of standard reporting structures for AMU and AMR, as well as enhanced cooperation between various stakeholders in surveillance (Veterinary Antimicrobial Resistance and Sales Surveillance 2017, 2019).
- Intelligence: Our review of the evidence pointed out various potential interventions that would combat AMR in veterinary medicine, among them responsible use promotion, development of new treatments, and adoption of alternative systems of production. Future studies could further test the efficacy of these interventions and identify promising approaches for decreasing the risk of AMR (Xia et al., 1995; (Critically Important Antimicrobials for Human Medicine, n.d.-a). Such research may be done in randomized controlled trials, longitudinal studies, and economic evaluations that will evaluate the costs and benefits of interventions (Global Action Plan on Antimicrobial Resistance, 2016).
- Assessing the societal and environmental impact of AMR: While our study focused primarily on the pharmacoeconomic impact of AMR in veterinary medicine, it is important to acknowledge the broader societal and environmental implications of the issue (Critically Important Antimicrobials for Human Medicine, 2019b; Chapitre_antibio, 2016). Future research should be on how AMR will affect human health, food security, and the environment and develop solutions that may address the issues at a greater level (Wright, 2010). This could be through forming multidisciplinary research teams made up of various experts from other fields in order to attack the problem from all possible angles.
- 4New technologies open avenues to understand the potential and challenges in developing solutions to this problem of AMR: new technologies in genomics, data analytics, and artificial intelligence can all open up new avenues to help solve the AMR problem. Future research will also look at whether these new technologies hold promises toward the drivers of AMR, new treatment discovery, and optimal use of antimicrobials in veterinary medicine. It could include creating new diagnostic technologies, predicting AMR by the use of machine learning algorithms, and precision medicine that targets the treatment to specific animals (Tasho and Cho, 2016).
- International collaboration: The best way of solving the problem of AMR is by collaboration and coordination of various stakeholders at the international level, such as governments, industry, and civil society. Future research might include the examination of improving collaboration and coordination through such means as the development of international networks and partnerships that foster knowledge sharing, capacity building, and innovation. These may include: international research consortia, designing a joint funding mechanism, and forming cross-sectoral partnerships that drive different types of stakeholders into action (Zhu et al., 2013).

From a pharmacoeconomic perspective, opportunities for further research into the development of our understanding of the challenges and opportunities of antimicrobial resistance in veterinary medicine are vast.

These will allow for innovative solutions to this important problem to develop through better surveillance systems, intervention effectiveness evaluations, assessments of broader societal and environmental impact, examination of the potential of new technologies, and facilitation of international collaboration.

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