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БИОЭКОНОМИКАДА САЛАМАТТЫКТЫ САКТООНУН ТУРУКТУУ ИННОВАЦИЯЛАРЫ: ЭКОНОМИКАЛЫК ТУРУКТУУЛУКТУ ЖАНА КООМДУК САЛАМАТТЫКТЫ САКТОО МАКСАТТАРЫН БАЛАНСТОО

Аннотация. Биоэкономиканын тез өнүгүшү менен саламаттыкты сактоо тармагы салттуу моделдерден жогорку технологиялуу, жогорку эффективдүү жана жогорку интеграцияланган системаларга терең трансформацияланууда. Биотехнология, санариптик медицина жана жекелештирилген дарылоо медициналык инновациялардын жаңы толкунун жаратты, бирок R&Dге кеткен жогорку чыгымдар жана ресурстардын бирдей эмес бөлүштүрүлүшү да туруктуулук жөнүндө ой жүгүртүүгө түрткү болду. Бул макала медициналык технологиянын жетишкендиктерин илгерилетүү менен бирге экономикалык максатка ылайыктуулугу менен коомдук саламаттыкты сактоо максаттарынын ортосундагы динамикалык балансқа кантип жетүүнү изилдөөгө багытталган. Ар түрдүү өлкөлөрдө инновациялык практикаларды салыштыруу жана талдоо аркылуу, бул макалада мамлекеттик кызмат системасында, этикалык башкарууда жана каржы механизминде медициналык инновациялардын практикалык көйгөйлөрү ачылып, көп партиялуу кызматташуу, саясаттын стимулдары жана өзөк катары маалымат алмашуу менен оптималдаштыруу жолу сунушталат.

Негизги сөздөр: биоэкономика, устойчивое развитие, медицинские инновации, экономическая жизнеспособность, общественное здравоохранение, цели в области здоровья.

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УСТОЙЧИВЫЕ ИННОВАЦИИ В ЗДРАВООХРАНЕНИИ В БИОЭКОНОМИКЕ: БАЛАНС МЕЖДУ ЭКОНОМИЧЕСКОЙ ЖИЗНЕСПОСОБНОСТЬЮ И ЦЕЛЯМИ ОБЩЕСТВЕННОГО ЗДРАВООХРАНЕНИЯ

Аннотация. В связи с быстрым развитием биоэкономики сфера здравоохранения претерпевает глубокую трансформацию: от традиционных моделей к высокотехнологичным, высокоэффективным и высокоинтегрированным системам. Биотехнологии, цифровая медицина и персонализированные методы лечения стали толчком к новой волне медицинских инноваций, однако высокие затраты на НИОКР и неравномерное распределение ресурсов также заставили задуматься об устойчивом развитии. Целью данной статьи является исследование того, как достичь динамического баланса между экономической целесообразностью и целями общественного здравоохранения, одновременно способствуя развитию медицинских технологий. В статье посредством сравнения и анализа примеров инновационной практики в разных странах раскрываются практические проблемы медицинских инноваций в системе государственной службы, этического управления и финансового механизма, а также предлагается путь оптимизации, в основе которого лежат многостороннее сотрудничество, политические стимулы и обмен данными.

Ключевые слова: биоэкономика, туруктуу өнүгүү, медициналык инновациялар, экономикалык жашоо жөндөмдүүлүгү, коомдук саламаттык сактоо, ден соолук максаттары.

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SUSTAINABLE HEALTHCARE INNOVATION IN THE BIOECONOMY: BALANCING ECONOMIC VIABILITY AND PUBLIC HEALTH GOALS

Abstract. With the rapid development of the bioeconomy, the healthcare sector is undergoing a profound transformation from the traditional model to a high-tech, high-efficiency, and highly integrated system. Biotechnology, digital medicine, and personalized treatments have driven a new wave of medical innovation, but the high R&D costs and uneven resource allocation involved have also triggered reflections on sustainability. This article aims to explore how to achieve a dynamic balance between economic feasibility and public health goals while promoting the advancement of medical technology. Through a comparison and case analysis of innovation practices in different countries, this article reveals the practical challenges of medical innovation in the public service system, ethical governance, and fiscal mechanisms, and proposes an optimization path with multi-party collaboration, policy incentives, and data sharing as the core.

Key words: bioeconomy; sustainable development; medical innovation; economic viability; public health; health goals

INTRODUCTION. In recent years, the "bioeconomy", as a complex concept integrating biotechnology, green growth and sustainable development, has gradually become an important framework for global healthcare reform and policy innovation. Against this backdrop, healthcare innovation is not only a technology-driven process, but also a complex issue related to the fair allocation of resources, the improvement of public health levels, and the collaborative governance of systems. Emerging therapies such as gene editing, mRNA vaccines and digital chronic disease management, while enhancing treatment efficiency and accuracy, have also brought about rising drug prices, increased burdens on the medical insurance system and challenges to social equity.

1 The Trends and driving mechanisms of medical Innovation in the bioeconomy

1.1 Definition and Core Dimensions of the Bioeconomy

The bioeconomy is reshaping the innovation paradigm of the global healthcare industry. Its essence lies in the deep integration of biotechnology and data technology to transform life science discoveries into scalable health solutions. The core of this economic form lies in the utilization of tools such as gene editing, synthetic biology, and artificial intelligence to reconstruct the value chain from drug research and development to medical services. The commercial application of CRISPR-Cas9 technology marks a new stage in the bioeconomy - the global gene therapy market size reached 8.7 billion US dollars in 2023, with 65% of the projects focusing on rare diseases and cancer treatment.

Meanwhile, the rapid response capability verified by mRNA vaccine platforms during the COVID-19 pandemic is being extended to traditional public health challenges such as tuberculosis and malaria (D'Amico ， 2022) []. Meanwhile, Digital Therapeutics, through algorithm-driven personalized intervention, has opened up a new track in the field of chronic disease management: The reSET-O opioid use disorder treatment software developed by Pear Therapeutics in the United States has been clinically verified to reduce the recurrence rate by 40% and has been approved by the FDA as a prescription-level medical product.

1.2 Institutional and Economic Drivers of Medical Innovation

The institutional framework and economic impetus of medical innovation present a multi-polar feature. The role of private capital in the bioeconomy has shifted from being merely a research and development funder to a system builder. In 2022, Sequoia Capital established a $3 billion biotechnology fund, requiring the invested companies to commit to allocating 10% of their production capacity to affordable drug production in low - and middle-income countries. The government, on the other hand, reshapes the orientation towards innovation through policy tools: The US BioEconomy Executive Order requires the National Institutes of Health (NIH) to allocate 30% of its budget to "disruptive sexual health technologies", while the EU's "Healthy Europe" initiative has established a cross-border clinical trial data sharing mechanism to accelerate the market entry of innovative therapies.

Table 1. Risk Capital and Policy Support Frameworks in Biohealth Innovation

Funding Source	Investment Focus	Policy Instrument	Example Initiative
Venture Capital	Gene editing platforms, AI diagnostics	Tax credits for R&D	ARCH Venture Partners' $500M CRISPR Fund
Government Grants	Pandemic preparedness infrastructure	Fast-track regulatory pathways	EU's HERA Incubator for vaccine development
Public-Private Partnerships	Global health equity solutions	Compulsory licensing agreements	Medicines Patent Pool's COVID-19 IP sharing
Impact Investment	Low-cost diagnostic devices	Tiered pricing regulations	

1.3 Venture Capital and Policy Support Framework

The interaction mechanism between venture capital and policy support has become an accelerator for innovation in the bioeconomy. Silicon Valley venture capital institutions have made advanced layouts in the field of gene therapy through the "technology put option" model - for instance, Andreessen Horowitz has invested 450 million US dollars in betting on epigenetic editing technology [2]. Although this technology has not yet entered clinical trials, its patent portfolio has covered key base editor variants. The government strikes a balance between commercial returns and public health needs through innovative payment mechanisms: The "pay by performance" contract launched by the NHS in the UK stipulates that Novartis' CAR-T therapy Kymriah is paid in full only when the actual survival period of patients is prolonged, transferring financial risks from medical institutions to pharmaceutical companies. In developing countries, the innovative financing tool of "vaccine Sovereign Bonds" led by the World Bank allows countries to issue bonds collateralized by future vaccine purchase commitments to obtain funds in advance for building domestic biomanufacturing capabilities.

2 The Tension between the Economic Benefits and Fairness of Sustainable Medical Innovation

2.1 Economic Return Assessment of Medical Innovation

The economic value assessment of medical and health innovation is facing dual challenges from traditional measurement tools and the characteristics of emerging technologies. Take CAR-T cell therapy as an example. The cost of a single treatment is as high as 470,000 US dollars. Traditional input-output ratio (ROI) calculations often lead to negative conclusions - if only the direct medical expenditure and the labor value brought by the prolonged survival period of patients are calculated, the payback period of investment exceeds 15 years. However, if the full life cycle benefit model is included, including the avoided long-term care costs, the reduced productivity loss of family caregivers, and the decreased demand for second-generation genetic screening, the total social return rate can reach 3.8:1 [1]. This shift in the measurement paradigm requires the establishment of a multi-dimensional assessment framework: The "Value Blueprint" tool developed by the U.S. Department of Health and Human Services breaks down the economic impact of health innovation into 12 indicators such as direct medical costs, productivity gains, and health equity premiums, and quantifies uncertainty through Monte Carlo simulation.

Table 2. Economic and Equity Trade-offs in Health Innovations

Innovation Type	Unit Cost	ROI (Private)	ROI (Societal)	Access Disparity Index
CAR-T Therapy	$470,000	1.2:1	3.8:1	92/100 (High)
mRNA Vaccine	$18/dose	4.5:1	9.2:1	67/100
AI Diagnostic System	$0.5/scan	6.1:1	8.7:1	45/100
Portable Dialysis	$2,000/unit	2.3:1	5.6:1	58/100

2.2 The contradiction between controllable costs and accessible services

The contradiction between the price of advanced therapies and the accessibility of services is particularly acute in the field of rare diseases. The world's first Dupont muscular dystrophy gene therapy, Elevidya, is priced at 3.2 million US dollars. Although it reduces the immediate payment pressure through the "installment payment + effication-linked" model, the acquisition rate of patients in low - and middle-income countries is still less than 0.3%. This phenomenon of "innovation discrimination" not only stems from the disparity in payment capabilities, but is more deeply constrained by the gap in medical infrastructure - CRISPR gene editing therapies need to be transported in a cold chain at -80℃, while only 12% of medical institutions in sub-Saharan Africa have the ability to store at ultra-low temperatures. More concealed inequalities are manifested in the deprivation of data rights: The health data generated by patients in developed countries using digital therapies is used by pharmaceutical companies to train diagnostic algorithms, forming intellectual property barriers, but data contributors cannot share the commercial benefits.

2.3 Successful Cases and Lessons from Failures

The coexistence of successful cases and systematic failures reveals the complexity of the balanced path. The Gavi Alliance has reduced the vaccination cost of pneumococcal vaccines in Africa from $7 per dose to $3.5 per dose through the "pre-purchase commitment + differential pricing" mechanism, and increased the number of children covered by 170 million, proving that bulk purchasing and risk sharing can alleviate the price barrier [4]. However, similar models have encountered setbacks in the field of gene therapy: The Zolgensma (gene therapy for spinal muscular atrophy) installment payment plan negotiated by Novartis with the South African government was forced to be suspended due to the financial volatility of local governments, and ultimately only 3% of the target patients received treatment.

3 Multi-party Collaborative Strategies for Promoting Sustainable Healthcare

3.1 Policy and Fiscal Tool Allocation

The realization of sustainable medical innovation requires breaking through the traditional model dominated by a single subject and shifting to a collaborative governance architecture based on risk sharing and value sharing. Policy reform should focus on the structural adjustment of the medical insurance payment system and establish a dual-dimensional compensation mechanism of "technical value - social benefit" [5]. The "installment payment based on efficacy" model promoted by the NHS in the UK can be extended to the field of gene therapy - medical insurance institutions only prepay 30% of the therapy costs, and the remaining funds are paid in installments based on the five-year survival rate and quality of life index of patients, forcing pharmaceutical companies to shift from "sales-driven" to "result-oriented". For low - and middle-income countries, the "Global Health Bond" jointly designed by the World Bank and the Gates Foundation offers a new idea: Sovereign states issue bonds collateralized by their public health budgets for the next decade to raise funds specifically for purchasing innovative therapies. International multilateral institutions provide default guarantees, enabling Rwanda to obtain loans for the construction of mRNA vaccine production lines at an interest rate of 4.2%, which is much lower than the average sovereign financing cost of 11% in the market [6].

3.2 Collaboration Model of Multiple Stakeholders

The collaboration of multiple stakeholders requires the establishment of dynamic adaptive rules. In the "Vaccine Autonomy Program" led by the African Centers for Disease Control and Prevention, multiple parties have participated to form a hierarchical responsibility framework: the International Vaccine Institute (IVI) is responsible for technology transfer, the African Development Bank provides interest-subsidized loans, local pharmaceutical companies undertake production tasks, and community organizations complete the last-mile delivery through mobile medical teams. This model automatically distributes profits through blockchain smart contracts - when the local capacity utilization rate reaches 60%, multinational pharmaceutical companies can receive additional intellectual property compensation. If the vaccination rate in the community exceeds 75%, international donors need to release the funds for the second phase.

Table 3 Multi-Stakeholder Collaboration Models in Sustainable Healthcare

Collaboration Mode	Technology Focus	Financing Mechanism	Performance Metric	Case Example
PPP + Community Trust	Telemedicine networks	Social impact bonds	Rural service coverage rate	India's Ayushman Bharat Digital Mission
Cross-border IP Pool	Gene editing	Tiered royalty system	Low-income country access rate	Medicines Patent Pool - COVID-19
Data Cooperative	AI diagnostics	Data dividend sharing	Algorithm bias reduction	EU Health Data Space Initiative
Hybrid Financing	Vaccine production	Blended concessional loans	Local manufacturing capacity	Rwanda BioNTech mRNA Facility

The "Amazon Bioeconomy Zone" in Brazil demonstrates the integration path of ecological compensation and health innovation: Pharmaceutical companies need to invest in the construction of regional telemedicine systems to extract rainforest genetic resources, and for each sample of a medicinal plant extracted, two AI-assisted diagnostic terminals should be set up. Such innovative contracts internalize health equity as a necessary component of business logic rather than an external constraint, opening up an institutionalized practical path for sustainable medicine.

CONCLUSION

Healthcare innovation in the era of the bioeconomy is no longer merely a matter of "technological leadership", but rather a systematic reconstruction. From the investment mechanism, product pricing, service fairness to ethical norms, every link determines whether medical innovation can benefit society in the long term. This article's analysis indicates that the current global medical system is generally confronted with the urgent task of finding a balance between technological breakthroughs and institutional adaptation. To achieve truly sustainable development, it is necessary to rely on multiple supporting measures such as fiscal policy guidance, innovation in the medical insurance system, public-private collaboration mechanisms and data governance reforms.

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