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• Perspective •

The "Bright-X Line": bridging geographical ophthalmic disparities in China through digital new quality productive forces

Yuxuan Wu (吴雨璇)[1#], Zhenjun Tu (涂镇军)[1,2#], Zizheng Cao (曹子正)[1#], Wei Xiao (肖薇)[1], Nathan Congdon[1,3,4], Xiaohang Wu (吴晓航)[1,5], Haotian Lin (林浩添)[1,5,6]

1. State Key Laboratory of Ophthalmology, Zhongshan Ophthalmic Center, Sun Yat-sen University, Guangdong Provincial Key Laboratory of Ophthalmology and Vision Science, Guangdong Provincial Clinical Research Center for Ocular Diseases, Guangzhou 510060, China.
2. School of Biomedical Engineering, Sun Yat-sen University, Shenzhen 518107, China.
3. Queen's University Belfast, Belfast BT7 1NN, United Kingdom.
4. Orbis International, New York, NY 10006, USA.
5. Hainan Eye Hospital and Key Laboratory of Ophthalmology, Zhongshan Ophthalmic Center, Sun Yat-sen University, Haikou 570311, China.
6. Centre for Precision Medicine and Department of Genetics and Biomedical Informatics, Zhongshan School of Medicine, Sun Yat-sen University, Guangzhou 510080, China.

Abstract: The uneven distribution of population and resources across China has long been delineated by the Hu Huanyong Line, a diagonal connecting Heihe to Tengchong, yet a comparable divide in eye health remains conceptually undefined. Here, we propose the "Bright-X Line" as a clinical and economic frontier that demarcates the divide in ophthalmic capacity between the densely populated southeast and the sparsely populated northwest. National registry data reveal a steep gradient across this boundary: cataract surgical rates vary up to fivefold between provinces, and ophthalmic workforce density differs threefold between the east and the west. Furthermore, high-altitude regions in the west bear a disproportionately heavy burden of early-onset cataract, pterygium, and other blinding eye diseases. The divide persists because eye care remains anchored in a fixed, facility-based model.

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Co-first authors
These authors contributed equally
Corresponding authors: Xiaohang Wu, E-mail: wxhang@mail2.sysu.edu.cn;
Haotian Lin, E-mail: linht5@mail.sysu.edu.cn.

Full Text

Specialists, along with advanced diagnostic and surgical equipment, are heavily concentrated in eastern cities, and fixed facilities cannot be sustainably replicated in areas where sparse populations render them economically unviable. To address this, we propose leveraging digital New Quality Productive Forces (NQPF), including AI-enabled autonomous diagnostics (ChatZOC), 5G-enabled teleoperated robotic microsurgery, and mobile intelligent screening units (Vehicle-based Intelligent Screening Station, VISION), to decouple expert ophthalmic care from fixed infrastructure and immobile personnel. Rooted in health economics and systems innovation, this conceptual framework provides the theoretical foundation for a future empirical study on the cost-effectiveness of dynamically deployed AI-driven screening. Ultimately, it offers a scalable model for promoting ophthalmic equity in other regions that face comparable geographic asymmetries in eye-care resources.

Keywords: Hu Huanyong line; Bright-X Line; ophthalmic resource allocation; new quality productive forces; mobile AI screening

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Background

Visual impairment affects 2.2 billion people worldwide, with low- and middle-income countries (LMICs) bearing the heaviest burden.[1] China, the world's largest upper-middle-income country, faces an unprecedented convergence of rapid population aging and a rising prevalence of age-related blinding eye diseases, including cataract, glaucoma, diabetic retinopathy (DR), and age-related macular degeneration (AMD), etc.[2] Yet, the burden is far from uniform. The Hu Huanyong Line, proposed by geographer Hu Huanyong in 1935, runs from the northeastern city of Heihe to the southwestern city of Tengchong. It divides China into a southeastern region containing roughly 96% of the population on 36% of the landmass, and a northwest region holding just 4% of the population on the remaining 64%.[3] This demographic distribution has remained remarkably stable for nearly nine decades.[4] Originally conceived to map human settlement patterns, the line now mirrors profound inequalities in contemporary healthcare delivery, with eye care presenting one of the starkest examples. The coastal southeast concentrates the specialist workforce and advanced diagnostic technologies, whereas the sparsely populated, high-altitude northwest, where intense ultraviolet exposure exacerbates the burden of eye diseases like cataract and pterygium, suffers from the lowest density of eye care services.[5-6]

To render this geographic visible and actionable, we introduce the concept of the "Bright-X Line" in China. In this framework, "Bright" represents the universal goal of preserving sight and achieving eye health equity; "X" symbolizes the intersection where digital innovation, mobile healthcare delivery, and New Quality Productive Forces (NQPF) converge to transcend static, geography-bound service models. The Bright-X Line is not merely a cartographic restatement of the Hu Huanyong Line; rather, it is a dynamic conceptual boundary that highlights the gap between ophthalmic capacity and unmet need and contrasts fixed infrastructure from intelligent mobility. Ultimately, it provides a roadmap for shifting from entrenched health inequity toward universal eye care.

The Bright-X Line: a clinical and economic frontier

The Bright-X Line translates the geographical logic of the Hu Huanyong Line into a clinical and health-economic reality. While the Hu Huanyong Line maps population density, the Bright-X Line maps ophthalmic capacity, encompassing the density of skilled personnel, surgical volume, and diagnostic infrastructure, and consequently visual outcomes. Rather than a rigid cartographic boundary, it represents a transition zone across which eye-care resources decline steeply from east to west, as unmet need rises in the opposite direction.

National cataract surgical rate (CSR) data illustrate the magnitude of this divide. In 2017, the CSR reached 4,251 per million population in Shanghai and 2,051 in Jiangsu, compared to just 793 in Qinghai, 807 in Ningxia, and 1,342 in Xinjiang, representing up to fivefold disparity. Spatiotemporal analyses show that cataract surgery activity has increasingly clustered in the eastern coastal provinces, while low-rate clusters persist in the northwestern provinces of Xinjiang, Qinghai, and Gansu.[7] Human resources mirror this surgical gradient: within specialized ophthalmic institutions, the density of physicians was 0.06 per 10,000 population in the eastern region versus only 0.02 in the west. Furthermore, the proportion of ophthalmologists holding advanced medical degrees was 13% in the east, compared to just 2% in the west.[8]

The local disease spectrum further exacerbates this divide. High-altitude regions with intense ultraviolet exposure west of the line bear a disproportionate burden of early-onset cataract and pterygium. For instance, population-based surveys in high-altitude Tibetan communities reported a cataract prevalence of 13.8% among individuals aged 50 years and older,[9] pterygium affecting 14.5% of adults aged 40 years and older,[5] and a prevalence of cataract blindness among Tibetans more than double that of the Han Chinese (2.28% vs 1.01%).[10] Additionally, the burden of DR is heavier in rural than in urban populations across China, yet systematic screening coverage remains inadequate.[11] While this east-west gradient is pronounced, it is not absolute. Sustained targeted assistance has increased cataract surgical volume in certain western localities, whereas some central provinces continue to lag. This pattern is instructive rather than contradictory; it demonstrates that when ophthalmic capacity is strategically deployed, surgical output increases regardless of terrain. This is the exact principle underpinning the mobile and teleoperated delivery models we propose.

The Bright-X Line thus serves as both a capacity frontier and an equity frontier. It defines a threshold beyond which conventional, hospital-centric eye care fails to deliver acceptable visual outcomes. Addressing this disparity demands not merely incremental improvements, but a structural reconfiguration of how ophthalmic expertise is generated and delivered.

The immobility of ophthalmic care: why fixed infrastructure fails

Despite massive investment in transportation infrastructure that has significantly improved physical access to urban specialist centers, the binding constraint on eye-care access is no longer patient mobility.[12] Rather, it is the immobility of the core production factors of ophthalmic care, specialized personnel, advanced equipment, and clinical expertise, which cannot be easily relocated to where the patients are.

This immobility stems from three fundamental barriers. First, specialized personnel are largely immobile. Board-certified ophthalmologists remain overwhelmingly concentrated in eastern cities, anchored by economic incentives, professional development opportunities, and lifestyle preferences.[8] Second, advanced equipment cannot be ubiquitously deployed. Modalities such as optical coherence tomography (OCT) and laser systems are highly capital-intensive and require dedicated technical support; deploying them at every township health center west of the Bright-X Line is neither financially nor operationally feasible.[13] Third, clinical expertise has historically been inseparable from the specialists and machines that generate it. Consequently, the primary bottleneck is not the speed at which a patient can reach a hospital, but rather the inability of the hospital's core capacity to reach the patient. In this context, the "last mile" of ophthalmic care is not a barrier of physical distance, but the immobility of production capacity.

Digital technology offers a pathway to overcome this deadlock, as artificial intelligence (AI) can encode clinical expertise into software that, in principle, is replicable at a negligible marginal cost.[14] However, if that software is deployed via fixed screening stations, it inherits the same structural cost inefficiencies that constrain fixed hardware. In the densely populated east, a fixed station achieves high patient throughput, allowing capital costs to be amortized over a large volume of screenings. Conversely, in the vast, sparsely populated west, the same station serves a significantly smaller catchment area, driving the fixed cost per screening to prohibitive levels. In such regions, mobile deployment, which carries AI diagnostics, imaging equipment, and 5G connectivity to remote villages on a rotating schedule, offers superior economic viability compared to fixed installations. Ultimately, fixed and mobile models each have their optimal deployment environments. The choice between them is not binary, but rather a context-dependent decision shaped by local population density, primary healthcare coverage, and government's willingness to pay.[15]

Digital New Quality Productive Forces as the bridge

The answer lies in digital NQPF, a paradigm shift in which technological breakthroughs, data as a factor of production, and deep cross-sector integration together drive a step-change in productivity.[16] In ophthalmology, several converging streams have now reached deployable maturity.

AI-enabled autonomous diagnostics (ChatZOC)

AI-based screening for major blinding eye diseases has entered routine use, but most implementations remain tethered to ophthalmic imaging devices installed at the primary-care level. To eliminate this dependence on dedicated hardware, we developed ChatZOC, an ophthalmology-specific large language model that performs screening with smartphone. Users describe their symptoms and upload photographs of the eye taken with the phone; the model interprets the images, guides further questioning, and returns a preliminary diagnosis with referral advice.[17] Because it runs on devices people already own, ChatZOC carries virtually zero marginal equipment cost and sidesteps the fixed-capital constraint that limits stationary screening stations in sparsely populated regions. In Xinjiang, a ChatZOC-based digital-doctor application screened over 30,000 residents within two months; by December 2025, the system had recorded more than 560,000 interactions across eight languages, with pilot deployment underway in the Maldives.

5G-enabled teleoperated robotic microsurgery

Where AI transmits diagnostic decisions, 5G transmits the surgeon's hand. We developed a teleoperated robotic system for remote intraocular microsurgery that combines a hybrid parallel-serial micromanipulator, tremor filtering, and motion scaling to achieve micrometer-level positional accuracy over a 5G network. In a randomized animal study, robot-assisted subretinal injection raised first-attempt success from 37.5% to 91.7% and reduced intraoperative complications from 54.2% to 8.3%, enabling junior surgeons to perform at an expert-level.[18-19] In November 2025, the platform was used for the first reported human remote robotic intraocular procedure: a subretinal injection delivered from Guangzhou to a patient in Urumqi, over 4,000 km away, completed in under seven minutes.[20] Because it is the surgeon's movements, rather than the surgeon, that cross the Bright-X Line, a single specialist can deliver expert surgery across the sparsely populated west in a single day.[19]

Mobile intelligent screening units: the “VISION” model

AI and 5G still require a physical point of contact with the patient. To reach populations too dispersed or too impoverished to travel even to a county hospital, we developed the Vehicle-based Intelligent Screening Station (VISION), a "hospital-on-wheels" that integrates AI-driven multiple disease diagnostics, 5G connectivity, and self-contained power. A single VISION unit screens 150–200 people per day for multiple eye diseases, including cataract, DR, glaucoma, AMD, and refractive error, etc., generating immediate AI reports and providing referable advice. Building on this screening platform, we developed the second-generation Mobile Eye Hospital, which adds on-board treatment functions, including anterior-segment laser, fundus laser, and dry eye therapy, allowing common eye diseases to be screened and treated in a single visit.[21] To date, VISION has been deployed across 33 provinces and 182 urban and rural regions in China, providing eye health screening for over 420,000 individuals.

Together, these three streams transform ophthalmic care from a fixed, hospital-bound service into a mobile one that can be redeployed according to local geography, infrastructure and need.

Towards precision deployment: the need for dynamic economic evidence

Technological potential, however, does not automatically translate into population-level health gains. Policymakers face a strategic choice: invest in fixed AI-equipped screening stations in county hospitals and urban community centers, or fund fleets of mobile VISION-type units circulating through rural and pastoral areas. This is not a static choice but a dynamic, context-dependent decision that varies with local demographic structure, primary healthcare coverage and willingness to pay.[15]

Fixed AI screening is continuously available, integrates into routine chronic-disease management, and carries low marginal operating costs once installed. It is therefore cost-effective in dense urban districts, where high fixed capital is amortized over a large volume of screenings. But in sparsely populated western counties, a fixed machine serves a far smaller catchment, driving the cost per screen to potentially unacceptable levels. There, a mobile unit covering multiple villages on a rotating schedule achieves higher utilization and greater equity per yuan spent.

The policy implication is a graded, precision-deployment strategy rather than a nationally uniform investment. Remote and resource-limited areas should receive priority for mobile VISION units, with screening-identified surgical backlogs referred onward through the regional tele-surgical network; areas with baseline equipment in place should receive fixed AI screening with referral guidance. A forthcoming empirical study from our team will validate these thresholds with primary cost and effectiveness data collected from a multisite implementation trial.

Conclusions and future perspectives

The Bright-X Line crystallizes a long-recognized but conceptually unnamed reality: the geography of ophthalmic health in China follows the population gradient first described by the Hu Huanyong Line nearly a century ago. The divide is quantifiable, an up to fivefold gap in cataract surgical rates, a threefold differential in ophthalmic workforce density, a more than sixfold gap in the proportion of degree-holding ophthalmic physicians, and a disease spectrum that disproportionately burdens those least able to access care. Physical infrastructure, though transformative, has proven insufficient because it moves patients rather than the production factors of ophthalmic care; the critical bottleneck is no longer the road to the hospital but the immobility of the hospital's core cognitive and surgical capacity.

Digital NQPF is positioned to relieve precisely this bottleneck. AI delivers expert-level screening at the point of contact, on dedicated imaging devices and through conversational large language models such as ChatZOC, on the smartphones people already carry. Mobile screening units like VISION weave these capabilities into a roving platform that actively seeks out populations that stationary facilities rarely reach. And where screening uncovers disease requiring surgery, 5G-enabled teleoperated robotic microsurgery allows a specialist to deliver the procedure across the line, so that complex intraocular operations no longer depend on the patient's proximity to an operating theatre. Together, these three streams decouple high-quality eye care from fixed capital and immobile human resources, reanchoring it in data, connectivity, and intelligent mobility. The ground-based network is no longer ground-bound. An ophthalmic flying hospital already carries these capabilities into the air, while satellite and maritime platforms, and the logistics that would integrate all four layers into a full "air-ground-space-sea" network, represent the next frontier.

However, technology alone will not close the gap. Whether traditional face-to-face screening, fixed AI screening, or mobile intelligent units represent the optimal investment will vary with local conditions, including disease prevalence, primary healthcare coverage, and local willingness-to-pay. There is no one-size-fits-all answer. Determining the optimal strategy under different resource-allocation scenarios therefore requires dynamic cost-effectiveness analysis, and this is the direction in which our current work is moving. The immediate next step is empirical validation, with a multisite implementation study underway across provinces straddling the Bright-X Line. The impact of these interventions on patient-reported outcomes and long-term visual function trajectories must also be tracked.

Looking further ahead, we see the Bright-X Line as a dynamic frontier that can and should be dissolved. As intelligent screening becomes embedded in primary care and remote surgical mentoring networks mature, the "air-ground-space-sea" vision will move closer to practice: drone logistics will connect last-mile villages, flying hospital rotations bring surgery to remote and island communities, satellite links will supply connectivity where terrestrial networks are absent, and seagoing medical and research vessels will reach coastal and island populations. As these components mature, the line's defining gradient will progressively flatten. The ultimate goal is not to erase geography, since China's vast western expanses will always exist, but to erase the association between geography and preventable blindness. China's experience holds lessons far beyond its borders: many LMICs in South Asia, sub-Saharan Africa, and Latin America face analogous internal asymmetries between capital cities and remote provinces, and the combination of AI, telemedicine and mobile delivery platforms is not luxury technology but a context-adaptive, leapfrog strategy that bypasses the slow process of training and deploying a specialist workforce. The "Bright" in Bright-X is not just a vision for China. It is a vision for a world in which geography no longer determines who can see.

Correction notice

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Author contributions

(I) Conception and design: XH Wu and HT Lin;

(II) Administrative support: W Xiao, XH Wu, and HT Lin;

(III) Provision of study materials or patients: YX Wu and ZZ Cao;

(IV) Collection and assembly of data: ZJ Tu and W Xiao;

(V) Data analysis and interpretation: YX Wu, ZJ Tu, and N Congdon;

(VI) Manuscript writing: All authors;

(VII) Final approval of manuscript: All authors.

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Conflict of Interests

None of the authors has any conflicts of interest to disclose. All authors have declared in the completed the ICMJE uniform disclosure form.

Patient consent for publication

None

Ethics approval and consent to participate

None

Data availability statement

None

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Declaration of generative AI use

No generative artificial intelligence (GenAI) tools were used in the preparation of this manuscript.

References

1. World Health Organization. World report on vision. (2019-10-08). https://www.who.int/publications/i/item/9789241516570.
2. Xu T, Wang B, Liu H, et al. Prevalence and causes of vision loss in China from 1990 to 2019: findings from the Global Burden of Disease Study 2019. Lancet Public Health. 2020, 5(12): e682-e691. DOI: 10.1016/S2468-2667(20)30254-1.
3. Hu HY. The Distribution of population in China, with statistics and maps. Acta Geogr Sin. 1935, 2(2): 33-74. DOI: 10.11821/xb193502002.
4. Qi W, Liu S, Liu Z. The novel pattern and driving factors of population spatial distribution on both sides of the "Hu Line" based on seventh census in China. Acta Geogr Sin. 2022, 77(12): 3023-3040. DOI: 10.11821/dlxb202212006.
5. Lu P, Chen X, Kang Y, et al. Pterygium in tibetans: a population-based study in China. Clin Exp Ophthalmol. 2007, 35(9): 828-833. DOI: 10.1111/j.1442-9071.2007.01630.x.
6. An L, Jan CL, Feng J, et al. Inequity in access: cataract surgery throughput of Chinese ophthalmologists from the China national eye care capacity and resource survey. Ophthalmic Epidemiol. 2020, 27(1): 29-38. DOI: 10.1080/09286586.2019.1678654.
7. Wu X, Shi X, Li H, et al. Temporal and spatial characteristics of cataract surgery rates in China. Risk Manag Healthc P. 2021, 14: 3551-3561. DOI: 10.2147/RMHP.S317547.
8. Zhan L, Safaya N, Erkou H, et al. A comparative analysis on human resources among the specialized ophthalmic medical institutions in China. Hum Resour Health. 2020, 18(1): 29. DOI: 10.1186/s12960-020-00471-1.
9. Bassett KL, Noertjojo K, Liu L, et al. Cataract surgical coverage and outcome in the Tibet Autonomous Region of China. Br J Ophthalmol. 2005, 89(1): 5-9. DOI: 10.1136/bjo.2004.048744.
10. Jiachu D, Jin L, Jiang F, et al. Prevalence and service assessment of cataract in Tibetan areas of Sichuan Province, China: population-based study. BMJ Open. 2019, 9(11): e031337. DOI: 10.1136/bmjopen-2019-031337.
11. Liu L, Wu X, Liu L, et al. Prevalence of diabetic retinopathy in mainland China: a meta-analysis. PLoS One. 2012, 7(9): e45264. DOI: 10.1371/journal.pone.0045264.
12. Lawrence M, Bullock R, Liu Z. China's High-Speed Rail Development. Washington, DC: World Bank, 2019. DOI: 10.1596/978-1-4648-1425-9.
13. World Health Organization. Medical devices: managing the mismatch: an outcome of the priority medical devices project. (2010-07-11) https://www.who.int/publications/i/item/9789241564045.
14. Wu X, Wu Y, Tu Z, et al. Cost-effectiveness and cost-utility of a digital technology-driven hierarchical healthcare screening pattern in China. Nat Commun. 2024, 15: 3650. DOI: 10.1038/s41467-024-47211-w.
15. Rachapelle S, Legood R, Alavi Y, et al. The cost-utility of telemedicine to screen for diabetic retinopathy in India. Ophthalmology. 2013, 120(3): 566-573. DOI: 10.1016/j.ophtha.2012.09.002.
16. Xi J. Developing new quality productive forces is an inherent requirement and important focus for promoting high-quality development. Qiushi, 2024, 11.
17. Luo MJ, Pang J, Bi S, et al. Development and evaluation of a retrieval-augmented large language model framework

for ophthalmology. JAMA Ophthalmol. 2024, 142(9): 798-805. DOI: 10.1001/jamaophthalmol.2024.2513.

18. Lian Z, Xu A, Li Y, et al. Robotic augmentation of surgical skills in subretinal injection: a novel semiautomated system. Int J Surg, 2025: 6619-6628. DOI: 10.1097/JS9.0000000000004501.
19. Xu A, Lian Z, Chen W, et al. Development of teleoperated robotic system for remote intraocular microsurgery. Adv Sci. 2026, 13(6): e09849. DOI: 10.1002/advs.202509849.
20. Huaxia. Chinese medical team performs remote 5G robotic eye surgery over 4, 000 km away. Xinhua News. (2025-11-03) https://www.who.int/publications/i/item/9789241564045.
21. Xiao W, Iao W, Lin H. From barn lanterns to the 5G Intelligent Ophthalmic Cruiser: The perspective of artificial intelligence and digital technologies on the modality and efficiency of blindness prevention in China. Eye Science. 2024, 1(1): 1-6. DOI: 10.12419/es23122101.