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Economic valuation of open research data: A conceptual framework and methodological approach

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Abstract

The economic significance of open research data is widely acknowledged, yet its quantification remains challenging. This paper presents an effective valuation instrument to help stakeholders understand and evaluate the economic benefits of open research data. By conducting a scoping review and prioritizing user engagement, this study introduces a comprehensive conceptual framework for the economic valuation of open research data. The valuation is based on economic value and willingness to pay, employing the Contingent Valuation Method (CVM). It incorporates per-use models (view, download, and request) and periodic subscription models (monthly and yearly). An empirical survey was conducted at the National Basic Science Data Center (NBSDC) in China to verify this framework. Both pricing models, comprising five distinct tactics, was supported by surveyed users. Measuring economic value by views and by year was preferred, while willingness to pay by downloads and by year was considered more reasonable. Overall, the most applicable valuation approach is on a yearly basis. Through this case study at NBSDC, specific pricing tactics were identified, and the total economic value and users' willingness to pay were assessed. This study is arguably the first to establish a conceptual framework with pricing tactics from a user perspective. This methodological approach for economic valuation of open research data provides evidence and tools for future research, policy formulation, and resource allocation in the context of open science and innovation.

Keywords: open research data; economic valuation; conceptual framework; contingent valuation method (CVM); National Basic Science Data Center (NBSDC).

1. Introduction

In recent years, the production and dissemination of research data have grown dramatically, driven by advances in technology, increased funding for research, and a growing movement toward open science. Research data, defined as factual records (numerical scores, textual records, images, and sounds) used as primary sources for scientific research, which are accepted in the scientific community as necessary to validate research findings (Organisation for Economic Co-operation and Development [OECD] 2007). 'Open research data' refers to research data that is either fully open access to users or accessible through reasonable means, such as free registration and online application.

Open access to research data has led to numerous claimed benefits across scientific, technological, economic, social, cultural, and educational domains (Chan et al. 2002; International Federation of Library Associations and Institutions [IFLA] 2011; Office of Science and Technology Policy [OSTP] 2013; Tu 2021a; United Nations Educational, Scientific and Cultural Organization [UNESCO] 2021). Specifically, open research data has advanced scientific research, enhanced transparency and reproducibility, catalyzed new collaborations (Molloy 2011; Pasquetto, Borgman and Wofford 2019), and benefited broader communities and society (Research Information Network [RIN] and Joint Information Systems Committee [JISC] 2011; Schmidt, Gemeinholzer and Treloar 2016). Consequently, open research data holds significant value for various stakeholders, including funders, publishers, scientists, users, industries, government departments, hospitals, and the wider society (Tu and Yang 2020).

Despite the evident benefits of open research data, the expenses incurred in the production and management of this data can be considerable, and the economic worth of such data often remains ambiguous (Mueller-Langer and Andreoli-Versbach 2018). This has spurred a growing interest in the economic evaluation of open research data, including assessment of return on investment (ROI), total economic value, contribution to GDP, use value, and willingness to pay for open research data within datasets, data centers, institutions, countries, or regions. (Beagrie and Houghton 2014; Houghton and Gruen 2014; European Commission 2015; Open Data Institute 2016; Sanderson, Reeson and Box 2017; European Commission 2018; Zhu et al. 2019).

Prevailing economic valuations predominantly rely on market-based or institution-based statistics and evidence, differing from the approach of open research data centers and repositories, which focuses more on user-based metrics, such as data usage and data citation. In this context, users emerge as the principal stakeholders in open research data, playing a crucial role in realizing its potential value. Users engage with open research data by participating in scientific research and various socio-economic activities, and utilizing it in myriad ways, ultimately unlocking its value.

Furthermore, most existing economic valuations emphasize presenting measurement results but lack a comprehensive conceptual framework that encompasses theories, methodologies, pricing tactics, and implementation processes.

Consequently, stakeholders can only refer to the measurement results specific to particular datasets, data centers, institutions, countries, or regions, finding it challenging to apply these results to their contexts. In particular, these economic valuations often consider open research data as a whole within their respective contexts, without incorporating specific pricing strategies that would enable broader applicability in different contexts.

This study aims to address these gaps and answer three specific questions:

1) What processes and elements are involved in the economic valuation of open research data from a user perspective?
2) What potential pricing tactic models for open research data are applicable in various contexts?
3) What possible conceptual framework and/or methodological approach can assist stakeholders in better understanding and implementing economic valuation?

2. Related work

2.1 Theories and methodologies related to economic valuation

In the context of open data, prevalent theories applied in economic valuation include welfare economics and public goods theory. Welfare economics focuses on the optimal allocation of resources to maximize societal well-being, achieved through the enhancement of utility or satisfaction derived from consumption and various other economic activities (Waglé and Koirala 2014; Backhouse, Baujard and Nishizawa 2020). Applying welfare economics to the economic valuation of open research data involves assessing the impact of widespread data access on individual and societal well-being. Specifically, by using utility theory, researchers can measure the utility changes for individuals and society resulting from the use of open research data. Additionally, consumer surplus analysis and contingent valuation allow the evaluation of the users' willingness to pay for data access and the actual cost of generating these data, providing insight into the economic value. Considering total welfare enables the examination of the overall societal benefits derived from the extensive utilization of open research data (Cohen et al. 2016; Martens 2020).

Public goods theory elucidates why goods with the rigorously defined characteristics of publicness cannot be produced efficiently by the private sector, creating a market failure that implies a role for government and other public sectors in the production of those goods (Oakland 1987; Holcombe 2000). This theory is practical as open research data is acknowledged as a global public good by entities such as UNESCO (2021) and is considered essential for digital cooperation and key to achieving sustainable development goals (United Nations 2021; Iglesias 2022). Like typical public goods, open research data exhibits characteristics of non-excludability and non-rivalrous consumption, thereby presenting the potential challenge of the free rider problem in economic valuation (Buytaert 2019). Moreover, the economic and societal advantages arising from user access and utilization of open research data play a crucial role in enhancing its value chain (Open Data Watch 2018). The economic valuation of public goods involves various methods, such as market-based approaches, alternative cost methods, and non-market methods, with the choice contingent upon the specific study context, the nature of the public good, and data availability.

Beyond theories, commonly employed methodologies in economic valuation include return on investment (ROI) (Whicher, Raulik-Murphy and Cawood 2011), cost-benefit analysis (CBA) (Cellini and Kee 2015), consumer surplus (Cohen et al. 2016), contingent valuation method (CVM) (Venkatachalam 2004), investment value and use value (Beagrie and Houghton 2014), and total economic value (European Commission 2018), see Table 1. These methodologies offer practical techniques to address diverse economic valuation requirements, each with strengths, challenges, and application conditions. For example, Beagrie and Houghton (2014) evaluated the rate of ROI for three data centers in the United Kingdom (UK), which necessitated access to both investment and return data—a process that can be challenging due to data collection difficulties.

Moreover, economic valuations of scientific and technological resources (Zhang et al. 2020) and library services (Li and Ye 2012) are pertinent to this study. Open research data can be seen as a unique form of scientific and technological resource. Both open research data services and library services aim to create societal benefit, translating into economic value through service provision. For instance, the British Library applied welfare economics theory, cost-benefit analysis, multi-scale analysis, and other approaches to estimate ROI (Tessler 2013). Along with these economic methodologies, systematic review, questionnaire survey, and interviews were used for data collection.

2.2 Economic benefits derived from open research data

Economic benefits of open research data include cost savings and increased returns, which manifested in various dimensions such as cost and benefit, investment and return, time and efficiency, market and growth, job and opportunity, product and service, and annual monetary statistics (Houghton 2011; Beagrie and Houghton 2014; European Commission 2015).

The UK Joint Information Systems Committee (JISC) exemplified valuing of open research data centers. JISC estimated the economic value and impact of Economic and Social Data Service (ESDS), Archaeology Data Service (ADS), and British Atmospheric Data Center (BADC), highlighting significant increases in research, teaching, and studying efficiency realized by the users, with user value exceeding the investment made in data centers (Beagrie and Houghton 2014). Similarly, data agencies in Australia measure the value of open research data by focusing on cost savings, use value, non-use value, ROI, and potential wider impact (Houghton 2011; Houghton and Gruen 2014; Sanderson, Reeson and Box 2017).

European reports have utilized diverse indicators to gauge the economic impact of open data, including direct market size, job creation, cost savings, and efficiency gains (European Commission 2015). In 2018, additional indicators such as time spent, storage costs, license costs, research retraction, double funding, interdisciplinary research, and potential economic growth were used to quantify the cost and benefit of FAIR research data in Europe (European Commission 2018). By 2020, 'efficiency gains' included saving lives, time, the environment, and improving language

Table 1. Selected studies of economic valuation for open research data

Country/region	Open research data	Year	Economic valuation	Sources
UK	Economic and Social Data Service (ESDS)	2012	ROI is 2.5–10 fold	Beagrie and Houghton 2012
	British Atmospheric Data Center (BADC)	2013	ROI is 2.1–83 fold	Beagrie and Houghton 2013
	Archaeology Data Service (ADS)	2014	ROI is 4–12 fold	Beagrie and Houghton 2014
Australia	Australian Bureau of Statistics (ABS)	2011	ROI is 1.3–53 fold	Houghton 2011
	Office of Spatial Data Management & Geoscience Australia	2011	ROI is 10 fold	Houghton 2011
	Open data in Australia's public research	2012–13	Total economic value is 2 billion to 6 billion AUD per year	Houghton and Gruen 2014
	Commonwealth Scientific and Industrial Research Organisation (CSIRO) Data Access Portal	2017	Total economic value is 67 million AUD per year	Sanderson, Reeson and Box 2017
Europe	Open data in Europe	2016	Total economic value was 55.3 billion EUR in 2016;	European Commission 2015
		2020	Total economic value was 75.7 billion EUR in 2020	
	European Bioinformatics Institute (EMBL-EBI)	2015	The use value is 270 million GBP; The contingent value is 322 million GBP	Beagrie and Houghton 2016
	FAIR research data in Europe	2018	The cost of not having FAIR data is 10.2 billion EUR per year	European Commission 2018
	Open data in Europe	2019	184.45 billion EUR open data market size in 2019;	European Commission 2020
		2025	199.51–33421 billion EUR open data market size forecast for 2025	
USA	Landsat data	2015	1.8 billion USD for 2.38 million downloaded images	Loomis et al. 2015

ROI, return on investment, AUD, Australian Dollar, EUR, Euro, GBP, British Pound Sterling; FAIR, Findable, Accessible, Interoperable, and Reusable; USD, United States Dollar.

services; 'cost savings' included reductions in healthcare costs, labor costs, energy bills, and public sector costs (European Commission 2020).

2.3 Economic valuations for open research data

Over the past decades, numerous agencies and organizations in the UK, Australia, Europe, and the USA have conducted economic valuations of open research data, employing various methodologies and indicators. Table 1 presents selected studies from these countries and regions, highlighting the various approaches and findings.

3. Experimental background

3.1 Conducting a scoping review

To address the three research questions stated in Section 1, a scoping review method (Munn et al. 2018; Mak and Thomas 2022) was employed to systematically explore the literature on the economic valuation of open research data.

A scoping review is designed to clarify the extent or breadth of literature related to a specific topic, providing a comprehensive overview of available studies and research (Munn et al. 2018). Following established guidelines for conducting a scoping review (Mak and Thomas 2022), the subsequent review process included the following steps:

1) Identifying relevant studies: This study focused on user engagement with and pricing tactics for open research data. A comprehensive search strategy was formulated as '(economic valu* OR economic impact* OR economic benefit*) AND (open research data OR open scientific data OR open data)'. Besides, specific follow-up queries were conducted using keywords such as 'data sharing', 'data reuse', 'data management', 'data curation', 'data evaluation', 'welfare economics', 'public goods theory', 'contingent valuation method OR CVM'. Literature sources included data centers, journal papers, books and chapters, conference proceedings, scientific reports, and online resources, accessed through platforms such as Web of Science, Scopus, Google Scholar, and Google.
2) Selecting studies for inclusion: Studies were selected based on relevance, language, and the availability of informative abstracts or full texts. This step ensured that only pertinent sources were included in the review.
3) Extracting and analyzing data: Data extraction focused on economic theories, valuation methods, usage metrics, and measurement indicators. Comparative analyses were then conducted to evaluate different economic theories, techniques, metrics, and indicators.

3.2 Prioritizing the user engagement

To address research question of 'What processes and elements are involved in the economic valuation of open research data from a user perspective', this study focuses on user engagement with open research data as a key consideration.

An exploratory investigation of several representative data centers worldwide was conducted, including those in the United States (e.g. NASA's Earth Science Data and Information System (ESDIS), Alternative Fuels Data Center), China (e.g. National Genomics Data Center, National Basic Science Data Center), the United Kingdom (e.g. Environmental Data Service, High Energy Physics Data Repository), and the international community (e.g. Dryad, figshare, Zenodo). The investigation revealed that user engagement with open research data involves a variety of activities, such as registration, access, downloading, requests, comments, and subsequent applications or developments.

It is noteworthy that some datasets within certain data centers, such as those managed by the National Science Data Centers in China (e.g. National Basic Science Data Center, National Space Science Data Center), are not fully freely

accessible. Users are required to complete sign-up and login procedures to make online requests or submit offline access requests to the data center office. Therefore, in this study, such interactions are classified as 'requests'.

4. Conceptual framework

Based on exploration of theories, methodologies, procedures, and outcomes of economic valuations discussed in section 2, it is evident that the economic valuation of open research data typically involves three main components: selecting the valuation case (open research data), applying appropriate valuation methodologies (such as methods, techniques, and instruments), and presenting the valuation results. The overall conceptual framework of this study is illustrated in Figure 1. This framework consists of three key components organized into three levels: (1) pricing tactics for open research data; (2) relevant economic techniques for valuation; and (3) the methodology, which outlines the comprehensive approach and workflow for conducting economic valuation, from case study selection to data analysis. This framework provides the guiding structure for the empirical economic valuation conducted in this study.

4.1 Selecting China's open research data as the case

The reason for selecting open research data in China as the case for valuation is motivated by China's significant role in global open data initiatives. China's open research data practices include comprehensive policies, infrastructures, publication, standards, and more (Tu 2021b). Notably, the 'Scientific Data Management Rule' (2018) represents China's first national-level open data policy, supported by follow-up regulations at provincial and institutional levels (Tu and Yang 2021). The establishment of 20 national scientific data centers (NSDCs) serves as the pivotal platforms for the dissemination and sharing of scientific data, with ongoing development in data repositories, banks, and communities (Tu 2021b).

Conducting user surveys and valuation within China is both practical and feasible for the authors, given the existing networks and trust established with data centers. This collaboration simplifies the access to data users, making the approach more manageable. However, it is important to acknowledge the limitations of focusing solely on China's open research data. The unique economic, social, and cultural characteristics of China may influence the results and their applicability to other contexts.

4.2 Choosing CVM as the economic technique

Among the popularly used economic valuation techniques discussed in Section 2, a comparative analysis of their advantages, challenges, feasibility, and data accessibility led to the selection of the contingent valuation method (CVM) for this framework.

Contingent valuation is a survey-based technique that relies on stated preferences to estimate the demand for goods or services not traded in actual markets. Participants are asked to express their preferences in hypothetical scenarios, stating their maximum willingness to pay (WTP) for an improvement or their minimum acceptable compensation (willingness to accept, WTA) if no improvement occurs (Nriagu 2019). The process of adopting CVM includes defining the target respondents, selecting a sampling method, choosing techniques to assess willingness to pay and/or willingness to accept, and conducting data analysis (Cui and Miao 2005).

CVM has significant advantages such as its ability to value non-market goods and services, making it a practical choice when market prices are unavailable (Fujii, Kitamura and Suda 2004; Carson 2012). However, it has critical weaknesses, including concerns about the validity and reliability of results. Issues such as respondent biases, overstatements of value, discrepancies between willingness to pay and willingness to accept, and the challenge of creating a comprehensible hypothetical market can affect outcomes (Venkatachalam 2004; Hausman 2012). Despite these limitations, CVM remains a widely used methods for valuing public goods and services (Zhang, Xu and Cheng 2003).

The applicability of CVM in this study based on several key factors. Prior research has effectively employed CVM to assess the economic value of public research data confirming its feasibility for valuing open research data (Sanderson, Reeson and Box 2017). Unlike other methods that may require extensive data acquisition, market size statistics, or other difficult-to-obtain information, CVM offers greater practicality and independence. This is particularly relevant

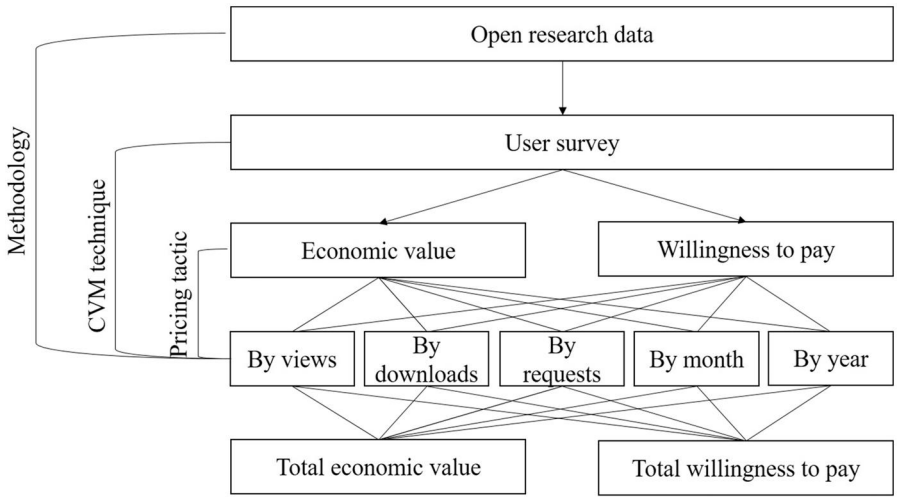

Figure 1. The conceptual framework of this study.

for open research data, which is often considered as a public good with no established market value. CVM's design for exploring the non-market value of public goods makes it well-suited for this study.

In this study, willingness to pay was selected as the primary measurement indicator. The study further distinguishes between 'economic value' and 'willingness to pay' in a narrow sense. 'Economic value' reflects users' assessment of the value they have gained from previously accessed open research data. It is influenced by their professional status and experience with open data, yet may not be closely correlated with their financial capacity. 'Willingness to pay' concerns users' forecasted appraisal of the value derived from open research data they expect to use in the future, which could be influenced by their financial capability as well as anticipated methods and costs of accessing academic data resources. These distinctions bear some resemblance to the differences between WTA and WTP in the CVM technique.

4.3 Determining the pricing tactics

Pricing tactics for open research data involves the strategies to determine the value of accessing, using, or sharing open research data. These tactics include methods for covering costs, determining fees, setting prices, or anticipating returns. This study, focusing on user engagement with open data centers and commercial databases, identified five specific pricing tactics categorized as either usage-based or subscription-based.

Usage-based tactics include views (reads, visits), downloads, and requests widely employed in statistical evaluations of both open data centers (e.g. Dryad, figshare, Zenodo) and paid databases (Yu, Jia and Shao 2019; Zhao, Hao and Zhang 2022).

Subscription-based tactics include monthly and yearly subscriptions aligns with prevalent measures in the statistical analysis of databases. Furthermore, these subscription models serve as common pricing tactics for numerous digital products, including various reading, music, and video applications (e.g. Cook 2018). Therefore, 'by month' and 'by year' were identified as the additional two pricing tactics, providing a holistic approach to capturing user engagement and economic valuation.

Accordingly, these five pricing tactics—views, downloads, requests, monthly subscription, and yearly subscription—for the economic valuation of open research data identified in this study.

5. Methodology

Adopting CVM technique, the methodological procedures of this study involves case selection, user survey design, respondent sampling, and data collection and analysis.

5.1 Case selection

National scientific data centers (NSDCs) exemplify advanced practices in open research data management and sharing in China. This paper focuses on the National Basic Science Data Center (NBSDC) as a case for the economic valuation of open research data based on several reasons:

1) Scope and resources: NBSDC is one of the first 20 NSDCs in China and hosts 23 subject databases with a total data resource of over 2.71 petabytes. It covers a wide range of disciplines including physics, chemistry, materials, optics, biology, botany, transportation, and information science.
2) Data and services: NBSDC provides data and services through various channels such as page views, online downloads, offline orders, and user requests. This variety of service delivery methods aligns with the five pricing tactics considered in this study.
3) Disciplinary coverage and user activity: With the broadest disciplinary scope and the highest cumulative number of visitors among NSDCs, NBSDC is highly representative of both disciplinary diversity and user engagement.
4) Data availability: Data for the valuation were obtained from NBSDC's website and annual reports for the years 2020 to 2022 (NBSDC 2021, 2022, 2023). Based on the five pricing tactics, thirteen specific subject databases were selected for analysis. Metrics collected include yearly views, downloads, requests, and user numbers, with a preference focus on the most recent and comprehensive statistics from 2022 or the 2020 to 2022 period. As of the end of September 2023, NBSDC recorded a total of 33 million views.

5.2 User survey design

The characteristics of NBSDC informed the design of the survey for this study, which also drew inspiration from a user survey used for the economic valuation of the CSIRO data access portal (Sanderson, Reeson and Box 2017). The final survey consisted of 13 questions covering 'demographic information', 'user engagement', and 'economic valuation' (see Supplementary Appendix A).

Questions on 'user engagement' provide a foundational background for understanding the 'economic valuation'. These questions covered (1) Frequency of users' access to NBSDC; (2) Purposes for access; (3) Assessment of the significance and (4) Irreplaceability of NBSDC open data for their work; (5) Evaluation of the time-saving benefits provided by NBSDC; (6) Satisfaction with NBSDC. The 'economic valuation' section aimed to gather users' evaluations, both quantitative and qualitative assessments, of the economic value of NBSDC, and to quantify their willingness to pay.

Participants were asked to (1) Provide estimates based on their academic background and experience with open research data; (2) Select from the proposed pricing tactics (by views, by downloads, by requests, by month, by year) and estimate a value or a numerical range; (3) Propose other pricing tactics with estimates or detailed explanations.

5.3 Respondents sampling

Considering the substantial user base of NBSDC, a random sampling method was applied to select users who have used the data or services (as determined by records of views, downloads, registrations, requests, etc.). Initially, these users were asked to qualitatively assess the economic value generated by the data. Subsequently, they were prompted to choose their preferred evaluation method for estimating economic value and willingness to pay from a provided set and provide quantitative estimates through numeric values or value ranges.

Non-users or potential users were excluded from the survey to ensure the reliability of the results, as they lack first-hand experience with NBSDC's open research data. Their inclusion could introduce significant challenges in conducting

an accurate economic valuation and result in less reliable outcomes.

5.4 Data collection and analysis

From January to February 2022, the survey questionnaire was transcribed into an Internet-based questionnaire platform and distributed to users via email and user WeChat groups. A total of 322 users' responses were collected, and the datasets are available in the Supplementary Appendix B. The data were cleaned, analyzed and visualized using Derwent data analyzer (DDA), Excel 2016, and Origin Pro 2021.

The data processing and analysis adhered to four principles.

1) Exclusion of non-statistically significant options: During the examination of the monetary estimates derived from the survey questions, the 'other' option was omitted from subsequent analysis due to its lack of statistical significance. Specifically, there were 15, 98, and 31 responses categorized under the 'other' option for Questions 7, 11, and 12 in the survey, respectively.
2) Median value utilization for ranges: For instances, where respondents provided a range of values for each pricing tactic regarding economic value and willingness to pay, the median value within that range was employed for the subsequent analysis. In particular, options A, B, C, D, and E of Question 11 had 0, 1, 11, 0, and 4 ranges, respectively; options A, B, C, D, and E of Question 12 had 1, 1, 15, 1, and 2 ranges, respectively.
3) Determination of statistical metrics: The maximum, minimum, mean, and median values of each pricing tactic for economic value and willingness to pay (corresponding to options A, B, C, D, and E for Questions 11 and 12) were determined. The maximum and minimum values determined the range of each pricing tactic. When the range between the maximum and minimum values was extensive, the mean value largely lost its statistical significance, making the median more informative and suitable for selection as the corresponding value assessment.
4) Exclusion of outliers: Outliers were removed when generating violin plots to illustrate the distribution of values for each pricing tactic. For Question 11, we removed 8, 5, 6, 2, and 3 outliers for options A, B, C, D, and E, respectively, prior to graphing the results. For Question 12, we excluded 0, 3, 2, 4, and 1 outlier for options A, B, C, D, and E, respectively, during result visualization.

6. Results

6.1 Basic results

6.1.1 *Characteristics of participants*

The characteristics of the 322 survey respondents are outlined in Figure 2. First, these users were affiliated with a collective of 45 academic institutions, with 74% from research institutions (research-oriented) and 26% from universities (research and/or education-oriented). The majority of users occupied positions categorized as faculty and student roles. Specifically, the distribution revealed that the highest proportion consisted of graduate students (39%), followed by faculties (31%), doctoral students (21%), and a smaller contingent of undergraduate students (9%). Regarding disciplinary distribution, 55% of the respondents were from the natural sciences, 25% from engineering and technological sciences, 14% from the social sciences and multidisciplinary fields, and 6% from the medical and life sciences.

6.1.2 *User engagement*

Respondents' engagement with NBSDC is detailed in Table 2, revealing the following key observations: (1) Frequency: 79% of respondents accessed NBSDC daily or weekly. (2) Purposes: a majority (95%) of respondents used NBSDC primarily to advance original research processes. (3) Data significance assessment: 94% of respondents considered NBSDC to be 'significant' or 'very significant' to their work. (4) Time-saving assessment: 91% of respondents believed

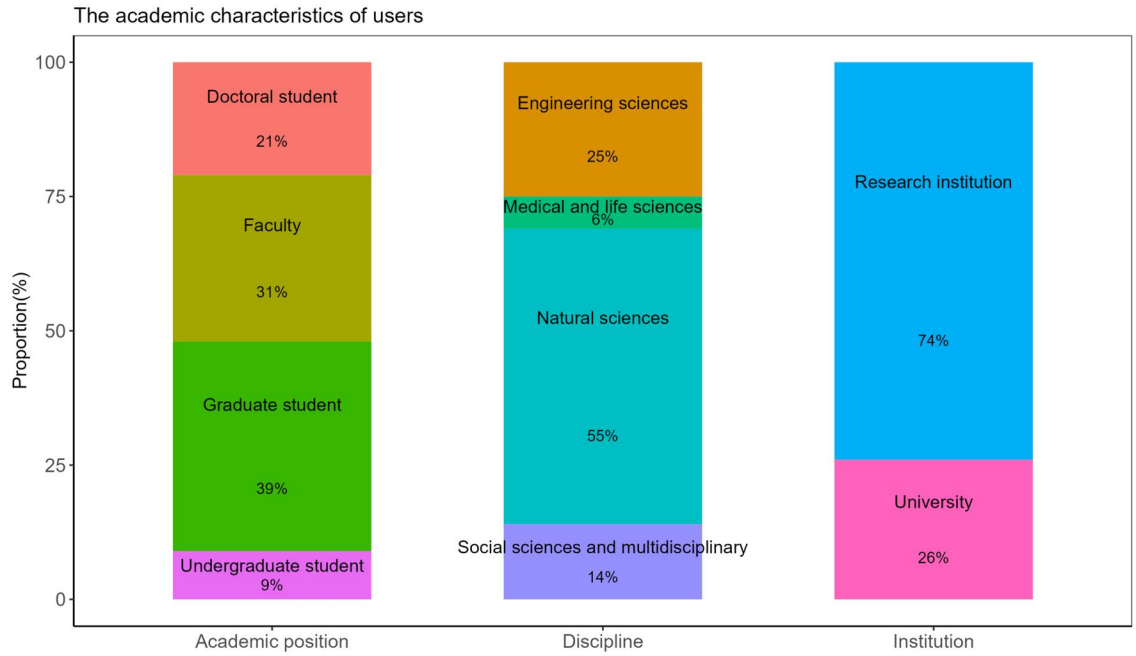

Figure 2. The academic characteristics of participants ($n = 322$).

Table 2. The characteristics of user engagement with NBSDC ($n = 322$).

User engagement	Frequency (percentage)
Frequency	
Every day	165 (51)
Every week	90 (28)
Every month	44 (14)
Every year or less	23 (7)
Purposes	
Advancing original research	306 (95)
Verifying or replicating published research	114 (35)
Educational activities	19 (6)
Commercial activities	13 (4)
Public service	40 (12)
No specific purpose	5 (2)
None of the above	5 (2)
Data significance assessment	
Very insignificant	13 (4)
Insignificant	2 (1)
Neutral	7 (2)
Significant	89 (28)
Very significant	211 (66)
Time-saving assessment	
Very small	4 (1)
Small	3 (1)
Neutral	22 (7)
Large	129 (40)
Very large	164 (51)
Alternative data	
Have and free	67 (21)
Have but charged	17 (5)
Don't have	238 (74)
User satisfaction	
Very dissatisfied	5 (2)
Dissatisfied	1 (0.3)
Neutral	33 (10)
Satisfied	156 (48)
Very satisfied	127 (40)

that NBSDC provided 'large' or 'very large' time-savings, with an estimated average time-savings of 159 h per year per user. (5) Alternative data: 74% of respondents did not have alternative data sources to NBSDC. (6) User satisfaction: 88% of respondents were satisfied or very satisfied with their experience using NBSDC.

6.2 Pricing tactics for economic valuation

6.2.1 *Pricing tactics for economic value*

A total of 85% of respondents indicated that the economic value produced by NBSDC open research data for them was 'large' or 'very large'. Another 12% of respondents selected the 'neutral' option, while 1% chose the 'small' and 'very small' options, respectively.

Excluding 98 respondents who were unable to evaluate based on the given pricing tactics, the remaining users ($n = 224$) selected their preferred tactic and provided a monetary estimation. The assessment of economic value by views (33%) was more prevalent than downloads (16%) and requests (13%). Furthermore, yearly assessment (25%) surpassed monthly assessment (14%). Monetary estimations for each pricing tactic are shown in Figure 3.

Among the respondents unable to provide an evaluation, some cited the challenge of quantifying the economic value of data when not used for commercial purposes. Others suggested that economic value should be measured over an extended period, or felt that the current free accessibility of the data implied an aversion to potential future charges. These reasons underscore the ongoing challenge of measuring the economic value of open research data, revealing an insufficient understanding of users' perceptions regarding economic valuation under current conditions.

Adhering to the data analysis principles described in Section 5, the median value was established as the definitive value of each pricing tactic. Consequently, the specific pricing tactics for estimating the economic value created by NBSDC open research data were determined as follows: 5 Chinese yuan (CNY) per view, 50 CNY per download, 2,000 CNY per request, 500 CNY per month per user, and 10,000 per year per user.

6.2.2 *Pricing tactic for willingness to pay*

A total of 291 users selected their preferred pricing tactic and provided a monetary estimation. Notably, respondents demonstrated a preference for payment based on downloads (27%) over views (15%) and requests (11%). Furthermore, a substantial majority favored a yearly payment structure (36%) over a monthly one (11%). Detailed estimations for each pricing tactic are illustrated in Figure 4.

Accordingly, the specific pricing tactics for estimating users' willingness to pay for NBSDC open research data were determined as follows: 2 CNY per view, 5 CNY per download, 1,750 CNY per request, 20 CNY per month per user, and 300 CNY per year per user. Additionally, it is noteworthy that the correlation coefficient between the five pricing tactics for economic value and those for willingness to pay is 0.1.

6.3 Calculations of economic valuation

The specified pricing tactics for economic valuation were applied to calculate the total economic value and total willingness to pay for each of the NBSDC subject databases, as presented in Table 3. The computation of the total economic value relies on the statistics of views, downloads, requests, and users (for monthly and yearly figures). These figures are then multiplied by the designated pricing tactics: 5 CNY per view, 50 CNY per download, 2,000 CNY per request, 500 CNY per month per user, and 10,000 CNY per year per user. This approach yields the total economic value for each NBSDC subject database. Similarly, the total willingness to pay for each NBSDC subject database is calculated by multiplying the corresponding statistical data by the previously derived pricing tactics: 2 CNY per view, 5 CNY per download, 1,750 CNY per request, 20 CNY per month per user, and 300 CNY per year per user. For example, consider the Qinghai Lake Region Comprehensive Research Topic Database. It has 200,000 views, with an economic value pricing tactic of 5 CNY per view and a willingness to pay pricing tactic of 2 CNY per view. Therefore, the total economic value is $200{,}000 \times 5 = 1{,}000{,}000$ CNY, and the total willingness to pay is $200{,}000 \times 2 = 400{,}000$ CNY.

Additionally, based on the total view count (33 million, as referenced in Section 5.1), the total economic value of NBSDC is 165 million CNY, with a total willingness to pay of 66 million CNY.

7. Discussions

This study explores the conceptual framework and methodological approach for economically valuing open research data. It introduces two pricing tactic models: the per-use model (views,

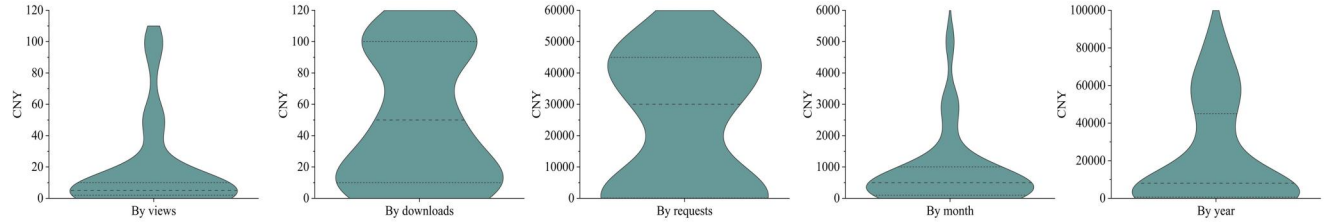

Figure 3. The distribution of economic value in different pricing tactics ($n = 224$).

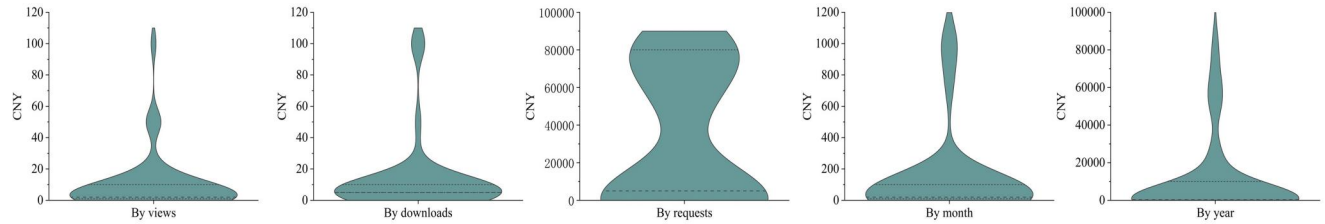

Figure 4. The distribution of willingness to pay in different pricing tactics ($n = 291$).

Table 3. The total economic value and users' willingness to pay for 13 NBSDC subject databases.

Pricing tactic for subject database	Number	Total economic value (thousand CNY)	Total willingness to pay (thousand CNY)
Qinghai Lake Region Comprehensive Research Topic Database			
By views	200,000	1,000	400
Optical Technology Database			
By views	760,000	3,800	1,520
By requests	214	428	37,450
International Camellia Register			
By views	20,000,000	100,000	40,000
Geospatial Data Cloud			
By views	297,000,000	1,485,000	594,000
By requests	15,457	30,914	27,050
By month	416,157	208,079	8,323
By year	416,157	4,161,570	124,847
Chemical Database			
By views	350,000	1,750	700
Chinese Plant Science Data Center			
By views	839,608	4,198	168
By month	184,547	92,274	3,691
By year	184,547	1,845,470	55,364
Chinese Plant DNA Barcode Database			
By views	2,850,000	14,250	5,700
Cosmology Numerical Simulation Database			
By views	120,000	600	240
Virus Resource Database of China			
By requests	302	604	529
Basic Science and Technology Database of Heilongjiang Province			
By downloads	160	8	0.08
By month	12,453	6,226.50	249
By year	12,453	124,530	3,736
Space application data promoting service platform for China Manned Space Engineering			
By views	1,200,000	6,000	2,400
By downloads	600,000	30,000	0.03
By month	1,000	500	20
By year	1,000	10,000	300
Materials Science Database			
By views	3,690,000	18,450	7,380
Database of Medicinal Resources in Arid Area			
By downloads	100	5	0.5

downloads, and requests), and the periodic subscription model (monthly and yearly access). The effectiveness of these frameworks, methods, approaches, workflows, and procedures is substantiated through empirical validation in a case study using open research data sourced from the NBSDC in China. To the best of our knowledge, this study is among the first to establish a conceptual framework with user-centered pricing tactics for open research data.

7.1 Discussions of results

Users exhibited a strong preference for NBSDC open research data. Firstly, they primarily used NBSDC for their original research activities, and secondarily for verifying or replicating previous studies, mirroring findings from the CSIRO data access portal (Sanderson, Reeson and Box 2017). Secondly, 94% of respondents considered NBSDC to be significant (28%) or very significant (66%) to their work, a higher proportion than figures reported by the CSIRO data access portal (78% in total, with 34% and 44% respectively). Thirdly, 51% of respondents believed that NBSDC facilitated a 'very large' level of time-savings, a proportion comparable to that reported by the CSIRO data access portal (52%). The strong user preference for NBSDC data provides a robust foundation for economic valuation.

While users acknowledged the value of NBSDC open research data, their estimated monetary values varied considerably, ranging from <1 CNY to thousands of CNY or more. Similar variations were observed in the CSIRO data access portal estimations, ranging from a low of $5,000 to values in the millions (Sanderson, Reeson and Box 2017). Users' awareness and experience with open research data significantly impact economic valuation results.

Comparatively, the economic value of NBSDC open research data is noteworthy, but users' willingness to pay is not equally strong. The coefficient of 0.1 indicates a relatively weak correlation between the two. In individual usage instances, the economic value generated per view, download, and request all exceeds the corresponding user's willingness to pay. Even with periodic subscriptions, the economic value generated by NBSDC monthly or yearly also surpasses the corresponding user's willingness to pay. The disparity is attributed to the user's perceptions and attitudes regarding the data's worthiness of payment and their financial capacity. This aligns with Beagrie and Houghton's (2014) findings on three UK national data centers. In summary, NBSDC open research data provides actual economic value to users that surpasses their ideal willingness to pay. This highlights the value-added nature of open research data, which lies at the core of the concept of opening and sharing research data.

Consequently, valuing open research data based on views is the users' preferred method for assessing its economic value. Conversely, estimating users' willingness to pay is more feasible through downloads. Additionally, calculating the monetary value on a yearly basis proves to be a practical solution for both economic value and willingness to pay.

Admittedly, one challenge with survey respondents providing estimated economic value and willingness to pay is that they are projecting something they may not directly know. Therefore, their estimated values may vary widely, as evidenced in the data where responses range from <1 CNY to thousands of CNY and more. This variability complicates the accurate calculation of expected monetary value measurements.

7.2 Discussions of methodologies

The user-based CVM effectively addresses the challenge of economic valuation for open research data. Open research data generates value through various user activities, making user survey a reliable reflection of their value. A valuation approach based on usage metrics aligns with the nature of open data centers and is broadly applicable to various economic valuation issues, overcoming limitations associated with specific datasets, data centers, institutions, fields, regions, or countries.

The advantage of employing CVM in this study lies in the fact that open research data is a public digital good, not yet commercialized in China or globally. Therefore, surveying users becomes a more feasible approach compared to alternative market-based methods. However, implementing CVM presents challenges, such as accessing users and addressing potential biases, both of which can directly impact the accuracy and credibility of the valuation. Despite these challenges, the successful application of CVM in this study offers a viable solution for measuring the economic value of data, information, and knowledge in the field of library and information science.

Various alternative quantitative methodologies for economic valuation exist, including cost-benefit analysis (CBA) (Gascó et al. 2019), real options analysis (ROA) (Bowman and Moskowitz 2001), and data-driven impact assessment (DDIA) (Qazi 2022). Each of these approaches has its strengths and challenges when applied to economic valuation for open data initiatives. For instance, CBA necessitates both cost and benefit information for effective application, but obtaining cost information for NBSDC is currently unavailable. ROA focuses on long-term value akin to users' willingness to pay in this study, and aligns with providing evidence for decision-makers to evaluate their open data policies and practices. DDIA concentrates on the direct impact of open data, similar to the estimated economic value of open research data in this study, but emphasizes specific outcomes such as economic growth, innovation, or improved public services, which may require more supporting data and may not always be available.

In comparison to previous studies, this research conducts economic valuation for open research data from users' perspectives. It develops per-use-based and periodic subscription-based pricing models applicable to various contexts. Furthermore, the study establishes a conceptual framework and methodological approach, offering a comprehensive overview of the economic valuation of open research data. This framework enhances understanding of the economic impact of open research data, providing valuable insights for stakeholders involved in open data initiatives.

7.3 Implications

This study carries significant policy implications and provides practical recommendations for decision-makers, funding agencies, data centers, data users, and future researchers.

Firstly, the investment strategies of funding agencies regarding open research data are directly influenced by the estimated monetary value. A higher estimated value can encourage funding agencies to invest in and support open research data initiatives, while a lower estimated value may prompt them to optimize their policies and consider more efficient allocation of resources.

Furthermore, data centers can leverage the estimated monetary value as concrete evidence of their significance in curating open research data and promoting open science. By

demonstrating the economic value of open research data, data centers can justify their funding requirements and attract increased support from funding agencies. Additionally, they can refine their curation strategies to provide more valuable data to researchers, thereby enhancing the dissemination and reuse of open research data.

Moreover, both academic and non-academic users can benefit by saving time and enhancing their work through more frequent use of open research data as needed. This increased utilization creates a stronger incentive for greater data reuse and leading to heightened economic benefits. The outcomes of this study can motivate various users to engage with open research data more frequently, thereby promoting increased efficiency and productivity.

In addition, building upon the summarized pricing tactics and monetary calculations, future researchers can explore the development of pricing tactics and conduct economic valuation from the perspectives of multiple stakeholders, including funding agencies, data centers, users, and more. This exploration can draw upon different statistics and evidence, including market-based, institution-based, and user-based approaches, while incorporating various theories and methodologies. This comprehensive approach can further refine the economic valuation of open research data and optimize policies and practices to maximize their value.

7.4 Strengths and limitations

There are several strengths in this study. Primarily, a user-centric research approach was established, aligning with the practical emphasis on user-centric management and services in data center contexts. Five distinct pricing tactics was proposed based on the usage patterns of both open research data and paid-for datasets, expanding beyond the limitation to free open research data and enhancing the comprehensiveness of the pricing tactics. This study implements the CVM, a widely adopted economic technique for discerning non-market value, as its principal approach. By integrating user engagement, pricing tactics, and the CVM technique, a conceptual framework is constructed, providing a comprehensive overview of economic valuation. Furthermore, NBSDC is selected as a case study, and a high-quality set of user valuation data is collected to effectively validate the conceptual framework. These merits collectively offer valuable insights for policymakers and practitioners in shaping policies and conducting practical implementations.

However, several limitations exist in this study. First of all, the sample size of respondents is relatively small compared to the overall user base, primarily due to the challenges associated with identifying and accessing users. The selected open research data and data users are within the context of China, which may limit the generalizability of the analysis results. Moreover, diverse institutions managing NBSDC subject databases have different statistical standards for data usage, leading to missing statistics and variations in calculations of total economic value and willingness to pay. Furthermore, this study lacks a detailed analysis of the relationships between different pricing tactics, offering limited insight into the underlying reasons behind the observed phenomenon. Additionally, the results lack comparisons with paid-for datasets to validate the findings, potentially affect the robustness of the conclusions drawn from the analysis.

This paper acknowledges the challenges inherent in valuing open research data, such as the difficulty in quantifying intangible benefits and the potential for biases in user responses. Addressing these challenges requires a multidisciplinary approach, incorporating economists, data scientists, and domain experts to refine the conceptual framework and improve the accuracy of economic valuations.

Future research can address two main aspects: addressing the limitations identified in this study, and exploring alternative methods and pricing tactics for economic valuation. Expanding the user base to include diverse data centers in various countries and regions would provide a more comprehensive understanding of open research data valuation. Examining market substitution approach could offer insights into pricing for data resources purchased by academic libraries, serving as a proxy for open research data. Furthermore, a deeper exploration of theories, indicators, and methodologies related to economic valuation require to develop a more robust framework for valuing open research data.

8. Conclusions

This study developed a user-centric conceptual framework for the economic valuation of open research data, integrating user engagement, the CVM technique, and various pricing tactics. The valuation was addressed in terms of both economic value and willingness to pay. The framework utilized two primary valuation strategies: a per-use model and a periodic subscription model, which can be adapted to various contexts beyond specific datasets. Validation was conducted across 13 NBSDC subject databases with participation from 322 users. The preferred valuation tactics for assessing economic value based on views and yearly metrics, while willingness to pay was most reasonable evaluated through downloads and yearly measurements. Overall, the most applicable valuation approach is on a yearly basis. The study's results offer significant policy implications and practical recommendations for stakeholders, such as funding agencies, data centers, data users, and future researchers.

Supplementary data

Supplementary data are available at *Research Evaluation Journal* online.

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