Research on the Measurement of Personal Data Value Based on a Modified BDM Mechanism (Postprint)

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Abstract

[Purpose/Significance] By modifying the BDM mechanism, this study measures the Chinese public's perception of personal data value, providing a reference for economic compensation in personal data infringement cases and privacy policy formulation.

[Method/Process] The BDM mechanism was modified to clarify the purpose of personal data usage, and the TIOLI mechanism was introduced to mitigate anchoring effects, thereby measuring users' minimum selling price for their personal data, which reflects users' perceived value of their personal data.

[Results/Conclusion] 85% of users are willing to sell their personal data for monetary gain. The average selling prices for personal preference data, contact information data, combined data, Sina Weibo account data, and Sina Weibo historical data are 38.8 yuan, 136.3 yuan, 237.9 yuan, 221.8 yuan, and 231.4 yuan, respectively, while the actual economic compensation in personal data infringement cases in China is far lower than these measured values.

Full Text

Research on Personal Data Valuation: A Modified BDM Mechanism Approach

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Abstract: [Purpose/Significance] This study modifies the Becker-DeGroot-Marschak (BDM) mechanism to measure Chinese public perception of personal

data value, providing a reference for economic compensation in personal data infringement cases and privacy policy formulation. [Method/Process] The modified BDM mechanism clarifies the purpose of personal data usage and introduces a TIOLI (Take-It-Or-Leave-It) mechanism to avoid anchoring effects, measuring users' minimum selling price for their personal data—that is, their perceived value of personal data. [Result/Conclusion] Eighty-five percent of users are willing to sell their personal data for profit. The average selling prices for personal preference data, contact data, combined data, Sina Weibo account data, and Sina Weibo historical data are RMB 38.8, RMB 136.3, RMB 237.9, RMB 221.8, and RMB 231.4, respectively—far higher than current economic compensation in China's actual personal data infringement cases.

Keywords: personal data; data privacy; value assessment; BDM mechanism
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1 Research Significance

The valuation of personal privacy data has long existed, but its measurement has become particularly important in today's digital era. For instance, a survey of personal privacy infringement cases published on China Judgments Online reveals that illegal trading of personal privacy data is especially prominent. Medical data is leaked by healthcare institutions to commercial insurance companies without patient consent, and online retailers sell users' purchase data to other businesses without authorization. From a legal perspective, all these actions constitute violations of personal privacy rights and involve relevant laws and regulations. However, from a user perspective, the implementation of these laws and regulations is inefficient because the public or commercial benefits derived from using such data far exceed the marginal costs of usage (which are nearly zero, as increased usage occasions only minimally raise data management costs). Therefore, formulating these laws and regulations requires balancing the use and protection of personal privacy data to simultaneously satisfy users' privacy protection needs and commercial enterprises' usage requirements, with personal data valuation forming the foundation for establishing this equilibrium.

Personal data value is also closely related to data sensitivity; higher value implies that data subjects have greater awareness of the privacy nature and degree of their personal data. Consequently, measuring personal data value is fundamental to identifying and detecting privacy risks associated with such data. Moreover, personal data constitutes the most important component of big data, and valuation is essential for mining, utilization, privacy protection, management, and other operations.

Commercial use of personal data faces significant challenges. On one hand, enterprises, governments, and research institutions invest substantial funds to acquire and preserve data from various sources, which contain large amounts

of personal privacy content. On the other hand, the public is increasingly concerned about the commercial use of their personal privacy data, generating anxiety and apprehension. To alleviate these concerns, legislative and administrative bodies have enacted personal privacy data protection laws and regulations. However, the lack of uniform compensation standards for personal data infringement cases has resulted in vastly different compensation amounts for similar privacy data breaches, with some differences being substantial. Therefore, it is necessary to measure personal data value to serve as a reference or basis for establishing these compensation standards.

2 Measurement Methods

The fundamental approach derives from the Becker-DeGroot-Marschak (BDM) mechanism, but requires appropriate modifications to suit the unique characteristics of personal data valuation.

2.1 BDM Mechanism and Its Modification The BDM mechanism, proposed by G.M. Becker et al. [1] in 1964, has become one of the most commonly used price discovery methods in experimental economics. The mechanism employs market auction principles where bidders submit bids for an auctioned item (not owned by the bidder) and state the highest price they are willing to pay to obtain it—that is, their Willingness to Pay (WTP). Unlike conventional auctions, the BDM mechanism proceeds as follows: First, the bidder reports a bid to the auctioneer within a known, fixed price range, with only one bidding opportunity. Second, the auctioneer draws a price from a random generator following "a certain distribution" (J.L. Lusk [2] suggests that a normal distribution works better than a uniform distribution). The random generator's price range matches the bidder's selectable range. Finally, the winner is determined by the highest bid: if the bidder's offer is not lower than the randomly drawn price, the bidder wins the item and pays the randomly drawn price; otherwise, the bidder loses.

In the BDM auction mechanism, the auctioned item belongs to a third party, and the bidder competes against the randomly drawn price. Observing bidding behavior effectively reveals the bidder's valuation of the auctioned item because if a bidder bids higher than their true psychological valuation, they may win the item when the random price falls between their bid and true valuation but would have to pay the price difference between the transaction price and their true valuation, resulting in a loss.

However, in this study, the auctioned item is the bidder's personal data, whose initial rights belong to the bidder. The bidder's goal is to sell their personal data to the auctioneer, who then provides it to the user, thereby monetizing the bidder's personal data value. Therefore, this study aims to obtain the minimum price at which bidders are willing to sell their personal data—that

is, their Willingness to Accept (WTA)—necessitating modification of the BDM mechanism.

The modified BDM mechanism is as follows: The rules for generating bidders' offers and random prices remain unchanged, but the winning mechanism is altered. If the bidder's offer is lower than or equal to the randomly drawn price, the bidder sells their personal data and receives the randomly drawn price to maximize their benefit; otherwise, the bidder retains their personal data. For example, if the randomly drawn price is RMB 30 and the bidder's offer is RMB 20, the bidder sells their personal data and receives RMB 30; if the offer is RMB 40, the auction fails and the bidder receives no monetary benefit. This modified winning mechanism effectively obtains the minimum price at which bidders are willing to sell their personal data—that is, their perception of personal data value.

For narrative convenience in describing the experimental process, users are referred to as bidders, experimenters as auctioneers, and the user is China Mobile Communications Group Henan Co., Ltd. (which pays the monetary compensation for successful auctions in the following experiments).

2.2 Applicability Analysis of the Modified BDM Mechanism Several empirical studies have measured personal data value [3-8], but results vary significantly. Analysis reveals multiple factors causing these discrepancies, with three primary factors being research method, data usage purpose, and anchoring effects.

2.2.1 Research Method Existing personal data valuation methods have concentrated on direct survey approaches for non-market product valuation, represented by the Contingent Valuation Method (CVM). CVM was first proposed by H.R. Bowen [9] and applied to environmental valuation by R.K. Davis [10] in 1963. Nearly all existing personal data valuation research employs questionnaires in hypothetical scenarios, directly asking users about their willingness to pay for personal data protection measures or their willingness to accept compensation for personal data infringement. However, when users make valuation choices in hypothetical scenarios, hypothetical bias occurs—that is, users' decision-making behavior in hypothetical scenarios may not match results obtained in real scenarios, causing their WTP or WTA to be higher or lower than their true psychological values [11]. Additionally, different empirical studies employ different hypothetical scenarios, and even within a single study, the lack of a defined scenario may lead to inconsistent hypothetical contexts across users, both contributing to measurement errors. Therefore, this study utilizes the modified BDM mechanism in a real market environment (selling to China Mobile Communications Group Henan Co., Ltd.) with real items (users' personal data), guiding users to auction their personal data to obtain the minimum price they are willing to accept, thereby authentically reflecting users' perception of personal data value and avoiding hypothetical bias. Furthermore, the

modified BDM mechanism experiments with individual users sequentially rather than in groups, avoiding potential mutual influence among individuals in group experiments [12].

2.2.2 Data Usage Purpose CVM does not specify data usage purposes, thus only reflecting users' valuation of personal privacy data itself rather than value preferences arising from different uses. In reality, different uses of the same privacy data lead to varying sensitivity levels. For example, medical sensitive data is generally considered more sensitive when used for commercial purposes than for public services. Data sensitivity is an important factor in value manifestation. Therefore, this study clearly informs users of their personal data usage purpose: for marketing by China Mobile Communications Group Henan Co., Ltd., with no third-party access, completely avoiding valuation differences caused by unspecified usage purposes.

2.2.3 Anchoring Effect In the modified BDM experiment, experimenters must preset the price range for auctioned items. However, this price range setting influences users' price selection—that is, the anchoring effect [13]. For the same auctioned item, anchoring effects have two impacts: First, for users with higher psychological prices, an overly low price range may reduce their selling willingness; second, for users with lower psychological prices, an overly high price range may increase their psychological price expectations. For personal data, without reference market prices, users struggle to determine their true value, making their valuations susceptible to anchoring effects. To address this, this study designs a TIOLI (Take-It-Or-Leave-It) mechanism control experiment to verify the rationality of the price range setting in the modified BDM experiment. The TIOLI mechanism is relatively simple: users only need to answer whether they agree to sell their personal data at a specific price. For example, in this study's TIOLI experiment, users are asked: "Do you agree to sell your personal data at a price of RMB 50?" Based on this TIOLI experiment, we can measure the proportion of users willing to sell their personal data at RMB 50 and compare it with the proportion of users in the modified BDM experiment whose bids do not exceed RMB 50. If the two proportions show no significant difference, the price range setting in the modified BDM experiment is relatively reasonable. If the latter proportion (modified BDM) is significantly lower than the former (TIOLI), the price range setting is too high; if the latter is significantly higher, the price range setting is too low. In both latter cases, the price range in the modified BDM experiment must be gradually adjusted until the two proportions show no significant difference.

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3 Experimental Design

The experiment was conducted in April 2019. The author and 14 master's students in Information Science from Zhengzhou University served as exper-

imenters, divided into 7 groups, randomly inviting citizens to participate in Zhengzhou's urban area.

3.1 Personal Data Sample Personal data includes many types. To simplify the experiment, this study selected only certain personal data items based on two principles: first, users could provide them on-site; second, they had a certain degree of representativeness. On one hand, personal preference data and contact data apply to all users. On the other hand, according to the "2018 Weibo User Development Report" [14] released by Sina Weibo Data Center, Sina Weibo had 462 million monthly active users by the end of 2018, making it an important social media platform in China containing vast amounts of user personal data. These two types of data meet the selection principles and were therefore chosen as experimental objects, specifically 细化 into five types:

1. **Personal Preference Data**: Anonymous, including gender, age, hobbies, occupation, and salary income.
2. **Contact Data**: Non-anonymous, including name, address, email, and mobile phone number.
3. **Combined Data**: Non-anonymous, including all the above personal preference and contact data.
4. **Sina Weibo Account Data**: Non-anonymous, account page data (provided via screenshots). The account page may include follower/following counts, Weibo wallet, occupation and company, educational background, city, preferences for music, movies, and brands, real-name verification, etc., depending on how thoroughly users have completed their profile information.
5. **Sina Weibo Historical Data**: Non-anonymous, published Weibo post data (provided via screenshots). This includes not only users' own published posts but also private messages received from other users, likes, comments, and other data.

3.2 User Sample User samples were divided into two categories: The first category included users for personal preference data, contact data, and combined data. The experiment site was Zhengzhou's urban area, with 7 groups of experimenters distributed across different locations, all using on-site random invitation methods. The second category included Sina Weibo users, selected using the same method but with additional screening criteria.

Weibo users had to meet two conditions: First, they had to be active Weibo users to authentically reflect their perception of personal Weibo data value. Since such users lack clear definition standards, this study set screening criteria: Weibo account registration for at least one year, mutual following count of no fewer than 50 friends, and at least 20 posts published annually. Second, user structure composition followed the "2016 China Social Media User Behavior Research Report" [15] by China Internet Network Information Center, which indicated Sina Weibo's age structure as 10% over 50 years old, 67% aged 20-49, and 23%

under 19, used as the age distribution for random selection; gender structure was 52% male and 48% female, used as the gender sampling distribution. Other dimensions such as education and occupation were difficult to assess visually and were not used as selection criteria.

3.3 Experimental Preparation First, users were informed of their personal data usage purpose: for marketing by China Mobile Communications Group Henan Co., Ltd., with no third-party access. Second, users received a form detailing the types of personal data to be sold. Third, experimenters inquired about users' willingness to sell each data type. If willing to sell, users filled in the corresponding personal data content and received RMB 10 compensation; otherwise, they did not fill out the form and received no compensation. During form completion, experimenters repeatedly informed users of their right to refuse to fill out the form or retain completed personal data forms at any time. For non-anonymous personal data, users had to provide their real names and present student IDs, identity cards, or driver's licenses to verify their identity.

3.4 TIOLI Experiment The TIOLI experiment aimed to provide a basis for price range setting in the modified BDM experiment. The TIOLI experiment consisted of 5 groups: personal preference data group, contact data group, combined data group, Weibo account data group, and Weibo historical data group. User selection methods for each group corresponded to the sampling methods for their respective data types in the user sample formation. Selected users underwent experimental preparation. Based on the anchoring effect TIOLI mechanism, the TIOLI experiment was implemented, calculating the proportion of users in each group willing to sell at RMB 50. The experimental results are shown in Table 1 .

3.5 Modified BDM Pre-experiment The pre-experiment aimed to select price ranges for the formal modified BDM experiment. First, based on the target number of users for the formal modified BDM experiment and following sample size empirical rules [16], the number of users for the pre-experiment was calculated. Second, user samples were obtained according to the sampling method, and selected users underwent experimental preparation. Third, following the formal modified BDM experimental procedure, the pre-experiment was conducted, calculating for each data type the proportion of users whose bids were not lower than the price set in the TIOLI experiment. Finally, Fisher's Exact Test was performed to compare the two proportions for each data type. Based on the anchoring effect adjustment mechanism, the price ranges for the BDM experiment were determined for each data type. Results showed that price ranges for the formal modified BDM experiment were: personal preference data RMB 0-100, contact data RMB 0-300, combined data RMB 0-500, Weibo account data RMB 0-500, and Weibo historical data RMB 0-500.

3.6 Modified BDM Formal Experiment The formal experiment followed the modified BDM mechanism described above, with price ranges set according to pre-experiment results. Regardless of auction success, each user's bid was recorded as their true perception of personal data value for experimental data analysis.

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4 Experimental Data Analysis

4.1 Sample Statistics and Data Processing A total of 445 users participated in the experiment, with group participation numbers shown in Table 2 . The modified BDM experiment was divided into two groups using within-subject designs: the first group bid sequentially on personal preference, contact, and combined data; the second group bid on Sina Weibo account and historical data. The TIOLI experiment used a between-subjects design, with users divided into 5 groups, each making decisions on only one personal data type.

In the modified BDM experiment, the price distribution for selling personal data is shown in Table 3 . When calculating average selling prices, to reduce data errors, all bids above the corresponding price range upper limit were excluded. However, when calculating medians and percentiles, all user bids were included, with users refusing to sell personal data recorded as infinite bids.

4.2 Modified BDM Experimental Data Analysis

4.2.1 Selling Willingness Table 3 shows that most users are willing to sell their personal data for profit. The proportion willing to sell personal preference data is highest (95.3%), but the average selling price is lowest (RMB 38.8), likely because personal preference data is anonymous. Since users' decisions on personal data are binary ("agree to sell" or "disagree to sell") and the same group of users made sequential decisions on different data types, McNemar's Test for paired chi-square analysis was appropriate. Paired chi-square test results show that compared with personal preference data, users' willingness to sell contact and combined data decreased significantly (McNemar's Test, $p < 0.001$). However, no significant difference exists between willingness to sell Sina Weibo account data and historical data (McNemar's Test, $p = 0.629$).

4.2.2 Selling Price Normality tests revealed that all experimental group data failed to follow normal distributions (normality tests, all $p < 0.05$). Therefore, when analyzing selling prices, parametric paired T-tests were avoided in favor of the non-parametric Wilcoxon Signed Ranks Test. Wilcoxon test results show that users' selling prices for personal preference data were significantly lower than for contact data, and combined data selling prices were significantly higher than contact data (Wilcoxon Signed Ranks Test, both $p < 0.001$). For Sina Weibo data, no significant difference exists between selling prices for account

data and historical data (Wilcoxon Signed Ranks Test, p = 0.270), with most users bidding similarly for both data types.

4.2.3 User Gender When analyzing gender's impact on personal data selling prices, the non-normal distribution again necessitated the Mann-Whitney U Test. Using user gender as the grouping variable, Mann-Whitney U test results are shown in Table 4 . Female users' valuations of personal preference data, contact data, and combined data were all significantly higher than males' (Mann-Whitney U Test, all $p < 0.05$). However, user gender had no significant effect on selling prices for Weibo account or historical data.

4.2.4 Visualization of Experimental Results To clearly display price distributions for the five personal data types, Minitab software was used to plot cumulative price distribution graphs, as shown in Figure 1 [Figure 1: see original paper] and Figure 2 [Figure 2: see original paper]. The figures demonstrate significant differences in price distributions among personal preference data, contact data, and combined data, while selling prices for Sina Weibo account data and historical data show minimal differences, consistent with Wilcoxon test results.

Overall, in the modified BDM experiment, the proportion of users willing to sell Sina Weibo data was comparable to those willing to sell combined data, with similar average selling prices. This may be because both datasets involve contact data and content related to preferences or other personal privacy. Additionally, the Sina Weibo dataset includes third-party data (such as information about Weibo friends), indicating that users largely ignore potential privacy leakage to others when deciding whether to sell their personal data and setting prices.

4.3 Hypothetical Bias Verification

4.3.1 Cause Hypothetical bias arises when using CVM to value non-market products because the method implicitly assumes that respondents know their personal preferences, can accurately value the non-market product, and are willing to report their true WTP or WTA. However, in actual surveys, users often lack the incentive to report true WTP or WTA.

4.3.2 Verification Object In 2013, Germany's largest polling organization "Forsa" conducted a survey on German citizens' attitudes toward their privacy data [17], using telephone interviews with 1,000 participants (460 male, 540 female, aged 18-94). Users were asked: "If receiving monetary compensation, would you agree to sell your personal data for commercial use?" Table 5 lists the proportion of users agreeing to sell each data type.

4.3.3 Verification Results Table 5 shows that using CVM, only about 6% of users agreed to sell their personal data for commercial use. However, in this

study's modified BDM experiment, about 85% of users agreed to sell personal data. Although differences in survey population nationality and timing may contribute to the discrepancy, hypothetical bias may also be a cause.

5 Discussion

Regarding personal data value, the modified BDM experiment reveals that approximately 85% of users are willing to sell their personal data, but selling prices vary by type. Personal preference data has the lowest average price (RMB 38.8), contact data averages RMB 136.3, combined data averages RMB 237.9, Sina Weibo account data averages RMB 221.8, and Sina Weibo historical data averages RMB 231.4, demonstrating that users have different sensitivity levels toward different types of privacy data. Notably, when calculating average selling prices, the approximately 15% of users who refused to sell were not considered, so experimental conclusions may slightly underestimate true personal data value. Most users are willing to sell personal preference data, likely because it is anonymous. However, when anonymous personal preference data is bundled with non-anonymous contact data, the proportion of willing sellers decreases significantly in both the modified BDM and TIOLI experiments, indicating that data anonymization substantially alleviates privacy leakage concerns.

In terms of hypothetical bias, the modified BDM experiment concludes that about 85% of users are willing to sell personal data for economic compensation, whereas telephone survey-based CVM yields only about 6%. This difference between research methods suggests potential hypothetical bias.

According to statistics, current actual compensation levels in China's personal data infringement cases are approximately RMB 10 per record [18-23], far below users' perceived value from this study. Although implementing these research results as actual compensation standards may be difficult, compensation standards should be appropriately increased to meet user expectations. Additionally, privacy policy formulation should consider factors such as region and gender, as economic development level differences across regions affect users' personal data value perception.

This study has two limitations: First, the sample size is relatively small and geographically restricted, necessitating mostly non-parametric tests for significance testing. Future research should expand sample sizes to meet T-test application conditions, thereby fully utilizing data information and more easily detecting true population differences. Second, constructing a comprehensive personal data list to measure values for all types of personal data represents a future research direction.

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Author Contributions

Zhang Kailiang: Data collection and analysis, chart creation, drafting initial manuscript.
Zang Guoquan: Proposed research ideas, designed research framework, re-

vised final manuscript.
Yan Li: Data collection and technical support.

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Note: Figure translations are in progress. See original paper for figures.