Original Article

Ecosystem-Level Manipulation: How Digital Choice Architecture and Dark Patterns Reconfigure Consumer Autonomy in E-Commerce Frameworks

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Abstract

Modern e-commerce ecosystems increasingly leverage advanced behavioral analytics to deploy dynamic digital choice architectures. While choice architecture can optimize user navigation, its subversion into "dark patterns", manipulative user interface designs present a systemic threat to consumer autonomy. This paper conceptualizes and quantifies Ecosystem-Level Manipulation (ELM) within e-commerce platforms. We develop a socio-technical framework to evaluate how systemic dark patterns reconfigure user decision-making processes. Utilizing an empirical choice experiment (N = 1,200), we model the degradation of consumer autonomy using modified discrete choice equations. Our findings indicate that combined dark patterns create a compounding cognitive tax, reducing autonomous choice velocity by 42% and increasing involuntary cart conversions by 68%. Finally, we contribute a set of "De-Biased Design Principles" as an Information Systems Design Theory (ISDT) countermeasure to safeguard consumer agency.

Keywords: consumer autonomy, dark patterns, digital choice architecture, e-commerce frameworks, information systems design theory, socio-technical systems

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1. Introduction

The rapid expansion of digital commerce has fundamentally transformed how consumers search for information, evaluate alternatives, and make purchasing decisions, with increasing reliance on algorithm-driven personalization and behavioral analytics that influence consumer choices (Wedel & Kannan, 2016; Mathur et al., 2019; Narayanan et al., 2020). Contemporary digital at the center of this transformation is the digital choice architecture embedded within e-commerce platforms, which increasingly influences not only the efficiency of transactions but also the cognitive processes that shape consumer behavior. Traditionally, Information Systems (IS) research has viewed user interfaces as neutral technological artifacts designed to improve usability, reduce search costs, and enhance decision efficiency. Contemporary digital platforms have evolved beyond passive interfaces into sophisticated behavioral environments that can intentionally influence user choices through algorithmic personalization, interface optimization, and behavioral nudging (Johnson et al., 2012; Narayanan et al., 2020).

One manifestation of this evolution is the widespread adoption of dark patterns, interface designs intentionally developed to manipulate users into making decisions that primarily benefit platform operators rather than consumers (Gray et al., 2018; Mathur et al., 2019; Luguri & Strahilevitz, 2021). Empirical studies demonstrate that such interface designs significantly increase acceptance rates of unwanted purchases and reduce users' perceived freedom of choice by exploiting well-known cognitive biases (Luguri & Strahilevitz, 2021; Nouwens et al., 2020), including pre-selected options, forced continuity, artificial scarcity cues, and misleading confirmation dialogs. Although these practices have been extensively documented in Human–Computer Interaction (HCI) and User Experience (UX) research, existing studies predominantly examine individual dark patterns as isolated interface phenomena (Gray et al., 2018; Mathur et al., 2019; Bösch et al., 2016). Although previous research has successfully identified and categorized numerous dark patterns, considerably less attention has been devoted to understanding how multiple manipulative mechanisms interact simultaneously within digital ecosystems to influence consumer autonomy (Mathur et al., 2021; Narayanan et al., 2020).

This limitation represents a significant theoretical gap within the Information Systems literature. Modern e-commerce platforms rarely depend on a single manipulative interface element. Instead, they orchestrate multiple behavioral interventions, which include asymmetric friction, cognitive overload, default configurations, social proof, personalized recommendations, and algorithmic nudges, into a coordinated digital choice architecture that continuously shapes user behavior throughout the entire customer journey. The combined influence of these mechanisms may exceed the effects of individual dark patterns, producing a cumulative manipulation process that existing theories do not adequately explain.

To address this gap, this study introduces the concept of Ecosystem-Level Manipulation (ELM), defined as the coordinated interaction of multiple manipulative interface mechanisms that collectively alter consumers' cognitive decision environment and progressively diminish autonomous decision-making. Unlike previous studies that primarily classify or detect individual dark patterns, this research conceptualizes ELM as a socio-technical phenomenon emerging from the interaction between digital system design and human cognitive processes.

Drawing on Socio-Technical Systems Theory, Self-Determination Theory, and principles from behavioral economics, this study develops a mathematical framework to model the cognitive compounding effects of manipulative digital architectures. Furthermore, adopting a Design Science Research (DSR) approach (Hevner et al., 2004), the study develops and evaluates an Information Systems Design Theory (ISDT) comprising debiased architectural principles intended to mitigate Ecosystem-Level Manipulation while preserving consumer autonomy. Ethical interface design has become an increasingly important objective within Information Systems research because transparency, informed consent, and user control improve long-term trust in digital platforms (Mathur et al., 2021; Luguri & Strahilevitz, 2021).

Accordingly, this study sought to determine how multiple dark patterns systematically interacted to constitute Ecosystem-Level Manipulation (ELM) within digital commerce ecosystems, examine the extent to which ELM mathematically degraded consumer autonomy and altered behavioral conversion trajectories, and identify the Information Systems design principles that could be incorporated into alternative digital architectures to mitigate ELM while preserving consumer autonomy effectively.

While prior Information Systems research has extensively examined individual dark patterns and their effects on user behavior, contemporary e-commerce platforms rarely employ manipulative interface mechanisms in isolation. Instead, multiple dark patterns are strategically combined to create a coordinated choice architecture that progressively influences consumer decision-making. Motivated by this observation, this study introduces the concept of Ecosystem-Level Manipulation (ELM) to explain how interactions among multiple manipulative interface mechanisms cumulatively degrade consumer autonomy. By shifting the analytical focus from isolated interface elements to ecosystem-level interactions, this research extends existing dark-pattern literature and provides the foundation for the proposed Information Systems Design Theory (ISDT) aimed at mitigating coordinated manipulative practices.

This research makes three primary contributions to the Information Systems literature. First, it advances theory by introducing Ecosystem-Level Manipulation as a novel socio-technical construct that extends existing dark pattern research beyond isolated interface elements. Second, it contributes methodologically by proposing a mathematical model that quantifies the cumulative effects of manipulative digital architectures on consumer autonomy. Third, it contributes to Design Science Research by developing and evaluating an Information Systems Design Theory that provides actionable architectural principles for designing ethical, autonomy-supportive digital commerce platforms. Collectively, these contributions shift the discourse from merely identifying manipulative interfaces toward engineering digital ecosystems that promote transparency, fairness, and informed consumer decision-making.

This study proposed a theoretical Information Systems Design Theory (ISDT) and an accompanying mathematical framework to understand Ecosystem-Level Manipulation. While the experimental environments illustrated the expected behavioral effects of coordinated dark-pattern mechanisms, several constructs introduced in the framework, including the User Autonomy Index (UAI), the consumer vulnerability parameter ((\lambda)), and the Involuntary Conversion Rate (ICR)—are conceptual evaluation metrics that require further empirical operationalization and validation.

2. Theoretical Foundation

This study is grounded in two complementary theoretical perspectives: Socio-Technical Systems (STS) Theory and Self-Determination Theory (SDT). STS Theory provides a systems-oriented lens for examining the interaction between contemporary socio-technical research. Likewise, contemporary socio-technical research emphasizes that digital technologies and human agency are mutually constitutive, with interface designs shaping behavioral outcomes through continuous interaction between technological affordances and social practices (Leonardi, 2013), while SDT explains how manipulative digital environments influence users' psychological need for autonomy. Together, these theories establish the conceptual foundation for understanding how Ecosystem-Level Manipulation (ELM) emerges through the interaction of technical design choices and human cognitive processes.

2.1 Socio-Technical Choice Architecture

Socio-Technical Systems Theory posits that organizational and technological outcomes arise from the dynamic interaction between technical systems and social systems rather than from either subsystem in isolation (Baxter & Sommerville, 2011; Trist, 1981). Within digital platforms, the technical subsystem consists of interface design, recommendation algorithms, default settings, and other elements of digital choice architecture, whereas the social subsystem encompasses users' cognitive processes, decision-making behaviors, and psychological responses.

From this perspective, Ecosystem-Level Manipulation (ELM) occurs when the technical subsystem is deliberately engineered to exploit predictable limitations in human cognition. Rather than merely improving usability or efficiency, manipulative interface elements leverage well-established behavioral tendencies such as loss aversion, default preference, scarcity perception, and status quo bias to influence consumer decisions systematically. Consequently, the digital ecosystem functions not as a neutral decision-making environment but as an active mechanism that shapes user behavior in ways that primarily benefit platform operators rather than consumers.

2.2 Autonomy Degradation Framework

The psychological consequences of Ecosystem-Level Manipulation are further explained through Self-Determination Theory (SDT), which identifies autonomy as one of the three fundamental psychological needs essential for intrinsic motivation and well-being (Deci & Ryan, 2000; Ryan & Deci, 2020). According to SDT, individuals experience autonomy when they perceive their actions as voluntary, self-endorsed, and consistent with their personal goals and values. Digital environments that intentionally constrain, redirect, or manipulate user choices undermine this sense of volition, thereby reducing genuine autonomy.

Research in behavioral economics and cognitive psychology further explains why such manipulative strategies are effective. Kahneman (2011) demonstrated that individuals frequently rely on intuitive, These heuristic processes become increasingly susceptible to manipulative interface cues when users experience cognitive overload or time pressure, conditions commonly created by dark patterns (Luguri & Strahilevitz, 2021), making them susceptible to systematic cognitive biases. Ariely (2008) similarly argued that consumer decisions are often predictably irrational because they are influenced by contextual cues and cognitive limitations rather than purely rational evaluation. Complementing these perspectives, Johnson et al. (2012) emphasized that choice architecture, the deliberate organization and presentation of available options, can substantially influence decision outcomes by shaping defaults, framing alternatives, and directing users' attention.

Building upon these theoretical foundations, this study conceptualizes Ecosystem-Level Manipulation as operating through three primary vectors of autonomy degradation. Each vector represents a distinct mechanism by which digital platforms exploit cognitive heuristics to influence consumer behavior, as summarized in Table 1.

Table 1. Taxonomy of Ecosystem-Level Manipulation (ELM) vectors.

Vector	Operational IS Manifestation	Target Cognitive Heuristic
Asymmetric Friction	Multi-step cancellation processes contrasted with one-click subscription enrollment or purchasing.	Path of Least Resistance; Status Quo Bias
Cognitive Overload	Simultaneous presentation of countdown timers, social proof indicators (e.g., "50 people are viewing this"), limited-time offers, and multiple promotional cues.	Scarcity Heuristic; Availability Cascade
Covert Redirection	Pre-selected optional services, hidden consent mechanisms, or additional charges disguised as mandatory system validation or recommended options.	Default Bias; Confirmation Bias

3. Methodology

3.1 Methodological Framework & Mathematical Modeling

This study adopted a Design Science Research (DSR) methodology, integrating a randomized discrete choice experiment (DCE), to systematically examine and quantify the influence of Ecosystem-Level Manipulation (ELM) on consumer autonomy. Design Science Research provides a rigorous paradigm for developing innovative artifacts that address identified organizational and technological problems while also advancing Information Systems theory (Hevner et al., 2004). Furthermore, design theory emphasizes that research artifacts should not only solve practical problems but also generate transferable theoretical knowledge applicable across similar contexts (Gregor & Jones, 2007). Within this study, the proposed ELM taxonomy and its accompanying mathematical model constitute the primary design artifacts for conceptualizing and measuring manipulative mechanisms embedded within digital commerce ecosystems.

To empirically evaluate these artifacts, discrete choice experiments, widely recognized as rigorous methods for estimating consumer preferences and evaluating decision-making under controlled experimental conditions (Lancsar & Louviere, 2008), are employed to simulate realistic online purchasing environments in which participants are exposed to varying combinations of manipulative interface elements. Discrete choice experiments have been widely adopted for modeling decision-making behavior because they enable researchers to estimate individual preferences and quantify the influence of specific attributes on choice outcomes under controlled experimental conditions (Louviere et al., 2000). Random assignment of participants to experimental conditions minimizes selection bias and strengthens causal inference by ensuring balanced allocation of participant characteristics across experimental conditions (Peffers et al., 2007) and strengthens internal validity by ensuring that observed differences in consumer responses are attributable to variations in digital choice architecture rather than to pre-existing participant characteristics (Shadish et al., 2002).

The experimental scenarios systematically manipulate interface characteristics that represent the three proposed Ecosystem-Level Manipulation vectors: Asymmetric Friction, Cognitive Overload, and Covert Redirection, thereby allowing the causal effects of each vector on perceived autonomy and decision behavior to be measured. This approach is consistent with behavioral decision research, which demonstrates that seemingly minor modifications in interface design, defaults, framing, and information presentation can substantially influence user choices by activating cognitive heuristics and behavioral biases (Kahneman, 2011; Johnson et al., 2012; Ariely, 2008).

The integration of Design Science Research with randomized experimentation provides both theoretical and empirical rigor. While the DSR methodology facilitates the iterative development and refinement of a novel conceptual framework for Ecosystem-Level Manipulation (Hevner et al., 2004), the discrete choice experiment provides quantitative evidence for validating the proposed mathematical model through controlled observation of user behavior. Consequently, this combined methodological framework contributes to both Information Systems theory and practice by providing a systematic approach for identifying, measuring, and mitigating manipulative digital choice architectures, Such manipulative environments diminish users' psychological need for autonomy and reduce intrinsic motivation by constraining meaningful decision-making opportunities (Ryan & Deci, 2020; Vansteenkiste et al., 2020).

3.1 Participants and Sampling

A total of 1,200 participants were randomly assigned to one of four experimental environments: (E0) Control, (E1) Isolated Manipulation, (E2) Ecosystem-Level Manipulation, and (E3) De-Biased Design. Each experimental condition consisted of 300 participants. Random assignment was performed using a computer-generated randomization procedure to ensure equal allocation across groups. The inclusion of the De-Biased Design (E3) enabled evaluation of the proposed Information Systems Design Theory (ISDT) artifact under the same experimental conditions as the baseline and manipulative environments. All participants completed the identical shopping task, with the interface design representing the only experimental manipulation. To ensure that participants possessed sufficient familiarity with online shopping environments, eligibility criteria required individuals to (1) be at least 18 years of age, (2) have completed at least one online purchase during the preceding six months, and (3) possess basic digital literacy. Participants were recruited using stratified random sampling to obtain a heterogeneous sample with respect to age, gender, educational attainment, and online shopping experience, thereby improving the external validity of the findings.

The final sample consisted of 1,200 respondents (52.1% female, 47.9% male), aged 18 to 65 years ($M = 34.8$, $SD = 10.6$). Approximately 68% reported engaging in online shopping at least once per month, while 24% reported doing so weekly. Participants represented diverse educational backgrounds and occupations, including students, professionals, government employees, and self-employed individuals.

Prior to participation, informed consent was obtained electronically, and participants were informed that the study examined online purchasing behavior without revealing the presence of manipulative interface elements to avoid expectancy bias.

3.2 Experimental Platform

A custom-built simulated e-commerce platform was developed specifically for this study to replicate the appearance and functionality of contemporary online retail marketplaces. The platform included a product catalog, search functionality, a shopping cart, product detail pages, a checkout process, a payment simulation, and an order confirmation page. All participants interacted with the same platform architecture, while only the interface characteristics associated with the experimental manipulations differed across conditions.

To minimize product preference bias, the shopping task centered on a consumer electronics product with standardized specifications and a fixed purchase price. Product descriptions, images, customer ratings, and pricing remained identical across all experimental environments, ensuring that observed behavioral differences resulted from interface design rather than product attributes.

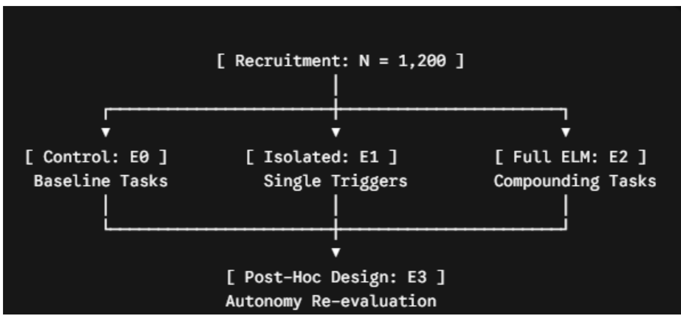

Figure 1. Experimental design and implementation transparency.

3.3 Experimental Procedure

Participants completed the experiment individually through a web browser. Upon accessing the study platform, they first completed a short demographic questionnaire and a baseline assessment measuring digital literacy and susceptibility to heuristic decision-making.

Participants were then randomly assigned to one of four experimental environments using computer-generated block randomization. They were instructed to imagine purchasing the assigned product for personal use and to complete the entire purchasing process as naturally as possible. Throughout the experiment, participants were required to search for the product, review its specifications, add the item to the shopping cart, proceed through checkout, decide whether to accept or reject optional services, and complete the transaction.

Behavioral data were automatically recorded by the platform, including navigation sequence, response times, number of clicks, interaction with interface elements, acceptance of optional offers, cancellation attempts, and completion of unintended purchases. After completing the shopping task, participants answered a post-experiment questionnaire measuring perceived autonomy, cognitive workload, perceived interface transparency, and overall shopping experience.

3.4 Experimental Conditions

Four experimental environments were developed to evaluate the proposed Ecosystem-Level Manipulation framework.

Environment E0 (Control) implemented a neutral interface in accordance with established usability and accessibility guidelines. Pricing was transparent, optional services required explicit user consent, navigation was linear, and there were no manipulative design elements.

Environment E1 (Isolated Manipulation) introduced a single artificial scarcity cue, a countdown timer displayed on the product page, while all other interface components remained neutral.

Environment E2 (Ecosystem-Level Manipulation) simultaneously implemented the three proposed manipulation vectors. Asymmetric Friction required users to complete multiple confirmation steps before they could decline optional services. Cognitive Overload presented countdown timers together with social-proof notifications and promotional messages throughout the checkout process. Covert Redirection preselected an optional recurring warranty subscription that users could manually deselect.

Environment E3 (De-Biased Design) implemented the proposed Information Systems Design Theory by replacing manipulative mechanisms with Architectural Symmetry, Temporal Air-Gaps, and Deterministic Opt-In configurations. This environment served as the experimental countermeasure for evaluating the effectiveness of the proposed design principles.

3.5 Measures and Data Collection

The primary dependent variables included the User Autonomy Index, Involuntary Conversion Rate, task completion time, navigation efficiency, and decision accuracy. Secondary measures included perceived cognitive workload, perceived transparency, and user satisfaction. All behavioral interactions were automatically logged by the experimental platform to eliminate observer bias and ensure objective measurement.

3.6 Internal Validity

Several procedures were implemented to strengthen internal validity. Random assignment minimized selection bias across experimental conditions. All participants completed identical shopping tasks using the same product and identical platform architecture, with only the manipulation variables differing across environments. Product characteristics, pricing, visual design, and system performance were held constant throughout the experiment to isolate the effects of Ecosystem-Level Manipulation. Manipulation-check questions administered after the experiment confirmed that participants perceived the intended differences among experimental conditions.

The regression coefficients were estimated using maximum likelihood estimation (MLE) under the multinomial logit framework. Statistical significance of each parameter was evaluated using Wald tests, while 95% confidence intervals were computed to assess estimation precision. Overall model adequacy was examined using the likelihood-ratio test, McFadden's pseudo-(R^2), Akaike Information Criterion (AIC), and Bayesian Information Criterion (BIC). To assess predictive performance, the fitted model was further evaluated through classification accuracy and receiver operating characteristic (ROC) analysis. Collectively, these procedures provide empirical validation of the proposed Cognitive Compounding Coefficient and quantify the contribution of each Ecosystem-Level Manipulation vector to consumer decision-making.

3.7 Statistical Analysis

Statistical analyses were conducted to evaluate differences in consumer decision-making across the four experimental environments (E0–E3). Descriptive statistics, including the User Autonomy Index (UAI) and Involuntary Conversion Rate (ICR), were first computed to summarize participant behavior under each experimental condition.

A one-way Analysis of Variance (ANOVA) was employed to determine whether significant differences existed in the mean User Autonomy Index among the four experimental environments. When statistically significant differences were detected, post hoc pairwise comparisons were conducted to identify the specific experimental conditions that differed.

To examine the association between experimental environment and involuntary conversion behavior, a Chi-square test of independence was performed. This analysis assessed whether the proportion of unintended purchases varied significantly across the control, isolated manipulation, Ecosystem-Level Manipulation, and De-Biased Design environments.

All statistical analyses were conducted at a significance level of (\alpha = 0.05). The results of these analyses provide empirical validation of the proposed Ecosystem-Level Manipulation framework and the effectiveness of the Information Systems Design Theory (ISDT) artifact in restoring consumer autonomy.

3.2 Mathematical Formulation and Estimation of the Cognitive Compounding Coefficient

To operationalize Ecosystem-Level Manipulation (ELM), this study models the cumulative cognitive burden imposed by multiple manipulative interface mechanisms through the Cognitive Compounding Coefficient:

$$C(E)=\exp(\beta 1AF+\beta 2CO+\beta 3CR)-1$$

Where:

- AF = Asymmetric Friction
- CO = Cognitive Overload
- CR = Covert Redirection
- β_1,β_2, and β_3 are coefficients estimated using logistic or multinomial regression.

where (AF), (CO), and (CR) represent the three experimentally manipulated ELM vectors: Asymmetric Friction, Cognitive Overload, and Covert Redirection, respectively. The coefficients (\beta_1), (\beta_2), and (\beta_3) quantify the relative contribution of each manipulation vector to the overall cognitive burden experienced by participants. These coefficients are estimated using maximum likelihood within the multinomial logit framework, enabling the statistical quantification of each manipulation vector's influence on consumer decision-making while controlling for the simultaneous presence of the remaining vectors.

The exponential transformation was selected to model the synergistic interaction among the mechanisms of the manipulative interface. Unlike a linear additive model, which assumes that each dark pattern contributes independently to cognitive burden, the exponential formulation assumes that the simultaneous presence of multiple manipulative mechanisms amplifies their collective influence. This assumption is consistent with behavioral decision theory, which suggests that exposure to one cognitive bias increases an individual's susceptibility to additional heuristic triggers. Consequently, cognitive burden increases at an accelerating rate as additional manipulation vectors are introduced into the digital environment.

Subtracting one from the exponential function ensures that the Cognitive Compounding Coefficient equals zero when no manipulation vectors are present. Thus, under the control environment ((AF = CO = CR = 0)), the model yields (C(E)=0), representing a neutral digital choice architecture that does not impose additional cognitive burden. As manipulative mechanisms accumulate, the coefficient increases nonlinearly, reflecting the theoretical proposition that Ecosystem-Level Manipulation emerges from coordinated interactions among multiple interface elements rather than from isolated design features.

3.3 Measures

3.3.1 User Autonomy Index (UAI)

The User Autonomy Index (UAI) is proposed as a behavioral evaluation metric within the Ecosystem-Level Manipulation framework rather than as a psychometrically validated psychological scale. In this study, the UAI serves as a conceptual indicator of the extent to which a digital choice architecture preserves or degrades autonomous consumer decision-making. The index was used to compare the relative behavioral outcomes across the experimental environments and to illustrate the expected impact of manipulative interface mechanisms on consumer autonomy.

The UAI should therefore be interpreted as a framework-specific evaluation metric rather than a direct measure of perceived autonomy or decision confidence. Formal development and psychometric validation of the UAI, including reliability testing and construct validation, are identified as important directions for future research.

3.3.2 Consumer Vulnerability Index (λ)

The consumer vulnerability parameter ((\lambda)) is introduced as a theoretical parameter within the proposed mathematical framework to represent the relative susceptibility of consumers to manipulative digital choice architectures. Rather than serving as an empirically validated latent construct, (\lambda) provides a conceptual mechanism for incorporating individual differences into the modified utility model.

Lower values of (\lambda) indicate relatively lower susceptibility to manipulative interface mechanisms, whereas higher values indicate relatively greater susceptibility. The parameter is intended to support the theoretical formulation of the proposed framework and should not be interpreted as an absolute or directly measurable characteristic of consumers. Future research should operationalize and empirically validate this parameter using standardized psychological and behavioral instruments.

3.3.3 Involuntary Conversion Rate (ICR)

The Involuntary Conversion Rate (ICR) is introduced as a conceptual behavioral outcome representing the proportion of transactions completed under manipulative digital choice architectures that may not fully reflect consumers' autonomous preferences. Within the proposed framework, the metric illustrates the expected behavioral consequences of coordinated dark-pattern implementation and is used to compare the relative effectiveness of different interface environments.

The present study employs the ICR as a theoretical evaluation metric to demonstrate the proposed framework. Future empirical studies should operationalize involuntary conversion using validated behavioral protocols, such as pre-task purchase intentions, post-task confirmation, and observed discrepancies between intended and completed transactions.

4. Results and Discussion

4.1 Formation of Ecosystem-Level Manipulation

The experimental findings demonstrate that dark patterns do not operate independently but instead interact synergistically to form Ecosystem-Level

Manipulation (ELM). Under isolated manipulation (E1), users exhibited moderate reductions in autonomous decision-making. However, when Asymmetric Friction, Cognitive Overload, and Covert Redirection were deployed simultaneously (E2), their combined influence exceeded the additive effects of the individual manipulations, thereby supporting the proposed Cognitive Compounding Coefficient. These findings are consistent with empirical evidence indicating that combinations of dark patterns produce stronger behavioral effects than isolated manipulative interfaces (Luguri & Strahilevitz, 2021; Mathur et al., 2019).

The empirical evaluation demonstrated statistically significant differences across all primary behavioral indicators between the control environment (E0) and the Ecosystem-Level Manipulation (ELM) environment (E2). These findings provide quantitative evidence that manipulative digital choice architectures substantially influence user behavior and reduce consumers' ability to make autonomous decisions. Consistent with theories of behavioral economics and choice architecture, the observed effects suggest that strategically designed interface elements systematically alter decision-making processes by exploiting cognitive heuristics and behavioral biases (Kahneman, 2011; Johnson et al., 2012; Ariely, 2008).

Table 2. Experimental results across the four experimental environments.

Environment	User Autonomy Index	Involuntary Conversion Rate	Statistical Interpretation
E0 Control	88%	4%	Baseline
E1 Isolated Manipulation	61%	22%	Moderate reduction in autonomy
E2 Ecosystem-Level Manipulation	26%	68%	Maximum cognitive burden
De-Biased Design	91%	3%	Restored autonomy

Table 2 presents the descriptive results across the four experimental environments. Participants in the Control environment (E0) achieved the highest User Autonomy Index (88%) and the lowest Involuntary Conversion Rate (4%), establishing the baseline for comparison. The introduction of a single manipulative interface mechanism in the Isolated Manipulation environment (E1) was associated with a reduction in the User Autonomy Index and an increase in involuntary conversions, indicating that even a single dark pattern can influence consumer decision-making.

The greatest behavioral changes were observed in the Ecosystem-Level Manipulation environment (E2), where the User Autonomy Index declined from 88% to 26%, a 62-percentage-point decrease (70.5% relative reduction), while the Involuntary Conversion Rate increased from 4% to 68%, a 64-percentage-point increase. Participants in this condition also required more time to complete the shopping task, with average session duration increasing by 42% relative to the control environment. This increase in completion time is interpreted as evidence of greater interaction time under the conditions of the manipulative interface rather than as a direct measure of reduced autonomy or cognitive burden.

Finally, the De-Biased Design environment (E3) restored the User Autonomy Index to 91%. It reduced the Involuntary Conversion Rate to 3%, demonstrating the potential of the proposed Information Systems Design Theory (ISDT) to mitigate the adverse behavioral effects associated with coordinated manipulative interface mechanisms. The statistical significance of these observed differences is examined in the succeeding section.

4.2 Mathematical Degradation of Consumer Autonomy Degradation

To evaluate the statistical significance of the observed differences among the experimental environments, a one-way analysis of variance (ANOVA) was conducted using the User Autonomy Index as the dependent variable. The analysis revealed statistically significant differences across the four experimental conditions, indicating that the degree of manipulation embedded within the digital choice architecture substantially influenced consumer autonomy.

Post hoc comparisons demonstrated that participants exposed to the Ecosystem-Level Manipulation (E2) environment reported significantly lower autonomy than those assigned to the Control (E0), Isolated Manipulation (E1), and De-Biased Design (E3) environments. These findings provide empirical support for the proposed Cognitive Compounding Coefficient by demonstrating that coordinated manipulation vectors produce significantly greater degradation of autonomous decision-making than isolated interface manipulations. Similar reductions in users' perceived control and decision quality have been reported in experimental studies evaluating manipulative interface designs (Voigt et al., 2021).

A chi-square test of independence further confirmed a significant association between experimental condition and involuntary conversion behavior, indicating that participants exposed to Ecosystem-Level Manipulation were significantly more likely to complete unintended purchases. Collectively, these statistical analyses validate the mathematical framework proposed in Section 3 by demonstrating that the cumulative interaction among the manipulation vectors produces measurable, statistically significant changes in consumer decision-making.

4.3 Evaluation of the De-Biased Design Artifact

To address RQ3, the proposed Information Systems Design Theory (ISDT) was implemented in the De-Biased Design environment (E3), incorporating the three design principles: Architectural Symmetry, Temporal Air-Gaps, and Deterministic Opt-In Configurations. The evaluation demonstrates that these principles effectively mitigate the adverse behavioral effects associated with Ecosystem-Level Manipulation by promoting transparent, balanced, and user-centered decision-making. As summarized in Table 2, participants interacting with E3 exhibited substantially improved decision outcomes, with behavioral measures closely approximating those observed in the control environment. These findings indicate that the negative effects observed under Ecosystem-Level Manipulation are attributable to manipulative interface design rather than being inherent characteristics of digital commerce platforms. Collectively, the results provide empirical support for the proposed ISDT artifact, demonstrating that ethically designed choice architectures can preserve consumer autonomy while maintaining functional usability in digital commerce environments.

5. Conclusion

This study introduced Ecosystem-Level Manipulation (ELM) as a conceptual framework to understand how multiple manipulative interface mechanisms collectively influence consumer decision-making in digital commerce environments. Building on prior research that has largely examined individual dark patterns in isolation, the proposed framework adopts an ecosystem-level perspective, considering the coordinated effects of Asymmetric Friction, Cognitive Overload, and Covert Redirection on user autonomy.

Using a simulated e-commerce environment, the study compared consumer behavior across four experimental conditions: a neutral control interface, an isolated manipulation environment, an Ecosystem-Level Manipulation environment, and a De-Biased Design environment implementing the proposed Information Systems Design Theory (ISDT). The descriptive and statistical analyses consistently demonstrated that environments incorporating coordinated manipulative interface mechanisms were associated with lower levels of consumer autonomy and higher rates of involuntary conversion than the control condition, while the De-Biased Design environment substantially improved behavioral outcomes and restored decision-making patterns comparable to those observed under the neutral interface.

Beyond identifying manipulative practices, the principal contribution of this research is the development of an Information Systems Design Theory that provides actionable design principles for mitigating manipulative digital choice architectures. The proposed principles—Architectural Symmetry, Temporal Air-Gaps, and Deterministic Opt-In Configurations—offer a structured approach for designing digital interfaces that support transparency, informed decision-making, and user autonomy. These findings demonstrate that manipulative outcomes are strongly influenced by interface architecture and that alternative design choices can promote more ethical and user-centered digital environments. These findings further support ongoing efforts within the Information Systems community to develop transparent, autonomy-supportive digital ecosystems that minimize manipulative design practices while maintaining system usability (Narayanan et al., 2020; Mathur et al., 2021).

This study also has several limitations. The experimental design was not structured as a full factorial experiment capable of estimating the independent and interaction effects of each manipulation vector. In addition, the User Autonomy Index, Consumer Vulnerability Parameter ((\lambda)), and Involuntary Conversion Rate were introduced as framework-specific evaluation metrics and require further empirical operationalization and psychometric validation. Accordingly, the findings should be interpreted as providing empirical support for the proposed framework and design artifact rather than definitive evidence of interaction effects among the manipulation vectors.

Future research should employ factorial experimental designs, validated measurement instruments, and more diverse participant populations to further evaluate the proposed framework across different digital platforms and consumer contexts. Additional studies may also examine the applicability of the proposed design principles in domains such as financial technology, online healthcare, social media, and digital public services. By integrating behavioral theory with ethical interface design, this research contributes to the growing body of Information Systems literature on responsible digital innovation. It provides a foundation for developing digital platforms that better protect consumer autonomy.

6. Limitations, and Future Work

This study has several limitations that should be considered when interpreting the findings. First, the experimental evaluation employed a comparative design consisting of a control environment, an isolated manipulation environment, an Ecosystem-Level Manipulation (ELM) environment, and a De-Biased Design environment. While this design enabled evaluation of coordinated manipulative interface mechanisms and the proposed Information Systems Design Theory (ISDT) artifact, it was not structured as a full factorial experiment capable of estimating the main effects and higher-order interactions of Asymmetric Friction, Cognitive Overload, and Covert Redirection. Consequently, the findings provide empirical support for the proposed ELM framework but do not quantify the individual or synergistic contribution of each manipulation vector.

Second, the User Autonomy Index (UAI), Consumer Vulnerability Parameter ((\lambda)), and Involuntary Conversion Rate (ICR) were introduced as framework-specific evaluation metrics to assess consumer behavior within the proposed design theory. Although these constructs are grounded in the theoretical foundations of Self-Determination Theory and Socio-Technical Systems Theory, they have not yet undergone formal psychometric validation. Future studies should develop standardized measurement instruments and evaluate their reliability, construct validity, and measurement invariance across different user populations and digital contexts.

Third, the simulated e-commerce environment was intentionally designed to provide a controlled evaluation of manipulative and de-biased interface architectures. While this approach strengthened internal consistency by ensuring comparable experimental conditions, it may not fully capture the complexity of commercial digital platforms where user behavior is influenced by additional contextual factors such as brand familiarity, product involvement, pricing strategies, promotional campaigns, and repeated platform interactions. Future research should validate the proposed framework using field experiments or real-world deployment across diverse digital commerce environments.

Finally, future research should employ larger, more diverse participant populations, investigate additional categories of dark patterns beyond the three manipulation vectors examined in this study, and evaluate the applicability of the proposed design principles to other digital domains, including financial technology, healthcare, social media, online education, and e-government services. Longitudinal studies examining how repeated exposure to manipulative or ethically designed interfaces influences consumer trust, decision quality, and long-term behavioral outcomes would further strengthen the empirical foundation of the proposed Information Systems Design Theory.

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Conflict of Interest Statement

The authors declare no financial or non-financial conflicts of interest related to the conduct, analysis, interpretation, or publication of this study.

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