Design of Currency, Markets, and Economy for Knowledge

by

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Abstract

Information markets benefit the communities they serve by facilitating electronic distributed exchange of information. Further benefits include enhancing knowledge sharing, innovation, and productivity. This research explores innovative market mechanisms to build long-term sustainable incentives that many existing platforms fail to provide, while encouraging pro-social behavior. A key advantage of this research is direct application of established information economic and macroeconomic theories to the design of social software and knowledge platforms.

The research contribution is the design of a complete framework for information economy, which consists of several distinct components: 1) a market engine for exchanging information products that are non-rivalrous and non-excludable; 2) a serialized currency system that enables monetary acceleration; 3) “monetary policies” that ensure a healthy growth of currency supply; 4) “fiscal policies” that reward information reuse and good behavior such as tagging, voting, tipping, and fraud reporting.

We built a web-based software platform called Barter, and have deployed it at several universities. Analysis of user data helps test information market effectiveness and illustrates effects of various market interventions. We present our key findings learned in the process of system deployment, such as the impacts of social connections on market interactions and fraud, effects of bounty on information quality, market fraud and intervention of fraud prevention mechanism.

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## Contents

<table>
<thead>
<tr>
<th>Abstract</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Introduction</td>
<td>15</td>
</tr>
<tr>
<td>1.1 Background</td>
<td>15</td>
</tr>
<tr>
<td>1.2 Problem Statement &amp; Goals</td>
<td>17</td>
</tr>
<tr>
<td>1.3 Contribution</td>
<td>19</td>
</tr>
<tr>
<td>1.4 Economic &amp; Market Theories</td>
<td>20</td>
</tr>
<tr>
<td>1.4.1 Overview</td>
<td>20</td>
</tr>
<tr>
<td>1.4.2 Economics of Information</td>
<td>20</td>
</tr>
<tr>
<td>1.4.3 Two-Sided Market Theory</td>
<td>21</td>
</tr>
<tr>
<td>1.4.4 Price Theory</td>
<td>21</td>
</tr>
<tr>
<td>1.4.5 Quantity Theory of Money</td>
<td>22</td>
</tr>
<tr>
<td>1.4.6 Financial Markets Theory</td>
<td>23</td>
</tr>
<tr>
<td>1.5 Organization</td>
<td>24</td>
</tr>
<tr>
<td>2 Design Fundamentals</td>
<td>25</td>
</tr>
<tr>
<td>2.1 Overview</td>
<td>25</td>
</tr>
<tr>
<td>2.2 Modeling Knowledge Objects</td>
<td>25</td>
</tr>
<tr>
<td>2.3 Challenges &amp; Design Goals - A Framework</td>
<td>28</td>
</tr>
<tr>
<td>2.3.1 Step 1 - Existing Organizational Challenges</td>
<td>28</td>
</tr>
<tr>
<td>2.3.2 Step 2 - Challenges of Today's Existing Solutions</td>
<td>30</td>
</tr>
<tr>
<td>2.3.3 Step 3 - Challenges in Incentive Design</td>
<td>32</td>
</tr>
<tr>
<td>2.3.4 Step 4 - Challenges in Designing Knowledge Markets &amp; Economy</td>
<td>35</td>
</tr>
<tr>
<td>2.4 Review Challenges of Knowledge Platforms</td>
<td>37</td>
</tr>
<tr>
<td>2.5 Summary</td>
<td>39</td>
</tr>
<tr>
<td>3 System Architecture</td>
<td>41</td>
</tr>
<tr>
<td>3.1 Overview</td>
<td>41</td>
</tr>
<tr>
<td>3.2 System Architecture</td>
<td>43</td>
</tr>
<tr>
<td>3.3 Knowledge Currency</td>
<td>46</td>
</tr>
<tr>
<td>3.3.1 Overview and Discussion on Incentive Design</td>
<td>46</td>
</tr>
<tr>
<td>3.3.2 Currency Value</td>
<td>48</td>
</tr>
<tr>
<td>3.3.3 Currency Supply &amp; Velocity</td>
<td>50</td>
</tr>
<tr>
<td>3.3.4 Currency &amp; Transaction Design</td>
<td>51</td>
</tr>
<tr>
<td>3.4 Market Engines</td>
<td>53</td>
</tr>
</tbody>
</table>
## List of Figures

2-1 Development of the problem space - how knowledge-related challenges and failure of existing solutions lead to this dissertation research ........................................ 29
2-2 Market design principles followed and implemented in Barter. ........................................ 36
2-3 Challenges faced by knowledge platforms that rely on user-generated contents (UGC) ........................................ 38

3-1 System architecture of the complete Barter knowledge economy framework - from a mechanism design perspective. ........................................ 44
3-2 System architecture of the complete Barter knowledge economy framework - from a technology perspective. ........................................ 44
3-3 Two-layer framework for virtual currency design - Separation between currency usage and currency backup (I: Internal backup, E: External backup). ........................................ 47
3-4 Four market engines of Barter and their supported markets ........................................ 55
3-5 Items posted on the product auction market. ........................................ 68
3-6 Demonstration of credit tracking and attribution 1 - documents are organized as a connected graph ........................................ 74
3-7 Demonstration of credit tracking & attribution 2 - revenues generated by a document are redistributed based upon reuse coefficients ........................................ 75
3-8 Social Navigation View. ........................................ 76
3-9 Expertise Tag Cloud and Experts Matching. ........................................ 77

4-1 Monetary policies that impact the currency exchange between the central bank and the knowledge economy ........................................ 85
4-2 Prototype of Economic Dashboard. ........................................ 93
4-3 Knowledge objects are organized as a tree structure ........................................ 98
4-4 Redistribution along the tree structure ........................................ 100
4-5 Illustration of the information securitization process and derivative markets ........................................ 106
4-6 Parameter estimation of the knowledge economy ........................................ 109

5-1 The entry page of Barter, captured from http://barter.mit.edu/ ........................................ 112
5-2 The landing page of Barter after users’ login ........................................ 112
Dashboards for monitoring the knowledge economy, which show time series of:
1) the number of questions and answers (top),
2) Price indexes (middle), and
3) frequency and volume of market transactions on each day from 04/20/2010 to 04/16/2011. Jumps in activity and price levels occurred in June 2010 when we offered an iPad prize, and March-April 2011 when we launched the News market with material prizes on the auction market.

Number of questions asked categorized by the number of points offered -
a) all questions; b) anonymous questions; c) non-anonymous questions.

Average number of answers obtained, categorized by the number of points offered for questions - a) all questions; b) anonymous questions; c) non-anonymous questions.

Average length of answers obtained, categorized by the number of points offered for questions - a) all questions; b) anonymous questions; c) non-anonymous questions.

Transactions categorized by 1) markets, 2) transaction types.
List of Tables

2.1 Real-world Examples: Two Incentive Schemes Designed by Two Firms . . . 32
3.1 Challenges of Information Products and Barter’s Solutions . . . . . . . 57
3.2 Comparison between U.S. economy and the Barter information economy . 80
Chapter 1

Introduction

1.1 Background

Knowledge and innovation represent significant organizational resources and directly affect organizational success and competitiveness. First-generation attempts to manage knowledge and support innovation relied mainly on centralized Knowledge Management Systems (KMS). Despite their potential, the top-down approach to both content elicitation and validation deployed in these systems has left a large community base with unsolved knowledge problems [3]. The emerging literature on open innovation and crowd-sourcing demonstrates the value of openness for innovation and problem solving[26]. But in addition to benefits, it highlights difficulties in motivating participation[19][16][1][8]. We believe an important reason for participation failure is faulty incentive structures. Members of an organization lack the motivation to participate and share information, especially given their existing work commitments and reporting hierarchies. In other cases, the competitive culture of the organization discourages members from sharing knowledge; questions can be interpreted as a sign of weakness; or people believe information sharing implies giving up competitive advantage. These practical challenges motivate the research presented here.

The importance of incentive design goes beyond the scope of organizational knowledge management. Pervasive web and mobile platforms gather the “wisdom of crowds” [26]. Web 2.0
systems encourage self expression and promote collaboration [22]. “Peer production” refers to the aggregate work of a decentralized community [22]. A cookbook of community design properties has been proposed to facilitate “collective intelligence” [18]. The abundance and convenience of information create an unprecedented information ecology among human beings. A flurry of platforms have been invented to realize these crowdsourcing models, including social bookmarking (reddit.com), review/rating exchange (yelp.com, Amazon.com), Q & A (quora.com), and task completion (Mechanical Turk) to name a few. New systems appear constantly on the horizon.

These systems are predicated on incentives: users need to feel motivated to spend limited time and attention sharing knowledge with others. Success therefore depends on sustainable incentives. People contribute for a variety of reasons: altruism, building reputations, gaining expertise, fun, compensation, etc. Broadly speaking, these fall into “social incentives” and “material incentives.” While many existing platforms rely heavily on social incentives, few explore material incentives. When they do, users may not perceive fair rewards in proportion to contribution. Fixed fees and managerial hierarchies employing top down centrally planned incentives, neglect the power of the crowd itself to determine appropriate rewards. As a result, market design has much to offer organizations whose earlier choices failed to deliver long-term effectiveness, fairness, and stability [9].

There are many starting points for designing incentives. But, whether the levers are social or material, it helps to first ask which specific behaviors we wish to motivate. Designing an information market should depend on behaviors firms want to promote. As a starting point, we suggest desirable behaviors include (1) motivation to participate in the market. This is sometimes called “market thickness” as people need others with whom to trade [13]. (2) The market should motivate sharing and disclosure. As noted, there are many reasons why keeping information private can provide strategic advantage or why sharing might simply be too bothersome. (3) Design should also motivate efficient allocation of resources and attention. Time spent sharing gossip might be better spent sharing insights or even working solo. (4) Motivation should promote idea development even when others can free ride. (5) De-motivation caused by theft and fraud should be avoided. Thus design
should include a measure of “market safety.” (6) Finally, apart from individual motivation, design should enable regulation and motivate those responsible for running the system to do so for the benefit of the community.

These challenges inspire us to reconsider and compare how we human beings organize our production and wealth distribution in the real world: we have created a product-service economy with market forces that guide the allocation of resources and direct human power. The goal shifts away from design of an IT or a knowledge management system to design of a complete knowledge economy. The shift resembles the transition from a centrally planned system to one that is market based. One view characterizes this problem differently:

"Managing an information economy within the firm can improve forecasting, innovation, and productivity. ... Markets cause resources to speak up and self-identify. Markets provide the framework to arbitrage the gap between problem and opportunity. To get these benefits, executives must bring market forces to bear within the firm. The rules, the rewards, and the running of internal markets differ from those of a hierarchy." [4, p. 67]

In our system, pivotal factors of such a decentralized economy include social factors such as status, reputation, and an ability to publicly acknowledge others members of the community. Economic factors include currency, a “Federal Reserve”, prices, and transfer payments. Though stumbling occasionally, a well-established economy sustains its own growth, fairness, and efficiency.

1.2 Problem Statement & Goals

Research presented in this dissertation is motivated by organizational challenges on information sharing and decentralized innovation. How can we build a platform that fully explores the wisdom of the crowd and maximizes the creation, contribution and distribution of knowledge and innovation. From the overview in the previous section, clearly user
adoption is a factual, and the most challenging problem to conquer. An effective incentive mechanism design lies at the center of the problem domain.

The set of problems are organized and tackled in the following order, which also shows how the related problem space has evolved:

1. Existing knowledge platforms inside organizations such as knowledge management systems (KMS) face the challenges of 1) early adoption and elicitation of user contribution, 2) validation and update of knowledge, and 3) valuation of knowledge, user contribution, and user expertise;

2. A crowd-sourcing based platform where users generate contents and innovation appears to be an effective mechanism. However, such platforms still suffer from user participation/adoption problem. Designing a long-term sustainable incentive structure is a critical goal;

3. Using virtual currency to construct incentives is gaining popularity in practice and proves effective in many systems. How do we back up the value of virtual currency with material utilities?

4. With the virtual currency, how does the platform price knowledge objects it elicits from users? Shall the platform deploy decentralized knowledge markets, or a top-down approach where different types of knowledge objects are fixed-priced?

5. Building information markets supported by the usage of virtual currency to construct economic incentives while still encouraging pro-social behaviors points to a promising direction to address the incentive problem. However, information, or knowledge, has peculiar properties that makes a market for information products prone to failure. How to build efficient information markets that tackle these peculiar characteristics of information products?

6. There are further challenges: what if users commit fraud or game market rules to gain unfair advantages? what if people hoard their points without spending? what tools
does the platform offer to managers for stimulating user activities and maintaining healthy growth of the platform?

These problems and goals will be revisited and further expanded in the next chapter. “Identifying” these challenges itself constitutes an important goal of this dissertation research.

1.3 Contribution

The main contribution of this dissertation is to apply established economic theories, market practice and mechanism design to optimize knowledge platforms and solve four problems:

1. Can we shift users from non-participants to participants?
2. Can we increase activity among those who do participate?
3. Can we cause information to be created?
4. Can we value this information?

We clearly identify and list challenges in the problem space. A key innovation presented in this dissertation is a complete design of a knowledge economy framework that effectively tackles these challenges, which consists of knowledge currency, knowledge markets engine, and economic policies.

We have developed a web-based software platform, Barter, to demonstrate the concept and deployed it at universities. As a beta test, our description of Barter does not yet provide complete answers to all questions. Rather, we will show how to incorporate economics and mechanism design into system architecture. We then provide insights gained from the deployments and data analysis.
1.4 Economic & Market Theories

1.4.1 Overview

Several domains of economic theories constitute the theoretical foundation of this dissertation research. Furthermore, they provide guidance in the design of an information market, and practical instruments to tackle various organizational challenges on knowledge management, crowd-sourcing and incentive design. Quoted from Foss & Mahnke[11]:

"Surprisingly, however, organizational economics ... has played no role in the development of knowledge management."

Market theories and industry practice provide further insights and guidance in having the market of information goods healthily grow and properly managed.

In the section, we review the set of economic and market theories used in this dissertation research, and explain how they are applied to different problem domains.

1.4.2 Economics of Information

A classical subject addressed by this discipline is the problem of information asymmetry, which is manifested as "adverse selection" and "moral hazard". A market with severe information asymmetry between buyers and sellers is prone to failure. "Screening" and "signaling" are effective mechanisms to mitigate information asymmetry.

A separate but related problem tackled by information economics is on trading information goods. Information products are fundamentally different from regular commodities such as crude oil, stocks, corns, or clothes. Information products exhibit similar properties as those of public goods: non-rivalry, non-excludability, 0-repetition cost, and spillover effects.

Economics of Information provides essential guidance in designing knowledge markets because of the information products exchanged on knowledge markets and information asym-
metry between buyers and sellers of knowledge. In addition, the spillover effects of information products make valuation of knowledge challenging. Near-zero reproduction cost also presents serious challenges to the safety and integrity of knowledge markets. When knowledge is non-excludable with zero reproduction costs, how shall we design a market that accounts for these distortions and prevents market failure[6]?

1.4.3 Two-Sided Market Theory

Two-sided markets, or two-sided networks, are economic platforms having two distinct user groups that provide each other with network benefits. The adoption of a new platform with two-sided networks faces a classical chicken-and-egg problem - participation by users on one side recursively depends on participation from the other side. Examples include credit cards (card holders / merchants), operating systems (end users / developers), etc.

Two-sided market theory describes how to promote adoption of a technology standard and stimulate third-party development by subsidizing user / developer network effects. For knowledge management, this tells us how to get users to adopt a new system and how to subsidize content creation and content consumption so employees themselves add continuous value [23].

An organizational information market platform is also a two-sided network with information consumers versus information producers (contributors). The success of deploying such a platform inside an organization thus critically depends on solving the chicken-and-egg problem during early user adoption. Compared with ordinary two-sided networks, an information market is equipped with unique tools to tackle the adoption problem by introducing virtual currency and using macroeconomic policies to seed the market.

1.4.4 Price Theory

Price theory describes how markets efficiently allocate resources across an entire economy using only private information. It also tells how markets supply missing goods. For knowledge management, this is critical in getting people to produce valuable knowledge for others
but only when this is more valuable than what they are already doing. It can also tell us how to value intangibles [27, 15], and measure the value created in an information economy.

Several case studies indicate that companies are willing to invest heavily to create monetary incentives for their employees to participate in knowledge sharing activities. However, many used fixed-pricing incentive schemes so that employees received a predetermined amount of money, frequent flier miles, or corporate shares for providing certain types of information. As a result, information whose value was above the given price was never provided, and lots of garbage information got collected. In these cases, prices and incentives were determined using a top-down approach, which resulted in mis-allocation of resources and under-creation of knowledge by the community. Moreover, these cases were one-time promotion campaigns after which knowledge got outdated and user activities withered quickly.

In contrast, floating prices facilitate decentralized knowledge creation, using the invisible hands to fully maximize the collective surplus of information consumers and suppliers. An information market provides long-term sustainable incentive structure for organizations.

1.4.5 Quantity Theory of Money

Quantity theory of money describes, as a special case of macroeconomics, how to manage a supply of value – money, credits, or points – to achieve economic vitality and growth by choosing expansionary or contractionary policies. For knowledge management, this shows how to stimulate and regulate trade volume in the firm’s internal knowledge economy[12, 10].

In its simplest form, quantity theory of money establishes a relationship among money supply, velocity of currency, and price levels in the economy

\[ M \cdot V = P \cdot Q \]  

(1.1)

where \( M \) is the total amount of currency supply in the economy, \( V \) is the velocity of currency in final expenditure, \( Q \) represents the real output, and \( P \) is the corresponding price level.
From this relationship, we learn that economic activities and price levels can be controlled by adjusting currency supply and turnover rate in the economy.

Based on quantity theory of money, an information market platform is equipped with a set of powerful and important macroeconomic tools to monitor and regulate the healthy growth of the knowledge economy. Managing and promoting a knowledge platform is no longer the sole responsibility of an IT manager, but also of a “chief economist” who monitors different economic variables to track the state of the knowledge economy, and employs different macroeconomic policies to stimulate or moderate activities.

1.4.6 Financial Markets Theory

General market design principles are covered in the following chapter. Financial Markets Theory provides conditions, rules and guidelines for securitizing information products so they can be exchanged on a secondary market [20]. As shown in later chapters, securitizing information products derives from a crucial fact that information published on the platform generates long-term income flows. Information providers have incentives to maintain and improve the quality of supplied knowledge for larger long-term gains. Other users, who are not original authors, can opt to participate in contributing to a knowledge object by purchasing its “shares”. Securitizing information and “trading” resulting securities on the derivative market provides advanced instruments to solve several challenging problems, and supplements fun and gamification components to the knowledge economy platform.

The theory also covers computerized market-making algorithms [7] when we design a market for trading certain types of standardized information products and securities.

Industry practice of today’s securities markets provides meaningful guidance and references when we design organizational markets for knowledge.

In addition to the economic theories listed above, several other research fields also play crucial roles in the design process of an information market and impact its overall success. For example, we apply Natural Language Processing (NLP) to understand textual contents users create. Social network modeling and analysis helps understand the dynamics
of social interactions and how information propagates through the network. Information presentation and visualization is particularly important when we design dashboards and gadgets to monitor or control global and personal economic activities. Another closely related area is user interface design, or more broadly, human-computer interaction (HCI), which determines the usability and user experiences of the software system.

1.5 Organization

The remaining chapters of this dissertation are organized as follows. In Chapter 2, we revisit the problem space and clearly present challenges that this dissertation plans to attack, and explain market design principles we adhere to. We then focus on applying economic theories and practice to designing a knowledge economy, and delineating the system architecture, covered in detail in Chapter 3. In Chapter 4, we select several key modules, such as monetary and fiscal policies, from the system architecture and perform a rigorous analysis of their inputs and outputs, further consolidating the mechanism design. Chapter 5 discusses about software development and deployment, and provides lessons learned from analyzing user data. We conclude and point to future directions in Chapter 6.
Chapter 2

Design Fundamentals

2.1 Overview

This chapter contains definitions, terminology, and design principles we adhere to throughout our system design and software development. We first define and model knowledge objects (KO) and extended knowledge objects (EKO). Next, we revisit the problem domain, clearly identify the problems this dissertation research is aiming to solve, and unambiguously differentiate our contribution. Magnifying targeted problems in an organizational setting and highlighting the failure of existing solutions help us lay down the groundwork and the context for our future discussions on information markets. We then focus on proving the effectiveness of a market-based architecture design, and explaining why certain design principles are followed so the targeted problems can be effectively tackled.

2.2 Modeling Knowledge Objects

In order to tackle knowledge-related challenges, we first need to define knowledge and its instantiation in the context of this research. We thus define "knowledge objects (KO)" and "extended knowledge objects (EKO)".
A knowledge object is a piece of information that carries wisdom. Other users care about its availability and value, and can learn something when reading it. On a knowledge platform, it can be instantiated as

- an answer to a question,
- a PDF / Word document, or a Powerpoint presentation,
- a solution to a problem,
- a Blog article or a WIKI article,
- a piece of news or a simple status update,
- a picture or a video clip,
- a comment on other knowledge objects, a comment on a comment,
- ...

These examples represent different subclasses of knowledge objects that are often under-created in today's knowledge-sharing and user-generated contents (UGC) platforms, and what we wish to promote in their creation and sharing.

There is a special type of knowledge objects - “requests for knowledge objects”. Knowledge objects may get created with or without elicitation. A question that waits for answers, a request for documents, are examples of such requests for knowledge objects. Requests and supplied knowledge objects constitute the two sides of the knowledge markets. User activities and interactions on the knowledge markets overtime build up the knowledge base for future search and reuse. Requests for knowledge objects are also modeled as knowledge objects because they carry wisdom, deliver value, and exhibit similar properties as covered below.

We model them as “knowledge objects”, an abstract class, because they carry common attributes that are essential to the knowledge-related problem space, and play important roles in the design of knowledge markets. Examples of these attributes include
Authorship & Credit Tracking - Who is the creator of a knowledge object; whether and how its content derives from other authors’ prior work; By tracking credits and derivation relationships, knowledge objects can be organized as a connected graph, on which each knowledge object is represented as a node;

Pricing Signals - A knowledge object may be protected by a price as the minimum currency needed for accessing contents, or may be freely available, in which case the price is zero; A request for knowledge objects may post bounty as “commitment to pay” once knowledge is supplied in future;

Reuse Tracking & Valuation - Valuation of regular goods is usually determined by fair market price of recent transactions, which does not apply to knowledge objects. Knowledge objects have spillover effects, so their valuation is significantly impacted by their reuse, in addition to the first-time transaction price;

Preview Generation - A summary, preview, or snapshot of the knowledge object should be disclosed to the buyer if the knowledge object is guarded with a price. The purpose is to reduce information asymmetry;

Signaling of Quality - Number of votes (thumb-ups) received, unique page visits, amount of payment received, are all proxies to the quality of the knowledge object. Similarly to preview generation, these signals help minimize information asymmetry when the knowledge object is non-free;

Tagging - Accurate and sufficient tags (keywords) provided to each knowledge object are instrumental in knowledge indexing, searching and reuse, and they help identify and categorize knowledge providers’ expertise.

Knowledge objects exhibit strong characteristics of information products which present significant challenges to constructing a marketplace for exchanging these objects.

Examples of extended knowledge objects (EKO) include
Voting (Thumbing) - Users vote on the quality, usefulness, or relevance by simply clicking on a vote-up or vote-down button, which is often referred to as collective or social filtering;

Tagging - Users supply new tags to knowledge objects or vote on existing ones, which helps knowledge indexing, searching, and reuse;

Payment (Tipping) - Users make payments on knowledge objects to their providers, or simply “tip” them to show appreciation.

Extended knowledge objects do not directly carry wisdom in them. Instead, their presence and sufficiency helps value, index, and sort the knowledge objects they are associated with. Extended knowledge objects are highlighted in this research, because in most platforms they also suffer from the under-creation problem. Although their creation involves very minimal efforts that are not more than clicking on a button, users lack the incentive to perform such simple actions.

2.3 Challenges & Design Goals - A Framework

Fig.2-1 shows the conceptual step-by-step development of how knowledge-related challenges faced by organizations lead to this dissertation research. We will discuss in detail on each block.

2.3.1 Step 1 - Existing Organizational Challenges

Today’s organizations often face the following challenges that have been long-lasting

1.a - Knowledge Sharing & Retention - How to encourage members to share knowledge with each other; how to retain people’s knowledge from their minds within the organization even after they depart;
Figure 2-1: Development of the problem space - how knowledge-related challenges and failure of existing solutions lead to this dissertation research
1.b - Expertise Recognition & Matching - This is a bidirectional problem: given a talent inside an organization, how to identify, recognize and promote his domains of expertise; given a problem, how to route it to the most suitable expert to solve it;

1.c - Decentralized Innovation - Instead of a top-down approach for innovation, how to decentralize the innovation process to all participatory members to collect creative minds, and execute the best ideas;

1.d - Adoption of IT Platforms - Two challenges are outstanding when an organization adopts a new IT platform: 1) Early user adoption - solving the chicken-and-egg problem, and 2) Justification on the ROI (Return on Investment).

The ultimate purposes of meeting these challenges are to 1) enhance knowledge workers’ productivity, and 2) enhance an organization’s competitiveness. [17] reports solid statistical evidence that accessing knowledge markets indeed enhances productivity gains. These challenges have been recognized and they have remained outstanding for decades. Proposed solutions flourish as technology evolves.

2.3.2 Step 2 - Challenges of Today’s Existing Solutions

A plethora of software solutions, either as consumer products or enterprise ones, are designed and implemented to tackle aforementioned challenges. In this dissertation research, we focus more on an organizational setting and addressing knowledge-related problems inside an organization boundary. At the time of writing this dissertation, enterprise 2.0, sometimes referred to as enterprise social network or enterprise collaboration platform, has gained tremendous popularity and is dominating the solution space. They have achieved effectiveness to various degrees, but they often face the following challenges [14]:

2.a - Incentive - The lack of incentive to participate, contribute and share of knowledge is still the most significant and outstanding challenge, which lies at the center of the problem space, and is the primary focus of this research.
In addition to continuously improved features and user experiences, most of today’s software solutions rely on incentives that are characterized as “social incentives” to attract and retain users. They include:

- Altruism
- Reputation
- Expertise recognition
- Self-learning
- Social interaction - maintaining friendship and making new friends
- Achievement / Fulfillment
- Organization guidelines and requirements

While social incentives are effective to a certain degree, adding economic incentives will further solidify the strength of the incentive structure and maximize the “pie” - the amount of knowledge creation and sharing within a platform. We also sometimes refer to economic incentives as “market incentives” or “material incentives”. We will use these phrases interchangeably in future discussions. A key research question is - how do we design market incentives in a pro-social manner? As we know, introducing market norms to a platform incautiously might jeopardize established social norms, which are difficult to recover once destroyed[2].

Other challenges faced by existing solutions include:

2.b - **Noise, Clamoring for Attention** - Not all information is relevant or valuable to a user. Too much information that demands attention creates too much noise that results in a reduction in productivity;

2.c - **Little Managerial Control** - When the platform experiences problems, there is a lack of effective managerial tools or instruments to influence the system and introduce corrections;
Table 2.1: Real-world Examples: Two Incentive Schemes Designed by Two Firms

<table>
<thead>
<tr>
<th>Firm 1 - Use Frequent Flier Miles</th>
<th>Firm 2 - Use Corporate Shares</th>
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<tbody>
<tr>
<td>• Installing Lotus Notes and reading a posting: 4,000 miles</td>
<td>• Answering an urgent request: 3 shares</td>
</tr>
<tr>
<td>• Posting a useful resource for others to share: 2,000 miles</td>
<td>• Developing customer, technology or market bids: 10 shares</td>
</tr>
<tr>
<td>• Posting a request for assistance: 1,000 miles</td>
<td>• Contributing solutions and success stories: 20 shares</td>
</tr>
<tr>
<td>• Posting a response to a request for help: 500 miles</td>
<td></td>
</tr>
</tbody>
</table>

2.3.3 Step 3 - Challenges in Incentive Design

Some organizations recognize the importance of combining market incentives and attempt various schemes of providing material rewards. However, a top-down approach often gets it wrong. Consider the following real-world examples - two sets of incentive rules designed by two firms are presented in Table 2.1.

In these two sets of incentive rules, firms used “fixed rewards” schemes, or “fixed-pricing” elicitation by presetting the price of needed knowledge objects or activities without respecting their true value. As a result of fixed-pricing, experts with knowledge that is more valuable than the given price would not contribute it to the platform. On the other side, novices flood the system with low-quality information just to collect rewards. In addition, the incentives came from merely one-time campaign that was not sustainable. After the promotion period, users lost the incentive to come back to the system, and knowledge got outdated and obsolete soon afterwards.

These two examples reveal two challenges:

3.a - Fixed Pricing - How to avoid fixed pricing for knowledge and user activities. On the contrary, how to reward users based on the true value of knowledge they con-
tribute? Two relevant problems are: 1) How to measure the value of knowledge? 2) How to avoid micro-management of a platform?

3.b - Long-term incentives - How to construct long-term sustainable incentives instead of one-time short-term promotion? How to maintain and manage an appropriate incentive level along time?

Designing rewards using a centralized top-down approach by putting fixed prices on goods and services leads to mis-allocation of resources and inefficiency. On a knowledge platform, users are under-incentivized to participate and knowledge is under-created.

An alternative efficient mechanism is to enable a true peer-to-peer marketplace for knowledge products. Let the price float and rely on the “invisible hands” to balance supply and demand of knowledge products and determine the real value of knowledge. It is proven in the real-world that a market-based economy achieves greater efficiency of resource allocation and maximizes the “pie” compared with a centrally-planned economy. In a market-based economy, the government, the manager of the economy, does not directly influence how prices of goods and services are determined. Instead, the government devises and implements rules and regulations to guarantee the fairness and efficiency of the market, and exerts fiscal policies to invest in products and services that are under-created in a decentralized economy such as fundamental research and public services.

A major contribution of this dissertation research is to apply established economic practice and theories to knowledge platforms in an innovative way. We aim at constructing a true marketplace for knowledge products in order to value knowledge accurately and maximize knowledge creation and sharing. The “governor” of the knowledge platform does not manage the platform by directly interfering with user activities. Instead, the “governor” monitors and guards the integrity and fairness of knowledge markets and exerts influences by executing economic policies.

In the two examples introduced above, frequent flies miles and corporate shares are virtually used as currency to measure knowledge value and deliver material rewards. Currency-based
incentive design is gaining popularity on many platforms. Using currency to facilitate incentive design, either virtual or real, has the following advantages:

- Currency serves as transaction medium, which provides convenience for exchanges of different knowledge objects and transactions. Thus, currency is absolutely necessary for building a true knowledge marketplace and economy;

- Currency enables accurate tracking of contribution, expertise, and reputation on different domains;

- Currency enables advanced economic tools for managers to control, moderate, and grow the platform, and modify user behaviors;

- Currency naturally comes with fun & gamification aspects to engage users.

Therefore, currency not only provides economic incentives, but also strengthens social incentives by calibrating measurement of contribution and reputation. Once we back up currency with what users deem valuable, economic incentives are provided through currency.

Other non-knowledge-based platforms often use currency to engage users and build incentives as well. Frequent flier miles, credit card reward points, dropbox.com on-line storage, SecondLife Linden Dollars, gold coins in computer games are all examples of currency. They are effective in engaging users and getting them rewarded. Campaign promotions such as “Triple miles for flights in XXX season between City A and City B”, or “Double bonus storage space for referring a friend to register” are realizations of currency-based economic tools to modify user behaviors, which would be difficult to implement without currency.

For knowledge platforms, currency-based design is extending its popularity and adoption. For instance, stackoverflow.com uses reputation points to track users’ contribution and expertise, and starts to make them fungible; on quora.com, users can earn and spend “Quora Credits” to promote their questions and acquire attention from experts. Such platforms, when designing reward rules based on currency, still often adopt and deploy fixed-pricing rules, and fail to measure value of knowledge or user activities properly. Managing currency
supply and backing up the value of currency are prominent challenges as well, which we cover in the next section.

2.3.4 Step 4 - Challenges in Designing Knowledge Markets & Economy

From the discussion above, designing knowledge markets supported by associated “knowledge currency” promises an effective mechanism to tackle challenges on knowledge platforms, especially on incentives. Based on this argument, we face a new set of challenges when designing knowledge currency and markets.

Currency-related challenges include:

4.a - Backing up Currency Value - How to provide currency with value that users care about inside and outside the knowledge platform?

4.b - Managing Currency Supply - Oversupplying currency causes inflation and jeopardizes users’ appreciation of currency value; under-supplying currency discourages economic activities which undermines knowledge creation and sharing. Currency growth should thus be maintained at an optimal level. How to inject / extract currency into /from the knowledge economy without negative effects?

4.c - Pricing & Valuing Knowledge - How to measure the value of 1) knowledge objects and 2) various types of user activities, denominated in knowledge currency, so that users get rewarded fairly? The peculiar properties of knowledge objects, i.e. characteristics of information products, make pricing and valuation challenging.

Designing an efficient and effective marketplace for knowledge objects presents a unique set of challenges, primarily due to the special nature of knowledge products.

4.d - General Market-design Principles - A knowledge market needs to first meet necessary conditions required by any generic market to be successful and efficient. Fig.2-2 lists four general market design principles and how we follow them in our
Market Thickness
- **Requirement** - There are opportunities to trade with a wide range of potential transactors.
- **Barter's design** - 1) Multiple types of information markets; 2) Primary and secondary markets; 3) World bank serves as a transactor in some cases.

Lack of Congestion
- **Requirement** - Market is rapid, participants can feasibly turn down offers in order to see better matches.
- **Barter design** - 1) Information seekers make offers; 2) Information providers can negotiate prices, and are rewarded fairly in the long-term; 3) market making is performed by algorithms in the secondary markets.

Market Safety
- **Requirement** - Avoid strategic interaction which might undermine allocative efficiency and social welfare
- **Barter design** - 1) a self-governing/regulating mechanism based on crowd wisdom plus market incentives; 2) the infrastructure tracks all suspicious activities and transactions; 3) organizational hierarchy limits frauds.

Management of Repugnance
- **Requirement** - Market trade is not undermined by other social values which limit the ability to charge positive prices for a good.
- **Barter design** - provides both social and economic incentives, encourages pro-social behaviors on the platform.

Figure 2-2: Market design principles followed and implemented in Barter.
design. They include: 1) market thickness, 2) lack of congestion, 3) market safety, and 4) management of repugnance, presented in [13][24];

4.e - **Information Asymmetry** - Asymmetric information about the quality of to-be-exchanged knowledge products, and asymmetric information about the knowledge buyers’ commitment to pay make the transaction difficult to proceed. How does the market facilitate transactions by minimizing information asymmetry?

4.f - **Market Fraud and Abuse** - Users tend to attempt to outsmart market designers and gain an unfair advantage by gaming the system. How do we design fraud prevention mechanism to clean fraudulent behaviors, sustain fairness, and protect the integrity of the market from abuse?

4.g - **Behavioral Modification** - Platform managers often want to promote certain behaviors. For example, as mentioned before, extended knowledge objects (EKO) are critical to knowledge valuation, indexing and sorting, but are also often under-created. How do we apply policies to modify users’ behaviors so that they do more voting or tagging? Fixed-pricing again usually renders adverse outcomes.

4.h - **Currency Hoarding** - Preventing currency hoarding falls under the category of behavioral modification, but it deserves emphasis as a separate item. In other words, how do we create incentives for spending? An unsustainable saving rate leads to low activities and causes the knowledge economy stagnant.

In previous sections, we have explained in detail the logic and derivation process of the problem space. We start from knowledge-related challenges inside organizations, and end up with tackling specific research questions on the design of knowledge currency, markets, and economic policies.

### 2.4 Review Challenges of Knowledge Platforms

We review and summarize challenges faced by knowledge platforms that rely on user-generated contents (UGC). Some overlap with the ones introduced above. Generally speak-
Eliciting

- Locate sources of relevant knowledge
- Get people to contribute

Validating

- Gauge relevance
- Identify obsolete content

Quantifying

- Measure direct content value
- Measure effects of applying content

Figure 2-3: Challenges faced by knowledge platforms that rely on user-generated contents (UGC)

Most knowledge platforms face challenges that can be categorized into three phases, as shown in Fig.2-3[4]:

**Phase 1 - Elicitation**

- Get the platform to take off by solving the chicken-and-egg problem: Knowledge consumers do not participate unless there is enough knowledge stored; knowledge producers do not contribute unless there are knowledge consumers and they get fairly rewarded; Early adoption of a new platform is also addressed in the subject of platform economics;

- Locate sources of relevant knowledge: given a request for knowledge, how to locate experts within an organization who owns the knowledge;

**Phase 2 - Validation**

- Identify obsolete contents, update or correct knowledge. In short, the platform oughts to maintain the quality of knowledge constantly;

- Gauge relevance of knowledge for targeted users to minimize noise;

**Phase 3 - Measurement**

- Measure the value of knowledge objects, possibly denominated using both knowledge currency and real currency;

- Measure an individual user’s contribution, and expertise on different areas.
Let us revisit the original problem statement:

For a knowledge platform built upon crowd-sourcing and user-generated contents, how do we incentive users to participate, share and contribute?

After our previous discussion on knowledge currency, markets, and economic policies, we transform and reshape the problem as:

How to turn a knowledge platform into a vigorous “knowledge economy”?

Inside a “knowledge economy”,

- Users create knowledge in a decentralized way through knowledge market exchanges;
- Users get fairly rewarded by earning and spending knowledge currency;
- Managers stimulate system growth using “macroeconomic” and “fiscal” policies;
- Knowledge-related challenges can be tackled using advanced tools.

2.5 Summary

The purpose of this chapter is not merely to enumerate all the problems and challenges, but also demonstrate the evolution of the problem space and interdependency among all challenges and research questions. This allows us to clearly differentiate our innovation and contribution in this dissertation.

To summarize the innovation and contribution from this research - we have designed a complete framework of a knowledge economy, which consists of three critical modules: knowledge currency, knowledge market mechanisms, and economic policies. We will discuss on system architecture in the following chapter.
Chapter 3

System Architecture

3.1 Overview

In this chapter, we present in detail the complete design of the Barter knowledge economy framework. We illustrate key concepts and design choices by using diagrams and screen shots from the software. The goal of this dissertation research is to design and build a knowledge economy for an organization or a community to address various organizational challenges on knowledge sharing and decentralized innovation, particularly on constructing incentives.

For clarification on terminology and future presentation, “Barter” is a term we use to refer to multiple concepts: 1) the software platform we build, 2) the design and architecture of the knowledge economy framework we present in the research. The subtle difference between “knowledge markets” and “information markets” might introduce some confusion. We do not attempt to seek unambiguous differentiation between the two concepts in this dissertation. Both phrases refer to the same mechanism for exchanging a special type of products - information products. Also, “knowledge markets” are constituent components of a “knowledge economy”, which also includes currency, user activities, economic policies and various types of entities, etc. For the convenience of presentation, in the following
chapters we use terms “Barter”, “information markets”, “knowledge markets”, “knowledge economy” interchangeably, the meanings of which should be self-evident from their contexts.

What is Barter? Broadly speaking, Barter creates an “information economy” or a “knowledge economy” inside an organization or a community. Barter consists of three key components in its architecture: 1) knowledge currency, 2) knowledge market mechanism, and 3) economic policies for influencing the knowledge economy. The following statements give a birds-eye view of Barter’s key features and strengths

- Barter is a market-incented wisdom exchange, or simply speaking, an information market, designed for organizations and communities to maximize the creation, reuse, and sharing of knowledge and innovation among members;

- Barter is capable of tackling the peculiar properties of information such as non-rivalry and non-excludability when constructing a market for information products;

- Barter provides long-term sustainable incentives to reward knowledge contributors and encourage participation;

- Barter deploys multiple types of information markets to address different organizational challenges, such as Q&A, document sharing, idea genesis;

- Barter provides a mechanism to monitor and govern the economy, and apply macroeconomic and fiscal policies to influence its operation and modify users’ behaviors;

- Barter completes the market by providing a product auction market where virtual currency can be exchanged for material goods, thus providing a mechanism to calculate the exchange rate between the Barter knowledge economy and real-world economy;

- Barter can accurately measure the value of information created sorted by users and by topics, and measure users’ reputation, contribution and expertise on different topics; such measurement can be denominated using both Barter currency and real-world currency;
• Barter is capable of self-governing, self-correcting, and self-improving by using innovative crowd-sourcing mechanism;

• Barter provides solutions to common challenges on IT platforms using innovative market-based approaches. Examples of these challenges include early user adoption and platform growth, market abuse and fraud;

• Barter is an internal social platform with fun and gaming aspects associated with it.

From a mechanism design perspective, Barter presents an innovative framework to tackle knowledge-related challenges, which consists of virtual knowledge currency, markets, and a set of rules and polices to meet the design goal. From a technical perspective, Barter provides an isolated technology engine stack, which implements the three aforementioned key modules, and can be interfaced with existing knowledge platforms to enhance them, as shown in Fig.3-2.

3.2 System Architecture

Before touching upon how each individual market or module works on Barter, we first present the overall system architecture, as depicted in Fig.3-1.

The infrastructure of Barter can be broadly divided into three crucial components:

Knowledge Currency - the virtual currency designed for exchanging knowledge. Users use knowledge currency to track contribution, reputation, and expertise on different topics, and can cash it out for material rewards. Managers of a platform use knowledge currency to measure information value, and use currency as tools to influence overall activities, introduce stimulation and modify user behaviors.

Knowledge Market Mechanism - the central pieces of which are multiple types of knowledge markets, where knowledge objects are created, exchanged (traded), and managed, such as Q&A, document, idea markets. These knowledge markets are
Figure 3-1: System architecture of the complete Barter knowledge economy framework - from a mechanism design perspective.

Figure 3-2: System architecture of the complete Barter knowledge economy framework - from a technology perspective.
tangible modules that directly provide user experiences. The rules and regulations that govern the running of these marketplaces are designed and implemented by the “Knowledge Market Engine” layer. Built on top of the system hierarchy is an interesting but powerful layer called “derivative market” of information, also introduced later in Table 3.2. It is built upon information securitization and fair distribution. Derivative information markets address big challenges such as incentives for spending and insufficient liquidity of markets. There are also four critical peripheral modules that guard and enhance the knowledge markets:

**Fraud Prevention** - a crowd-sourcing mechanism where the detection, reporting, and conviction of market fraud and abuse is done by all market participants;

**Attention Market** - a mechanism to prevent information oversupply and spam, and enhance relevance of provided information to a user. A user’s attention should not always be acquired for free, but should be obtained based on a fee that is calculated based on social connections and expertise level on an area;

**Reuse Tracking** - a module that captures the spillover effects of knowledge and helps measure the value of information. This module tracks reuse of knowledge objects based on their observable attributes and generate a reuse score for each knowledge object;

**Credit Tracking** - a module that is similar to the Reuse Tracking module, but is designed specifically to track credit sharing and assignment among document authors, where the overlapping portions of documents are tracked and measured;

**Economic Polices** are novel tools and devices designed for platform managers to control and maintain the health of the knowledge economy, and intervene when necessary. The set of policies are designed and provided based upon established economic theories and practice, and constitute Barter’s differentiating vision and strength. Economic polices can be broadly categorized into

**Monetary Policies** refer to the practice that the “Central Bank” of the knowledge economy stimulates / controls the economy by injecting / subtracting currency into / out of the economy;
Fiscal Policies refer to revenue generation and spending by the “government”. On Barter, we refer to the “government” as the “Planner”. There are certain types of activities and behaviors that can only be promoted by central spending, such as rewarding knowledge reuse, encouraging voting / tagging.

The descriptions above aim at providing a high-level overview of Barter’s architecture. One important mission of this research is to treat the subject of knowledge currency, markets and associated incentive design thoroughly, and provide a complete framework design of the knowledge economy covering all interplaying factors. Treating an individual sub-module alone tends to lead to deficient design choices. In the following sections, we cover each of the three components and their constituent modules in greater details.

3.3 Knowledge Currency

3.3.1 Overview and Discussion on Incentive Design

Sustained participation in online communities and markets is driven by mixed and heterogeneous motives. They generally fall into three categories: (1) Social rewards include peer-recognition and professional reputation,(2) intellectual rewards include learning and problem-solving and (3) material rewards include virtual points, money and a variety of other benefits[4][5].

Users on Barter can spend their virtual currency either on information they need or on tangible rewards through the auction market. Barter adopts a floating-price mechanism. Information seekers raise offered rewards for critical issues that require more efforts to provide. Information owners choose whether to supply it given the current price, or directly negotiate with information seekers. The auction market provides an organization’s management a layer to isolate material incentives from classifying and evaluating knowledge created inside the platform. Exchanges of all types of information products are denominated in virtual currency, the value of which is determined separately by market users through their activities in each market.
Instead of offering a one-time lump-sum reward, an organization can distribute material rewards through the auction market in a continuous and strategic way. Depending on several key economic indicators, such as user activities, price indexes and currency supplies, the "chief economist" of Barter can determine the density and value of the products posted in the auction market. While used to provide material incentives, the auction market is also an important mechanism to stimulate or stabilize the entire knowledge economy.

We follow an important mechanism design principle that using / earning virtual currency inside the knowledge economy and backing up the virtual currency in order to provide real value to users are separated and isolated into two independent layers, as demonstrated in Fig.3-3. Such a layered framework allows us to tackle one problem without worrying about the other one.
Economic activities inside markets are facilitated and denominated using commonly accepted currency inside an economy. In order for the currency to be recognized and accepted in a knowledge economy, organizations need to develop plans to backup the virtual currency to provide real and material value to the currency so that users have incentives to earn and use the virtual currency. Designing and deploying such a backup plan can be isolated from the problem of how currency should be used inside the knowledge economy to maximize knowledge / innovation creation.

On the top layer, when we design market rules and mechanisms, we can make the assumption that users care about earning more virtual currency, and building economic incentives for an individual user is abstracted as earning currency. We use virtual currency as units and tools to moderate economic activities inside the knowledge economy, and to encourage behaviors we want to promote.

3.3.2 Currency Value

For an individual user, willingness to earn more currency by performing various activities in the information markets and economy serves as the basis for incentive design. If users are not willing to accumulate more currency, the entire incentive structure cannot be sustained. As demonstrated in Fig.3-3, a user’s willingness to own and earn currency is supported by the following characteristics of knowledge currency:

- Currency serves as the transactional medium inside the knowledge economy. In order to do any type of spending such as eliciting knowledge or acquiring experts’ attention, users need the same type of currency to do so;

- Earned amount of currency on specific topics or domains serve as reputation scores or count towards expertise status;

- Users can exchange virtual currency for physical products. On the product auction market, every user can post real products / services in exchange for virtual points,
and other users can bid on the product following an auction mechanism that is similar as eBay’s. Note that in this case, the total amount of currency supply is unchanged.

In addition to the implied value and utility of currency listed above, organizations (firms) can further strengthen the value of virtual currency by designing other backup plans. Organizations can be creative on how to back up currency value. For example:

- Organizations purchase real gifts / products and post them in the auction market for sale, such as iPad, company t-shirts, mugs, etc. (the scarcity of which makes themselves more appreciated and effective);

- Organizations can devise titles to encourage competition, such as “the knight of Barter” as a fun example;

- Associate the amount of earned currency with honors and rewards, such as names mentioned on corporate web portal or having lunch with the CEO;

- Directly associate earned points with performance review or compensation.

By posting material gifts / products on the auction market, organizations effectively spend real dollars to back up the virtual currency. Moreover, this mechanism achieves several important goals:

**Currency Extraction** Organizations take currency out of circulation and put them back into the “central bank”;

**Measure Exchange-rate** We are able to approximate the exchange rate between virtual currency and real dollar value by linear regression between product value of posted items and transaction prices in virtual currency. The exchange rate allows us to further measure the value of knowledge created inside the entire knowledge economy;

**Monetary Policies** Organizations can have discretionary spending on stimulation of the knowledge economy, thus providing a long-term sustainable incentive structure.
The product auction market “completes” the knowledge markets. It has significant impacts on the design of economic policies, which will be covered later.

### 3.3.3 Currency Supply & Velocity

As mentioned in earlier chapters, quantity theory of money establishes a relationship among currency supply, velocity of currency, price levels and total production in an economy

\[ M \cdot V = P \cdot Q \]  \hspace{1cm} (3.1)

where \( M \) is the total amount of currency supply in the economy, \( V \) is the velocity of currency in final expenditure, \( Q \) represents the real output, and \( P \) is the corresponding price level. From this relationship, we learn that economic activities and price levels can be influenced by adjusting currency supply and turnover rate in the economy. In general, we wish to

- maintain a stable amount of currency supply \( M \) with a steady target growth rate \( g_c \);
- increase the velocity of currency \( V \).

The goal is to maximize the total knowledge production and maintain fairness in the knowledge economy.

Managing currency velocity has direct implications on virtual currency design. One effective and commonly recognized approach to control currency velocity is to manage currency expiration. Currency holders are motivated to spend the currency before expiration time rather than render the currency useless. In practice, it is often challenging to do a fine-grained control over currency expiration because of the difficulty involved to track the usage and expiration of each currency unit. For example, in real world economies, currency almost never expires. In the digital world, the expiration of virtual currency is well recognized and popularly adopted for similar purposes, and virtual currency expires often following a simple expiration schedule such as frequency flier miles of major airlines.
When designing and optimizing the expiration rules, we need to make trade-offs on two critical factors:

**Simplicity** We must take users' perception to currency expiration into consideration. A theoretically optimal but complicated currency expiration scheme discourages users from participation. Therefore, we need an expiration scheme that is simple enough, and present it to users through intuitive interfaces;

**Frequency/Period** If the expiration period is too long, it is not effective in driving users to spend; if the expiration period is too short, users need to pay too much attention to currency management, the opportunity cost of which may be too high for users compared with the importance of their other daily activities.

On Barter, thanks to the serialized design of currency, we are able to adopt sophisticated currency control over each individual unit. For currency used in the virtual economy controlled and managed by software, we can track the type, status and ownership of each unit of currency easily, and apply different expiration rules.

Barter, as a software platform, serves as an ideal testbed to search for the best expiration rule that optimizes currency velocity and overall knowledge production.

### 3.3.4 Currency & Transaction Design

When designing virtual currency and transactions following our previous discussions, we first need a basic set of features:

- Transactions, and associated currencies, have basic security, failsafe and rollback features. The integrity of every transaction needs to be protected;

- Transactions have different types depending on their purposes and other factors; they can be filtered, aggregated, and analyzed easily;
• Currency gets “minted” by the “Central Bank” and issued based on the requirement of monetary policies;

• Users have their individual bank accounts, and there is a special entity named the “Central Bank” for employing monetary policies; the “Central Bank” has its own account;

• Transactions can be taxed, fees can be charged on user accounts. In other words, basic accounting practice should be enabled.

For the knowledge economy, we also need some advanced features:

• Currency is serialized, which means each unit of currency is a separate object with its unique identification and ownership, for each transaction we not only track the lump-sum amount, but also specify which units of currency change hands; this allows us to have fine-grained control over currency behaviors;

• Each unit of currency has its own type (there are multiple types of currency), and its own expiration schedule. Currency type and expiration schedule get updated when the unit changes hands with a transaction;

• The history of each unit of currency can be traced accurately;

The platform periodically performs “knowledge accounting”. Transactions within the knowledge economy are all associated with knowledge objects. The value of total knowledge created, the expertise score of a user on different fields, leader boards, reputation signals as knowledge buyers or sellers all get updated as transactions occur. Some of these can be updated in real-time right after transactions occur, some can only be updated asynchronously following a periodic schedule when certain attributes of the associated knowledge object tend to change over time.
3.4 Market Engines

A market engine unambiguously defines

- Specifications of products / services that are permitted to be exchanged in the market;
- Rules two-sided market participants must obey for the market to run efficiently and prevent failure;
- Specifications on how products / services are delivered;
- Specifications on how a transaction is initiated and completed;
- How market participants feed information back into the market itself to improve the market efficiency;

From a technology and software design perspective, a market engine serves as a middleware that provides generic interfaces to different types of information markets and therefore information products, and communicates with other system modules such as user profiles and currency / transaction modules.

For example, ebay.com provides an auction-based market engine for tangible products and services; Nasdaq is an electronic market platform for trading equity stocks where a transaction automatically gets initiated when a “bid” and an “ask” get matched; Google Answers was an online marketplace where Internet users paid to get their questions answered by “Google researchers”; Intrade.com is a prediction market where users trade a special type of security whose value is determined by the binary outcome of a real-world event. Among these different market instances, each market has its own mechanisms, rules, and permitted products & services, which constitute its distinctive “market engine”.

Our goal is to abstract commonalities and generic components from different markets, and define a minimum set of core reusable market engines that support different information markets. Key differentiating factors in determining a market engine in information markets include:
Information properties of Exchanged Products & Services Whether products / services traded on the market exhibit strong characteristics of information;

Standardization of Exchanged Products & Services Whether products / services are customized and heterogeneous or they are standardized across the market;

Reputation Mechanism How critically a successful transaction relies on the reputation of providers of products / services. When information products are exchanged, two parties of the transaction need to deal with information asymmetry, and reputation alleviates the problem as a “signaling” mechanism.

Preview and Feedback Before a transaction occurs, how does the market enable the buyers to preview and evaluate the products before making a purchase decision? This is a key challenge for information products due to the nonexcludability nature of information. After a transaction occurs, how do we enable two parties of a transaction to provide feedbacks to the transaction to strengthen the reputation mechanism and reduce information asymmetry in future?

The list of factors are not independent but correlated surrounding the key factor - whether the products exchanged in the market exhibit strong information characteristics. In the context of organizational information markets designed to address organizational challenges, we have identified four core market engines. On top of the four market engines, we can build different types of markets for different purposes.

The list of market engines and their supported markets are depicted in Fig.3-4. How each market engine is differentiated, what properties each market possesses, and how they support various markets in addressing different organizational challenges are covered in detail in following subsections quadrant by quadrant. In this dissertation, we mainly focus on the market engine for information products.
Figure 3-4: Four market engines of Barter and their supported markets
3.4.1 Market Engine for Information Products

The market engine for exchanging “information products” is the most challenging and crucial one, where the peculiar characteristics of information make markets prone to failure. Three types of markets can be supported by the market engine for information products

**Question & Answer (Q&A) Market** A platform for peer-to-peer assistance, pairing experts with novices, matching expertise with problems. The Q&A market generates prompt responses.

**Document Market** An exchange that encourages document sharing and reuse, and tracks credits for authorship.

**Innovation (Idea) Market** A marketplace for generating, combining, ranking, and promoting ideas based on open contribution and decentralized innovation. The platform also matches complex R&D problems with a network of problem solvers.

Barter is a market of a special type – an information market – where users exchange ideas the value of which are difficult to judge prior to disclosure. However, Barter first needs to adhere to general principles of market design, as summarized in Fig.2-2. These four principles should be satisfied in order to have almost any type of information market run stably and efficiently [13][24].

Next, when the exchanged goods in a market are information products, the following characteristics of information need to be carefully taken into consideration when designing Barter, as illustrated in Table 3.1. Otherwise, the market is prone to failure. An in-depth mechanism design and feature descriptions of each market are covered in later sections. These three markets are grouped together and supported by the same market engine is because they exhibit similar characteristics, mainly based on the fact that goods exchanged in these markets are typical “information” products - answers, documents, innovative ideas or R&D solutions. Peculiar properties of information introduce the following practical challenges to the market design:
Table 3.1: Challenges of Information Products and Barter's Solutions

<table>
<thead>
<tr>
<th>Characteristics of Information Products</th>
<th>Barter's Design and Solutions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Information and innovation has spillover effects, and is non-excludable</td>
<td>1. The spillover effects should not be treated negatively in the context of organizational knowledge sharing and innovation creation. A more important issue is to reward information creators fairly; 2. We have devised algorithms to track information reuse, trace back contributors, and reward them fairly. 3. We encourage pro-social behaviors to reward information providers, such as tipping.</td>
</tr>
<tr>
<td>Information is costly to create and costless to replicate</td>
<td>1. The fair distribution mechanism guarantees that original information creators get continuously rewarded for providing valuable information; 2. A market-based approach for the detection of fraud and copyright infringement; 3. Several mechanisms are in place to protect information providers. For example, answerers in the Q&amp;A market can choose to hide their answers until the question expires.</td>
</tr>
<tr>
<td>Evaluation of information requires accessing non-excludable information first</td>
<td>1. Rewards are offered by information seekers upfront, and are frozen by the “Central Bank” to enforce payment and allocation. 2. Information seekers get penalized for ignoring to judge information quality and distribute rewards, and charged for extending the expiration time.</td>
</tr>
</tbody>
</table>

**Non-excludability** Information is non-excludable. Before a transaction of information occurs, evaluation of information by the buyer makes the transaction no longer necessary since the buyer already acquires the information.

**Non-rivalry** Consumption of information by one buyer does not prevent another user from enjoying the benefits of the knowledge. Information or innovation has the spillover effects, which makes the pricing of information challenging given the long-term implications of knowledge reuse. In order to decide to render knowledge to the platform, the seller of information requires an accurate pricing signal that reflects both immediate needs and long-term spillover effects.
We next present the mechanisms of the Q&A market in great detail. The goal is to show how the information-product market engine is integrated and used to support a particular type of knowledge products - questions & answers. We then briefly introduce the other two knowledge markets that are supported by the same engine. We have implemented and deployed them as key modules in the Barter software.

**Question & Answer (Q&A) Market**

This is an information market that allows users to ask questions to the Barter community and expect prompt answers. We emphasize on how mechanisms and design principles of the information-products market engine are instantiated in the Q&A market. Document and Innovation markets are both supported by the same engine, which have many rules and mechanisms in common.

The basic Q&A market interactions among users proceed as follows:

1. Each time a user asks a question, she can opt to post X points as bounty, or her “willingness to pay (WTP)”, and optionally an expiration date by which all answers must be received in order to be considered as reward recipients;

2. Other users visiting this page who have the same question can “sponsor” the question by supplementing more rewards as their “willing to pay (WTP)”. The pool of points combining multiple askers’ WTP serve as signals to knowledge owners to incentivize them to provide answers;

3. Answerers provide answers in two ways: without or with price tags, in which the first is usually encouraged in an organizational environment advocating open knowledge sharing:

   **Free** When an answerer provides an answer without setting a price, the content is freely accessible to other users in its entirety;
Non-free When an answer is guarded with a price tag, all other users, including the askers, need to pay a larger amount than the given price in order to access the content; Before making sufficient payment, other users can only access a preview of the content, which is automatically computed and displayed by the system;

4. When the question gets close to expiration, the asker and other endorsers who have committed WTP can review received answers and distribute reward funds among answerers based on perceived quality of answers. All askers with WTP committed can end up with paying more than signaled, or they can withdraw all or part of the committed rewards for any reasons such as they feel unsatisfied with provided answerers.

There are important mechanisms in place to minimize information asymmetry that threatens knowledge transactions. From the perspective of answerers, how to guarantee that askers have the capacity, i.e. enough funds in the account, to fulfill commitment, and deliver payment after answers are supplied?

Credit Freeze When a user makes a WTP commitment eliciting knowledge, the corresponding amount of funds gets “frozen” in the bank account and gets associated with the particular knowledge request. She cannot spend the frozen funds or use them to commit another WTP. Frozen points get unfrozen when transactions happen or the user decides to claim them back;

Buyers Reputation Askers can claim back their committed points with a transaction tax as penalty. The system keeps a record tracking every user’s history of WTP on knowledge requests and how much they really deliver as payments to knowledge providers. The ratio of delivery over WTP is associated with the user’s profile and serves as a reputation signal for potential knowledge providers;

Onetime Earning vs. Longterm Reuse Award An important mechanism as part of the market engine is reuse tracking that captures information spillover effects. The potential answerer does not necessarily need to be wary about the askers’ reputation
on fulfilling payment, but instead focus on delivering high-quality contents. Future income from reuse of the answer can generate fair returns.

From the perspective of askers, when answers are guarded with price, strong information asymmetry occurs. Askers hesitate to make payment before understanding the quality of answers. However, due to the non-excludability property of knowledge products, disclosing contents upfront is unrealistic either, since it lets askers consume the knowledge for free and unmotivated to deliver payment. Screening and signaling prove to be effective in tacking information asymmetry. More concretely:

**Preview** The system generates a preview of the content, which is freely accessible. Examples include random snippets of texts, a thumbnail of uploaded pictures or files;

**Sellers Reputation** The system tracks how many points each user earns on each specific area (tag) in the Q&A market and across all knowledge markets, and synthesizes an expertise profile from all past knowledge transactions. The expertise profile is presented to potential buyers so that they understand whether the answerer has demonstrated sufficient expertise in related fields (tags) before making a purchase;

**Feedback on Sellers** A potential buyer can access previous buyer’s comments and voting on the answer before making a purchase decision. After making the purchase, the buyer is prompted to provide similar feedbacks for future buyers, and is reminded to do so periodically;

**3rd-party Ratings** As the platform evolves, trusted members can form 3rd-party rating agencies evaluating answers’ quality and provide ratings and opinions on knowledge objects as an objective certificate. They can charge fees for their time and efforts. Members should earn enough credits and authority on related fields in order to make such an agency credible and trusted.

A user can make a bid offering less points if she thinks the answer is over-priced. The seller providing the answer gets notified about the offer, and can quickly decide to accept it or turn it down. The price history is openly disclosed.
Reuse tracking and getting knowledge contributors rewarded continually based on the long-term value of knowledge they create is a vital feature of Barter. In the context of the Q&A market, reuse tracking tackles several long-lasting challenges:

**Fair rewarding** Rewards paid by one or multiple askers only capture the value created for askers, a limited subset of all users. The full value of an answer is reflected by its reuse by other users in future. The bounty posted by askers does not capture the spillover effects of knowledge, thus emitting an incomplete price signal to knowledge owners. Only with reuse tracking, knowledge contributors get fairly rewarded. For the same reason, the importance of first-time payment for an answerer is weakened.

**Incentives to Ask (Spend)** Currency hoarding, or excessive saving, has always presented a challenge to active markets. Despite the desire for knowledge, a user often lacks the incentive to spend and prefers to save points. Especially in the case of knowledge markets, users prefer to wait for other users spend points to elicit knowledge and be a free rider enjoying “spilled” knowledge. A great question is as valuable as great answers. A user should get properly rewarded when her question inspires talented brains and elicits valuable answers into the platform. A user can potentially receive many more points in future than the points spent today as bounty, if her question is popularly reused. This is achieved through reuse tracking and fair distribution.

**Encourage Free-sharing** Generally speaking, we advocate building a culture of free knowledge sharing, and discourage users from putting price tags on their knowledge objects, especially in an organizational setting. However, a true market-based economy should allow its citizens to freely choose how they exchange knowledge they own, instead of forcefully requiring price tags forbidden. On Barter, a positive price tag implies that the knowledge seller decides to value the knowledge she owns in the traditional manner, and her income will solely come from other users’ payments. Such a price tag disqualifies the answer from receiving reuse rewards. With reuse tracking, an answerer has stronger incentives to post her answerers with zero-price, and can potentially receive higher rewards when the answerers become popular in future.
Reuse tracking will be covered in detail in the mechanism design chapter. The mechanism relies on users' collective opinions and inputs to judge the quality and popularity of a knowledge object and calculates its reuse value. Thus, the system needs to encourage users to contribute “extended knowledge objects (EKO)” as introduced in the previous chapter.

**Voting** Users do thumbing up / down on both the question and answers; Votes from users with different levels of expertise should be treated with different weights;

**Tipping** Users can “tip” the answerers or the asker for their contribution as a way to show appreciation. “Tips” present a stronger signal compared with a “thumb-up”.

**Commenting** Users can leave threaded comments on an answer or a question. Comments carry wisdom and generate value. They are considered as knowledge objects, and can receive voting and tipping as well. A question, its answers, and derivative comments on them form a tree of knowledge objects. The question is the root, and all other answers and comments are nodes within the tree having a parent and descendants. The number of descendants shows whether an knowledge object is popularly discussed upon and generates good contents for the platform.

Extended knowledge objects seemingly take users simple actions to perform, but they are often under-produced. Incentivizing users to perform these actions and provide EKO is related to behavioral modification, which is carried out through “fiscal policies”.

Within a Q&A market with thousands of participants, a question can easily get overwhelmed and hidden by a flood of questions, and it never gets answered or even noticed. Effectively acquiring other users’ attention, especially the attention of experts in relevant areas is essential to the efficiency of the Q&A market. A number of social-network based solutions have been devised and attempted, such as subscribing and social forwarding, the effectiveness of which is limited, especially when the asker and the knowledge holder are several degrees away along their social link.

Many software platforms, Barter included, provide in-site notifications and email association. However, sending notification messages or emails freely to all intended recipients is not...
a feasible solution. As stated in problem 2.b, spamming or clamoring for attention creates too much noise that annoys other users, and drags their productivity low. The “Attention” module of Barter is designed to tackle this problem. Rather than wait for other users to “pull” information, a user can choose to “push” instead. However, pushing information to users who are not socially connected costs points based on the value of their attention.

On Barter, when a question is first entered into the market, based on its tags and textual contents, Barter automatically matches a number of experts who are most likely to provide quality answers. However, acquiring their attention is not free. Prices for experts’ attention are different and calculated based on their expertise level.

The asker can choose whether and which experts to invest in acquiring their attention. Experts are then notified by Barter that they are requested to answer a question. They can visit the question page, where they can decide whether to provide an answer, and whether to claim the “attention points” or return them back to the asker. Barter tracks their behaviors on how many attention points users choose to accept, and how often they do provide answers. Such a record is presented on a user’s profile.

There are other scenarios when a user does not require experts’ attention or rely on their expertise. Instead, a user might simply wish to promote a news item or make an announcement to reach critical mass. Users can still utilize the “Attention” module to achieve this goal. The details of the Attention module will be introduced in a later section.

Tagging, another type of EKO, plays critical roles in 1) knowledge indexing, searching, and storage, and 2) expertise synthesis and experts matching. However, tagging is often insufficiently and inaccurately produced. On Barter, knowledge objects can be tagged by both original knowledge providers and the entire community as well. On the page of a knowledge object, users can provide new tags, or vote upon existing tags provided by other users earlier. Tags that receive most votes are considered associated with the knowledge object. The “Planner” incentivizes and rewards users for tagging activities through fiscal spendings.
Document Market

This is an exchange that allows users to request or share documents with the Barter community. Market rules and mechanisms are nearly identical to the Q&A market. A request for documents is similar to a question in the Q&A market, and elicited documents are similar to answers. A key difference is that on the Q&A market, answers are almost always provided following a question, but on the document market, users can directly share or sell documents without elicitation.

The document market is equipped with a unique module named “Credit Tracking & Attribution”. If a document contains proportions which give rise to other related contents on Barter, the original contributor receives a “kickback” for posting the original document. This module represents another type of “reuse”, which tracks content reuse in derived knowledge work, rather than other users’ consumption of contents. We will briefly introduce this module in a later section.

Innovation (Idea) Market

This is a marketplace for innovation, and for matching solutions to problems. A user can either submit a standalone idea or submit one in response to another user’s request. Compared with a Q&A market, the expectation on responses is less time-sensitive.

An organization uses such a market to achieve bottom-up decentralized innovation. Any member of an organization might have creative thinking on the organization’s operations, products or activities. She can submit her ideas to the idea market, get them scrutinized, validated and improved by other members, and receive rewards when her idea gets promoted or executed by senior management. On the other side, management can elicit ideas and innovative solutions to R&D problems and get members rewarded.

A problem faced by existing idea management platforms within firms is the “lack of conclusion”. After the initial excitement of getting their cool ideas created and deposited, users find their ideas left untouched, and gradually lose motivation over time. On the other side,
management lacks the time and resources to execute on collected ideas, or even carefully examine them. On Barter, ideas can be flagged with different status, or get promoted to higher levels, users receive points when such events occur without the idea being executed.

In the software deployment as part of this research, the idea market is used by two entrepreneurship courses at the university as class tools for students to exchange venture ideas and do cross-evaluation.

Summary of Information-Products Market Engine

Q&A, document and innovation markets are three exemplary markets that are supported by the information-product market engine. They are highlighted and illustrated because they have wide applications inside organizations, and are fundamental components of organizational knowledge management. With the same market engine, we can design and deploy new types of markets for other types of knowledge objects.

From the discussion above, "knowledge objects" and "requests for knowledge objects" are sometimes interchangeable and should not be distinguished unambiguously. A request for knowledge objects can carry wisdom itself, be appreciated, and receive rewards. Thus, it is also treated as a knowledge object. Conversely, knowledge objects can also be posted with bounty eliciting comments or modification suggestions. Therefore, a "knowledge object" is the root abstract class modeling both request and non-request types of knowledge items, which can emit both selling and buying signals.

3.4.2 Market Engine for Services

The Request & Service market and the Design (Fix) market are powered by this engine. We will not get into its details because the service market engine is not knowledge-related, thus not a primary focus of this dissertation. The service market engine is similar to that of online marketplaces for tasks and small jobs such as taskrabbit.com. Services are quite different from knowledge products. But there is also strong information asymmetry existent
that requires sufficient signaling between the two sides. The key is to solidify the contractual relationship.

**Design Market**

The purpose of the design market is to empower Barter to keep improving itself by having new features, bug fixes, and detecting market defects through the market mechanism itself. We also call it “design for self-design market”.

The crowd of users collectively help design the market and prioritize tasks. When a user discovers a bug, a market loophole, or needs an extra feature, she can submit it to the design market and offer a certain number of points as rewards to developers if her idea gets implemented. Other users can vote on the design idea to change its priority. If they deeply like the idea and want it to be realized sooner, they can sponsor more points to the pool of rewards. Developers prioritize all design items posted in the market based on both signals: votes and potential rewards.

The design market is supported by the service market engine because of the contractual relationship between users and developers.

**3.4.3 Market Engine for Regular Goods**

The Product Auction Market is supported by this engine. The market engine is similar to that of EBay.

**Product Auction Market**

In the product auction market, users can exchange their virtual currency for physical products or services they value in real lives. Any user can post an item for sale and other users can bid on the item using their earned points, similarly as how they buy and sell on eBay with real money. The auction market provides a mechanism for users to acquire points
when they run out of points, or cash points out for material rewards. When users buy and sell products among themselves, the total amount of outstanding currency in circulation does not change. If the seller is the "Planner", i.e. the government, currency is effectively extracted out of circulation as transactions occur, and becomes available in the "Planner"'s account for fiscal spending. The product auction market plays critical roles in the entire framework of knowledge economy:

1. It enables a mechanism to externally back up the value of currency and assign material value to virtual currency;

2. By performing linear regression between transaction prices denominated in Barter currency and dollar value of listed auctioned goods, we are able to accurately calculate the exchange rate between virtual and real currency at any given time;

3. It provides an important and effective mechanism to extract virtual currency out of circulation when the "chief economist" implements contractionary monetary policies;

4. It provides the organization's management with an important tool to offer long-term sustainable incentives to the users. The auction market isolates providing monetary incentives from unnecessary details of knowledge creation; Consider the two incentive-design examples in the previous chapter, the two firms can instead provide rewards by spending resources through the auction market, and let the markets decide how users value knowledge and virtual currency.

Fig.3-5 displays a screen-shot of the product auction market listing items being auctioned on the market. As seen from the list of products on sale, users are creative in choosing what products / services to sell. The auction market adds to the diversity and thickness of markets, and enhance the fun and gamification aspects of the system. We will revisit this topic when we discuss on monetary policies.
Figure 3-5: Items posted on the product auction market.
3.4.4 Market Engine for Standardized Securities

The Prediction Market and the Derivative Market for securitized information products are powered by this engine. Modern exchanges and electronic markets where stocks, financial securities, and commodities are traded all apply similar market engines. Compared with the market engine for information products, it has the following characteristics:

- Products are highly standardized. Once product specification is defined, one unit is entirely identical to another one, such as a share of equity;
- Minimum information asymmetry in terms of product quality or buyers’ commitment to pay, assuming users fully understand possible outcomes of purchasing the products and potential risks;
- Buyers or sellers all seek or sell exactly identical products; their reputation signals do not matter for product quality; only bid / ask prices matter;
- No spillover effects, the value of products depends on prices of latest transactions.

In a predictive market, the standardized security refers to an instrument whose return is binary, say 0 or 100 points, which is determined by the unambiguous outcome of a future event. Users might be willing to pay different prices to purchase such securities depending on their assessment of the probability distribution of the future event.

In the derivative market for knowledge securities, the returns on the security come from the income flows generated by the associated securitized knowledge object.

Again, we will not get into details of the market engine for standardized securities because it has been widely studied and deployed in practice today. Prediction Markets has been a popular topic for both academia and industry. We include it in the knowledge economy framework because it provides value to a firm for predicting market trends, product success, etc. All these markets are supported by the same currency, thus adding prediction markets also improves market thickness and gamification aspects. We will discuss about derivative market in the next chapter.
3.5 Economic Modules

3.5.1 Attention & News Sharing

We have introduced the attention module above when covering the Q&A market. This module plays critical roles in solving problem 2.b. Two problems co-exist in organizations:

- Social and knowledge management platforms create information A.D.D. - Attention Deficit Disorder. They create too much noise clamoring for attention;
- Managers publish important announcements or news which frequently get neglected by other members.

There are two cases when users need attention: 1) asking experts to pay attention to their knowledge requests, and possibly provide responses; 2) asking ordinary users to pay attention and read their knowledge objects for announcement or promotion. In both cases, attention should not be acquired for free with 0 cost. Users can certainly subscribe to other users, topics, or groups voluntarily, in which case they “pull” information into their attention. The “Attention” module mainly addresses the “push” scenario.

In the case of asking for experts’ attention when sending knowledge requests, an expert’s attention is priced according to his expertise level on relevant topics. The requester can select how much to spend and which experts to pursue. The system will then notify the experts that their attention is needed for knowledge requests. The experts can choose to accept the attention-acquiring fee or return it after they land on the page and finish reading the request. Whether they accept the fee and whether they provide knowledge will be recorded, tracked, and displayed on users’ profiles as signals.

In the case of promoting a knowledge object or making an announcement to attract more users’ eyeballs, the requester can set an offered price for attention, and specify how many users to reach. An example of a news sharing module is provided below. Other users can claim the attention points by performing simple actions, such as voting, after they visit the page.
News sharing module is a quasi marketplace that allows users to post articles, news, or announcements to the Barter community and reap a profit if their postings become popular. It is designed and built on top of the “Attention” module. Members of the Barter community can vote on all submissions, and the popularity of a posting snowballs over time as top trending posts work their way to the front page. When a user posts an article, news item, or personal anecdote, she needs to allocate for the posting an initial value (Budget) and a set number of points that are given to users who read her story (Points Per View, or PPV). It is helpful to think of PPV as an advertising cost paid for each user: when people read and vote on her story for the first time, the amount of points set as PPV is deducted from the user’s Budget. When the Budget runs out, the post expires. A posting’s Budget will increase if it would attract many users.

Does a user have incentives to make investment on acquiring more attention from others? Barter captures spillover effects of information and rewards knowledge reuse. Knowledge objects, news items included, generate long-term income flows based on their popularity and reuse. A user can potentially earn more points back if his knowledge request, knowledge object, or news item gets popularly reused. When a user makes a decision on attention/advertising investment, he actually makes a bet on the quality and popularity of knowledge he provides or elicits.

3.5.2 Market Fraud & Fraud Prevention

A companion of any type of market is market fraud, which jeopardizes market safety as stated in the four general market design principles, and highlighted as Problem 4.f. Once currency is backed with material value, users have incentives to outsmart market designers and take unfair advantages to gain points that do not reflect their contribution of knowledge.

It is important to recognize that the line between “market fraud” and “exploiting market loopholes” might appear blurry. “Market fraud” refers to user activities that violate real-world laws, and user conducts that are explicitly forbidden in market rules and regulations delivered to users upfront. Users might exploit market loopholes to earn points. Such
activities are entirely legitimate as long as they are not explicitly forbidden, though they might appear unfair and unwelcome. Market designers should bear the responsibility for deficient mechanism design. When such exploitation occurs, managers can either move them to the fraud category to prevent them from happening in future, or fix the loophole by devising and deploying better mechanisms.

Possible types of market fraud include

**Money Laundering** Users conduct fraudulent transactions for ill purposes. For example, one user asks a trivial question and transfers all bounty points to the other user who provides a naive answer. The goal is to 1) boost the user’s expertise status for relevant fields (tags), or 2) convert currency types: turn unearned points into earned points;

**Market Abuse** Users contribute garbage knowledge just to collect government subsidies. The “Planner” might reward users to encourage certain behaviors, such as voting, tagging and leaving comments. In order to earn the subsidized points, users might leave comments with trivialized contents, vote on knowledge object randomly. Strictly speaking, market abuse is a result of users’ exploitation of inferior market design, which can be fixed by prudent mechanism design;

**Copyright Infringement** Upload copyrighted materials and make a profit on them;

**Plagiarism** Copy & paste others’ original work without properly acknowledging or crediting the authors, and make a profit on the stolen work;

All these types of market fraud have been proven evident in our research deployment, where we did not deploy a governing and regulatory mechanism. To clean fraudulent behaviors from the markets and protect market safety and integrity, we have designed the fraud detection and prevention mechanism. Detection of market fraud is sourced to the crowd. Users collectively identify and report suspicious behaviors. When a user detects a potential fraud or inappropriate contents, she can red-flag it. When the number of red flags reaches a threshold, the case will be moved to the “resolution space” for users’ opinions and possible conviction. In the “resolution space”, users vote on the case based on whether they believe
the case actually involves market fraud. The judging process follows a state-transition diagram based on time and users’ votes. When the case is closed, a verdict is made about whether it constitutes a fraud or it is innocent. Users who vote on the right side will be rewarded. The offender gets penalized so that she experiences both economic losses and social damages on reputation. Speaking in Information Economics terms, fraud prevention module is another example of accurate signaling and screening.

Encouraging users to report suspicious behaviors and participate in the fraud voting process also requires appropriate incentives, and involves behavioral modification. We will revisit issues around market fraud in later chapters.

3.5.3 Credit Tracking & Attribution

This module aims at tackling some ailing pain points that particularly harasses the document market. In many knowledge-based organizations, such as consulting and law firms, effective document sharing and reuse is critical to the organization’s competitiveness and overall success. Contents used in one document can be referenced, reused, or even represented in other documents which deal with similar cases.

However, one discouraging factor that impedes effective document sharing is that there has not been an effective approach for tracking credits and getting original contributors recognized and rewarded fairly. For instance, an author of a Powerpoint presentation shares her deck of slides with her colleagues. The slides might include valuable figures, tables, or graphs that later appear in several other documents. The original author might not receive enough credits or rewards for her original work, which damages her incentives to share more in future.

The ultimate goal of our proposed solution is to establish a connected graph of knowledge objects, where each node represents a knowledge object, and each link represents “credit attribution”. There is a coefficient associated with each link. For example, for the link from A to B, the coefficient tells the percentage of document A’s contents that derive from
Figure 3-6: Demonstration of credit tracking and attribution 1 - documents are organized as a connected graph.

document B. When document A generates revenue, document B should receive a portion of the revenue based on the coefficient.

This module presents an innovative way of detecting and managing plagiarism, and transforms credit sharing from a pain into a powerful feature. The specific algorithms and mechanism design that implement credit tracking is beyond the scope of this dissertation research. Here, we simply recognize the power of such a module under the knowledge economy framework. Fig.3-6 and Fig.3-7 demonstrate the concepts. The graph was generated based on an algorithm that tracks textual overlapping portions among all documents stored in Barter's document market. The algorithm and implementation is developed and presented in work [25].

3.5.4 Reuse Tracking

The meaning and value of the Reuse Tracking module has been briefly covered when we discuss about challenges for building a market for information products and when we introduce the Q&A market. Reuse tracking refers to the algorithm for measuring and capturing the long-term value generated by the spillover effects of knowledge objects. A knowledge object, after being elicited and shared freely on the platform, creates value for users when it is revisited and reused. The reuse value is not manifested through regular market interactions,
but needs to be captured and rewarded centrally by the “government”.

Tracking the reuse value of knowledge objects and rewarding their creators fairly is a subject within “fiscal policies”. Thus, we cover reuse tracking algorithm and mechanisms in detail in the next chapter.

3.6 Peripheral Modules

Peripheral modules refer to Barter’s system features, user interactions, or visualizations that are not part of Barter’s core engine layer, but belong to the “presentation layer”. They significantly impact the usability and attractiveness of a knowledge platform.

3.6.1 Social Network

Social features are instrumental in getting users attracted and engaged. On Barter, a user manages her profile and controls what information is accessible to other users. Users can establish friendship and form communities among themselves if they share similar interests.
or job functions. Users can follow or subscribe other users and groups to have corresponding knowledge objects more readily accessible in their news feeds.

The formed social graph constantly updates itself with new market activities. For instance, a user can make her question or document private by sharing it only with her friends network or within a particular group. Conversely, the system has the capability to tell a user who she interacts with most in the market so that a friendship link can be potentially established, users who share similar interests and interact more can form a group.

Fig. 3-8 displays an interactive tool on Barter for social navigation with a user-centric view. Attributes of the visualization are interpreted as follows: (a) Radius: frequency of interac-
tions in the market; (b) Thickness of links: amount of points exchanged; (c) Color of links: inflow (Green) vs. outflow (Red) of points; (d) Pop-up list: historical interactions in the market; (e) Buttons shown when a user's icon is clicked: ask the user a question or go to the target user's self-centric view.

When Barter is deployed as an internal knowledge markets tool for an organization, organizational hierarchy is implied in the social graph in addition to user-formed connections. No user on such a socially bounded platform can act as an absolute stranger. Thus, we can expect that users exhibit socially responsible behaviors, which in turn reduces the risk of users gaming the system and sabotaging market fairness.
3.6.2 Experts Matching

Barter keeps accumulating and mining historic data about a user’s activities in the market, including questions she asks or answers, documents she shares and downloads, ideas she contributes or solicits, etc. “True” expertise tags are synthesized and displayed on the user’s profile. Barter is able to accurately measure the value a user has created on a particular area (tag).

Fig.3-9 shows an interactive tool on Barter named “Expertise Cloud”. On the left panel is a tag cloud that consists of the most popular tags in the system. Tags are positioned following a modified force-directed algorithm. The sizes of the tags encode the sizes of “Knowledge GDP” created on respective tags, i.e. the amount of transactions on knowledge objects that are associated with the tags. Links between tags represent concurrence in knowledge objects. Linked tags get highlighted when a tag is hovered or clicked. The top-right panel displays a list of experts for the clicked tag, sorted by expertise scores on that tag, and the bottom-right panel displays a list of most popular knowledge objects in the market tagged by the clicked keyword. This is a visualization tool on Barter for exploring popular topics inside the organization and matching top experts and top knowledge contents to query terms.

Here, Information Economics helps solve the disclosure problem in information asymmetry. Barter helps knowledge suppliers “signal” their expertise via their earned expertise points. So they do know what they claim to know. Barter helps knowledge seekers “screen” for good content by helping filter on the highest rated content and the highest earning experts.

3.7 Comparison between a real-world economy and the Barter knowledge economy

We find it helpful to compare Barter side-by-side with the U.S. economy to understand how different components of the platform operate, as shown in Table 3.2. It is worth emphasizing
that fine-grained currency controls enable certain advanced functions that are infeasible in a real-world economy, as explained in detail in subsequent sections.

3.8 Summary

In this chapter, we present a complete system architecture of the Barter knowledge economy, which consists of three key components: knowledge currency, knowledge market mechanism, and economic policies. We focus on introducing the market engine for information products. We demonstrate how economic theories and practice such as information economics and quantity theories of money are applied in the design framework. We also explain why certain design choices effectively solve problems listed in Chapter 2.
<table>
<thead>
<tr>
<th>U.S. Economy</th>
<th>Barter Knowledge Economy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Currency – U.S. $</td>
<td>Barter implements its own virtual currency system. It is universally accepted and circulated inside Barter. Users can exchange knowledge currency for either knowledge or material rewards. Advanced features include expiration at an optimal schedule.</td>
</tr>
<tr>
<td>Markets for products &amp; services</td>
<td>Barter implements multiple types of markets to meet various organizational needs. Markets include 1) Q&amp;A, 2) document exchange, 3) ideas, 4) prediction, 5) services, 6) news, 7) product auction, 8) design for self-design, etc. These are referred to as “primary information markets”.</td>
</tr>
<tr>
<td>Federal Reserve Bank &amp; monetary policies</td>
<td>Barter establishes an entity, dubbed the “Central Bank” to track issuance and callback of currency. Dashboards help the “chief economist” monitor and understand the status of the economy. A set of economic tools are provided tune parameters of the economy to improve its operation and running.</td>
</tr>
<tr>
<td>Organizations versus Individuals</td>
<td>Users on Barter can form groups, and perform intra-group or inter-group market activities. More advanced group structures include “guilds”, where users earn membership and “cliques” where membership is by permission.</td>
</tr>
<tr>
<td>Regulatory bodies</td>
<td>Barter uses self-governing and self-regulating crowds that are rewarded for community activities such as policing members and cleaning content.</td>
</tr>
<tr>
<td>Securitization and secondary markets (Equity, Commodity, Bond markets, and Derivative markets)</td>
<td>On Barter, information products can be securitized and traded on a secondary market. Securitization applies to multiple markets, such as the Q&amp;A market, document exchange, and ideas. Trading increases market thickness, helps sort and organize information by its value, and improves information timeliness and quality by emphasizing ownership. Securitization gives people a share of the future value their knowledge creates, which alleviate the free-rider problem for idea generation.</td>
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Chapter 4

Mechanism Design

4.1 Overview

This chapter introduces advanced architectural design on three important components:

Monetary Policies conducted by the “Central Bank” to manage currency supply;

Fiscal Policies conducted by the “Planner”, a term that represents the “Government” of the knowledge economy; Fiscal policies are employed to reward knowledge reuse and encourage good behaviors;

Information Securitization & Derivative Markets an innovative framework where knowledge products are securitized that generate long-term point inflows, and the ownership of knowledge objects are divided up into shares which all users can buy and sell.

Monetary and fiscal policies provide management of an organization who administers a knowledge platform advanced managerial tools. With these economic tools, management is able to supervise the platform on a macro-level, rather than micro-manage what knowledge objects ought to be created and how they are priced. How resources are allocated and valuation of knowledge should be determined by all market participants.
We have briefly introduced these modules in the previous chapter as part of the system architecture. Because of the complexity and significance of these modules, this chapter is dedicated to covering their mechanism design in detail.

4.2 Economy, Central Bank, The Planner, Monetary & Fiscal Policies

4.2.1 Overview

The knowledge economy consists of knowledge currency, knowledge markets, and economic policies that are designed for the prosperity and health of the economy. In the knowledge economy, there are two special entities: the “Central Bank”, and the “Planner”.

The primary role of the “Central Bank” is to issue, monitor and manage currency in the whole economy. Its role is similar to that of the Federal Reserve Bank to the U.S. economy. Monetary policies are tools employed by the “Central Bank” to stimulate or “cool down” economic activities. Currencies are injected into the economy or extracted out of circulation when the “Central Bank” employs expansionary or contractionary policies.

The corresponding counterpart of the “Planner” in a real-world economy is the government. We might use the two terms interchangeably. In a real-world market-based economy, the government does not directly participate in market activities or forcefully direct resources. However, the government is able to generate revenues for central spending through taxation, running state-owned enterprises, issuing debts, or simply printing money. In many western economies, issuing new currency is locked up with the “Central Bank” purchasing government-issued debt securities. Government spending and revenue generation have important implications for prosperity of an economy. The most relevant purposes in the context of knowledge markets are: 1) investing in products and services that are under-created in a decentralized economy such as infrastructure, security, and fundamental research, and 2) setting directions and encouraging certain behaviors, such as offering tax credits for green
energy or home ownership. In the knowledge economy, the “Planner” conducts government spending by employing fiscal policies.

4.2.2 Real-world vs. Knowledge Economy

Innovations tend to find inspiration or mirror analogs in natural precedents. We thus seek proven theories and practice from the real-world economy when we design and build the knowledge economy. Goals pursued by a real-world economy are multi-faceted with many historical, societal and economic concerns. The structure of a real-world economy is rather complex with various institutions and laws. In contrast, for a knowledge economy, the goal is straightforward: maximize knowledge creation and sharing, and get contributors fairly rewarded and recognized. Therefore, when we learn from real-world experiences and replicate the successful mechanisms in the knowledge economy, we have to manage the complexity and make necessary simplifications to make them most effective.

In a real-world economy, the roles of the “Central Bank” and the government are clearly separated. Using the U.S. economy as an example, the Federal Reserve exerts monetary policies independent from government policies. The Fed stimulates or cools down the economy by tightening or loosening credits injected in the economy. The Fed controls credits by setting target interest rate, which is affected by open market operations - buying and selling government-issued debt securities. The government does not issue new currency - the currency supply is increased when the Fed purchases government deb securities.

In a virtual knowledge economy, such a delicate and rather complex structure may not be justified necessary for knowledge management purposes. In practice, when deploying such a knowledge economy inside an organization, it adds perplexity to users trying to differentiate the “Central Bank”, the “Planner”, or the management of the organization from users’ perspectives. Both the “Central Bank” and the “Planner” are often perceived as the same invisible policy maker. They can be confused with managers of a firm who administer such an internal knowledge economy. Monetary and fiscal policies will eventually be designed and executed by humans. Therefore, such a layer of separation can be isolated from knowledge
markets participants. Conceptually separating the two entities does help us understand their roles and functions more clearly in the design framework.

In this dissertation research, we make the following important simplifications in our discussion:

- **Interests rates and credits are not considered.** In a real-world economy, borrowing from individuals and the government, lending initiated in the fractional banking system, drive the concepts of interests rates and credits, and form the basis of many economic activities; However, to simplify our discussion, we do not consider interest rates and credits;

- **The “Central Bank” and the “Planner” own the same bank account and initiate policies together.** In the U.S. economy, the clear separation between the Federal Reserve and the government relies on the existence of credits and debt issuance. Given that we do not include them in our discussion, we can combine their accounts into one account set up at the “Central Bank”, and consider them as a single policy maker. Both terms “Central Bank” and “Planner” are conceptually virtual entities which initiate monetary and fiscal policies.

The simplification above is helpful not only in facilitating our discussions on economic policies, but also in software architecture design and system deployment. It also implies that the “Central Bank” can directly create currency and save it in its account. The “Planner” injects currency into the knowledge economy through fiscal spending. This process does not involve complex exchanges such as debt issuance and open market operations.

### 4.2.3 Currency Circulation

After introducing the overall framework and making the simplifications, we clearly define how the “Central Bank” and the “Planner” interact with the knowledge economy:
The "Central Bank" monitors key economic indicators such as levels of economic activities, price indexes, and sets up a target growth rate of currency supply. This gap on new currency issuance also determines budgetary constraints for the "Planner";

The "Planner" generates revenue and meanwhile extracts currency out circulation, and injects currency into the knowledge by fiscal spending.

The two entities own the same bank account at the "Central Bank". The currency circulation between this account and the knowledge economy is shown in Fig. 4-1 and explained in detail below.

At a given time $t$,

$N$ - The total number of users in the economy;
$m$ - Average wealth - the average of currency owned by each user on average;

gc - Target currency growth - the expected issuance of new currency from time $t$ to $t + 1$
is thus $N \cdot m \cdot gc$.

There are multiple ways in which more currencies get injected into the economy from time $t$ to $t + 1$, which are modeled as follows

$\Delta N$ - The number of new users who join the economy during the unit time period; the average number of users during this time period for policy consideration is denoted using $\bar{N}$;

$i_n$ - New user reward rate - currency issued per newly registered user;

$i_s$ - Stimulation budget rate. The “Central Bank” deposits “fast” expiring points to users’ accounts to encourage spending and simulate activities. These “fast” expiring points are converted into regular “slow” expiring points when spent for knowledge before expiration time; $i_s$ denotes currency issued to each user for stimulation at time $t$;

$i_{fr}$ - Budgetary rate for fiscal spending on rewarding knowledge reuse; the “Planner” rewards knowledge reuse to capture the spill-over effects of information products; The total budget is thus $\bar{N} \cdot i_{fr}$;

$i_{fb}$ - Budgetary rate for fiscal spending on rewarding good behaviors; the “Planner” rewards good behaviors such as voting, tagging, and fraud reporting; the total budget is $\bar{N} \cdot i_{fb}$, which can be further divided into multiple pools rewarding different types of behaviors.

There are also multiple ways in which currencies get taken out of circulation from the economy, which are modeled as follows

$os$ - Rate at which the subsidized “fast” expiring points expire and get returned to the central bank. $os = i_s \cdot r_{ce}$, in which $r_{ce}$ represents the expiration ratio;
$o_{fp}$ - Rate at which users get penalized or charged for discouraged behaviors such as market fraud or content deletion; Charging penalty fees is considered as part of fiscal policies that can be controlled by the "Planner";

$o_{ft}$ - Rate at which the "Planner" taxes users for supporting fiscal spending; taxation is considered as part of fiscal policies for revenue generation;

$U_v$ - The amount of currency spent on the product auction market to purchase items sponsored by the organization. $U_v = U \cdot r_{ex}$, where $U$ is the $ budget the organization invests in the product auction market, and $r_{ex}$ is the exchange rate between the virtual currency and real-world currency.

Some of these rates and attributes are observable at a steady-state of the knowledge economy, and some of these rates can be controlled and tuned as part of the fiscal and monetary policies.

### 4.2.4 Monetary Policies

Definition of "money supply": total amount of currency issuance that are outstanding for usage in the knowledge economy. Currency that resides in the central bank account does not count towards the amount of money supply. Monetary policies represent the practice of stimulating or cooling down the knowledge economy by adjusting the money supply.

Money supply must be at the right level - if currency is over-supplied, inflation will be introduced, price indexes go up, and as a result users care less about currency since its value has been diluted; if currency is under-supplied, the economy becomes stagnated because users do not have enough currency to perform economic activities. This leads to a situation when knowledge and innovation is under-created.

Using the modeling variables introduced above, we can establish the following relationship among currency issuance, revenue generation and fiscal spending:
Reshuffling terms of the equation, and grouping terms with similar functionalities, we obtain a more succinct form of the equation:

\[ N \cdot m \cdot g_c + U_o + N \cdot o_s + N \cdot o_{fp} + N \cdot o_{ft} = \Delta N \cdot i_n + N \cdot i_s + N \cdot i_{fr} + N \cdot i_{fb} \]  \tag{4.1}

Each group of terms is interpreted and denoted as follows:

\[
\begin{array}{c c c c c c}
\text{New Currency Issuance} & \Delta N \cdot i_n & - & U \cdot r_{ex} & + & N \cdot i_s(1 - r_{ce}) & + & N \cdot (i_{fr} + i_{fb}) - N \cdot (o_{fp} + o_{ft}) \\
\text{New Users} & N \cdot m \cdot g_c & & & & & & \\
\text{Spending} & & & & & & \\
\text{Stimulation Policy} & & & & & & \\
\text{Fiscal Spending} & & & & & & \\
\text{Generated Revenue} & & & & & & 
\end{array}
\]  \tag{4.3}

Evident from Eq.4.3, the total amount of currency supply outstanding in the knowledge economy changes when the “Planner” executes fiscal policies, and when the organization management extracts currency out of circulation by selling material goods in the auction market. We have modeled how currencies get circulated between the central bank account and the economy. We can broadly categorize them into:

Spending policies or practice that require allocated budget, the effect of which is to take currencies out of the central bank account and push them into the economy:

**Stimulation Policy (SP)** - Users receive “free points” periodically for knowledge spending, which expire faster than regular points;

**New Users (NU)** - When new users join the knowledge economy, they need starting funds in their accounts; given that new users can always receive points through stimulation policy and the “Planner”’s subsidies for rewarding good behaviors, users can start their activities without initial funds; the spending on new users is expected to be near zero;
Fiscal Spending ($FS$) - The “Planner”’s spending for rewarding knowledge reuse, conducting behavioral modifications, or running campaigns;

Policies or practice that generate revenue, the effect of which is to extract currencies out of the economy, and save them back in the central bank account:

$\$$ Spending ($RS$) - Organizational management sells material goods on the production auction market to users;

Revenue Generation ($RG$) - Taxation, penalty and fees charged on users, aggregated as revenue to support different types of spending.

On one side, the “Planner” conducts spending for various purposes; on the other side, the “Planner” receives revenues to support such spending. The gap between the two, i.e. the “deficit”, is fulfilled by newly issued currency ($NIC$), or plainly speaking, the “printed money”. In Eq.4.3, the $NIC$ terms appears on the left-hand side of the equation. However, this does not imply that $NIC$ is determined by the other spending and revenue variables at the end of each budgetary cycle aftermath. Conversely, how much new currency can be created and issued, i.e. the target growth rate of currency, is totally independent from the other variables. The target growth rate is determined at the beginning of each budgetary cycle entirely based on the prosperity and fairness of the knowledge economy. Such a target growth rate determines the maximum amount of allowable “printed money”, which in turn sets budgetary constraints for spending and revenue generation. In conclusion, target currency growth rate is an independent variable solely determined by the “Central Bank” based on observing several economic indicators, rather than a dependent variable that results from the “Planner” the policies.

From a budgetary planning perspective, Eq.4.3 can be rewritten as

$$SP + NU + FS = RS + RG + NIC.$$  \hspace{1cm} (4.4)

We next interpret this relationship and explain how it impacts monetary and fiscal policies, and then draw a few important insights from this relationship.
Determining Target Currency Growth

Determining the target currency growth rate is the essential element of setting monetary policies, which in turn sets budgetary constraints for fiscal policies. One of the major contributions and innovations presented in this research is the introduction of the “Central Bank” entity, and monetary tools that stimulate or moderate knowledge activities through currency management.

In a real-world economy, such as the U.S. economy, monetary policies determine the availability of credits in the economy. When credits are under-provided, individuals and businesses do not have enough resources to conduct economic activities and make new investment, economy is stagnated; when credits are over-provided, the economy gets overheated, price indexes go up and inflation occurs, which will lead to social and economic problems.

Determining the optimal level of credit supply is not a straightforward process. It is a practical art that depends on macroeconomic theories and past experiences rather than rigorous science. In the U.S. economy, the Federal Reserve exerts monetary policies through 1) short-term interest rate, 2) discount rate, and 3) required reserve ratio. The overall goals include maintaining the stability of the financial system, reducing unemployment rate, and achieving long-term prosperity of the U.S. economy. Historically, the money supply keeps increasing at a steady pace, and it is well accepted that a moderate inflation rate and increase in currency supply is beneficiary to the vigor of the economy. The Federal Reserve keeps monitoring key economic indicators published by federal bureaus, and make monetary policies based on these statistics.

Barter mirrors established and successful practice and theories from the real world and adopts similar mechanisms for the knowledge economy. Because we do not consider interest rates and lending activities, the concepts of “credits” are not relevant. Instead, the “Central Bank” directly manages the currency supply.

The following economic indicators should be calculated and closely monitored for the “Central Bank” to determine appropriate currency growth rate:
“CPI” - Price indexes of knowledge products, the percentage of increase in which represents the inflation level of the knowledge economy. In a real-world economy, due to the wide diversity and quantity of goods and services, the statistics bureau can only select representative products and services from various industries to form the “basket”, and assign different weights to them when calculating the price index. Within a knowledge economy, there are usually less varieties and quantities of knowledge products and associated transactions, which are all stored in the database. This makes tracking price indexes convenient and accurate. A high inflation level indicates a risk of currency oversupply, and a low inflation level indicates there is still room for increasing currency supply;

Requesters Price Index - How many points on average users post as bounty when they request knowledge objects;

Sellers’ Ask Price Index - How many points on average users ask as price when they post knowledge objects with price tags;

Buyers’ Transaction Price Index - How many points on average a knowledge requester pays a knowledge provider who responds to the request and share knowledge for free;

Sellers’ Transaction Price Index - How many points on average a user pays a knowledge seller who sell knowledge objects with price tags;

Transaction Price Index - The average points transferred across all knowledge transactions between two users;

Each of them represents a different type of price index designed for a different purpose. However, we expect all these indexes having similar trends and movements.

“Exchange Rate” - The $r_{ex}$ term used in Eq.4.3, which can be measured by the $\$\$ amount of products posted in the auction market, and how much users spend to acquire them using virtual currency. If $r_{ex}$ increases, one $\$\$ can exchange more virtual currency, which implies that virtual currency depreciates. Users devaluing currency is a warning sign that the economy is experiencing inflation.
“GDP” - The amount of knowledge creation and the total value brought to the community by the created knowledge. GDP can be denominated in either virtual currency or real $ by use of the exchange rate. When GDP is calculated, it consists of two components:

“Consumption” - The sum of all peer-to-peer knowledge transactions among users, excluding the ones in the product auction market; This component represents the value of knowledge that is directly perceived and paid for by users;

“Investment” - The sum of all “Planner-to-users” transactions rewarding knowledge reuse and good behaviors as part of the fiscal spending. This component captures the reuse value brought by freely shared knowledge, and value created by extended knowledge objects such as tagging and voting;

We must be careful that double-counting must be avoided. Transactions that occur in the product auction market do not count towards the knowledge GDP. It is still valuable to track this portion since it shows user activeness and another type of value created by the platform;

The following indicators are also critical to the health and prosperity of the knowledge economy. They can be affected or improved by monetary policies, however, they cannot be fully addressed by monetary policies alone. Associated problems require both effective monetary and fiscal policies to solve.

“Wealth Imbalance” - Inequity of income and wealth among different users. Skewness and Kurtosis of wealth distribution are important indicators;

“Inactive Users” - The number of users who rarely or never participate in any activities in this knowledge economy; this group of users have not receive enough incentives to participate, contribute, and share knowledge; we can track users’ activeness by counting the number of user actions performed during the past period such as log-ins, votes, comments, answers, etc.;
"Fairness" - Sufficient fairness is a critical condition for a successful economy. This is not an index that can be measured quantitatively, but qualitatively through users' online or offline feedbacks.

Real $ Resources in Virtual Economy

An organization can use the Product Auction Market to back up the value of currency and provide material incentives to users. The framework of a knowledge economy allows an
organization to systematically inject $ resources into the platform, and provide long-term sustainable material incentives. Eq.4.1 and Eq.4.4 connect $ resources an organization plans to invest with the virtual knowledge economy. Let’s revisit and simplify Eq.4.4 and examine the roles of $ spending:

Central Spending = “Generated Revenue” + “Printed Currency” + “Currency Buyback”

(4.5)

At the beginning of each budgetary cycle, the “Planner” designs and allocates budgets for different spending policies: fiscal policies, stimulation policies, etc. The budget pool comes from three major sources: 1) currencies “printed” by the central bank via monetary policies; 2) revenue generation through taxes and fees; and 3) currencies that are bought back by the organization through selling $ resources in the auction market.

As we introduced earlier, when the organization’s management sells material items on the product auction market, the value of currency is backed up with material incentives, and an exchange rate can extrapolated. Eq.4.5 offers a new angle of viewing this practice. The organization’s management effectively purchases virtual currencies from the hands of all users, extract them out of circulation in the economy, save them back in the central bank account, so that they can be spent back into the economy to support different goals.

As introduced in the previous section, how much new currency can be printed out to support fiscal spending is determined independently, and considered fixed. If the budget for central spending is fixed, the “Planner” needs to balance between taxing / penalizing users to generate revenue or relying on $ spending to buy back currency. If the organization has a large amount of $ resources to support the knowledge economy, the “Planner” does not need to impose much taxation. On the other end, if the organization only has a small budget on using $ resources to put through the auction market, the “Planner” needs to rely more on taxation and fee generation, or simply reduces central spending, which might hurt the economy.
It is worth emphasizing that when organization management determines how much $ \text{re-}
\text{sources} \text{to invest in the knowledge economy, they should be aware that the exchange rate
between virtual currency and real currency does not stay constant, but will be directly
impacted by the availability of material goods on the market. In general, } r_{ex} \text{ is a decreasing
function of } U.  

4.2.5 Fiscal Policies

In a real-world economy, an efficient market mechanism allows all market participants to
optimally allocate resources and create goods and services among themselves in a de-centralized manner; an effective “Central Bank” designs monetary policies that maintain the
stability of the financial system and optimize currency supply. The government utilizes fiscal
policies to stimulate the economy, invest on basic infrastructure, set directions on economic
activities that should be encouraged, which are often infeasible for the crowd to accom-
plish in a decentralized manner. Examples include government investment on fundamental
science research, public services, basic infrastructure, tax credits on green energy or home-
ownership. As a result, the government needs to generate revenue by taxing individuals
who enjoy public goods, and spend the revenue back on the community.

In the context of a knowledge economy, there are also similar challenges that can only be
solved by similar fiscal policies set by the “Planner” in a centralized manner. There are
mainly three categories that exhibit properties of public goods and basic infrastructure:

**Rewarding Knowledge Reuse** - Capturing, measuring, and rewarding reuse of knowl-
edge objects;

**Behavioral Modifications** - Rewarding good behaviors inside the knowledge economy
such as voting, tagging, fraud reporting, etc., which are essential to the success of a
knowledge economy for various reasons;

**Running Campaign** - Depending on the status or problems of the knowledge economy,
the “Planner” can run campaigns to promote certain behaviors or activities during a
limited time period.
As shown in Eq. 4.5, budgets for fiscal policies are supported by 1) allowable newly printed currencies, 2) revenue generation from the economy through taxation and fees, and 3) currencies bought back through spending $ resources. The size of budgets is dependent upon the availability of each, and what is best for the economy. It is not the other way around that how much we spend on fiscal policies determine how much money we should print. After obtaining the overall budget, the “Planner” divides it into several pools to support different categories of fiscal policies. We will discuss each category of fiscal policies in subsequent sections.

4.2.6 Market Seeding

Original spending can help solicit knowledge and get the platform adopted. The chick-and-egg problem of a new two-sided network platform can be effectively solved using market seeding. In the early stage of opening the platform, organizational management can seed the market by requesting information via these markets and pushing more rewards to the auction market. It is explicitly the seed and subsidize strategy of two-sided networks, which helps address the motivation problem listed as part of our research strategy.

4.3 Reward Reuse & Long-term Fair Distribution

4.3.1 Encouraging Spending

An excessive saving rate - the problem of currency hoarding can lead an economy prone to failure. Real-world examples include China’s economy which is driven by government investment and export. Domestic spending / consumption is very low compared with U.S. economy which implies long-term structural problems. From the quantity theory of money, we have learned that a low turn-over rate of currency leads to a low production level, and the overall economy turns stagnant where economic activities are inactive.

To reiterate, we have designed two important mechanisms that aim to encourage user spending:
**Currency expiration** Currency expires if not spent before certain deadlines; users are thus encouraged to spend the points for knowledge or other products before expiration of points;

**Spending as investment** As introduced above, when a user spends currency to elicit knowledge / contents from other users, the user can potentially earn points back if the request brings good discussion on the topic and the elicited contents get reused in future. This “ballooning” distribution mechanism provides incentives for users to ask good questions or request important information by spending. This is why the initial spending for requesting knowledge is similar to an investment - spend today and expect returns in future.

### 4.3.2 Reuse Tracking

Knowledge objects (KO) can be organized using a tree structure based on their elicitation / response relationships, as depicted in Fig.4-3. Note that this tree structure is fundamentally different from the tree structure in credit tracking and assignment module for documents, where each link represents the ratio of overlapping contents between parent and child documents. In the context of reuse tracking, each link of the tree represents how the child knowledge object is elicited and attached.

In Fig.4-3, we use a Q&A thread as an example. The question is the root of the tree, its answers and direct comments or amendments are the first-generation children, whose comments and their threaded comments form further descendants. At any particular time, there are multiple trees in the knowledge base. We can trace the tree back to the root from any knowledge object node.

At the beginning of each budgetary period, the “Planner” allocates $FS_R$ as total budgets for rewarding knowledge reuse. At the end of this budgetary period, we have $K$ knowledge objects in the system. We can calculate a “reuse score” for knowledge object $k$ based on its observable attributes. Here we consider four attributes:
Figure 4-3: Knowledge objects are organized as a tree structure
Voting - Number of unique votes received during the past budgetary period, denoted using $n_{v,k}$;

Unique Page visits - Number of unique page visits during the past budgetary period, denoted using $n_{p,k}$;

Tipping received - Amount of tipping received during the past budgetary period, denoted using $n_{t,k}$;

Derivative contents - Number of derivative knowledge objects, i.e., the number of all descendants from this node generated during the past budgetary period, denoted using $n_{d,k}$; This number should be counted excluding the knowledge objects created by the same author.

These attributes are all proxies to the quality and reuse value a knowledge object, and they carry different weights. For example, the amount of tipping received is a much stronger signal compared with page visits in indicating the reuse value. A reuse score $R_k$ is a function of these observable attributes:

$$R_k = f(n_{v,k}, n_{p,k}, n_{t,k}, n_{d,k}).$$  \hspace{1cm} (4.6)

The simplest form of the reuse function is a linear function with different weights assigned to different observable attributes:

$$R_k = w_v \cdot n_{v,k} + w_p \cdot n_{p,k} + w_t \cdot n_{t,k} + w_d \cdot n_{d,k},$$  \hspace{1cm} (4.7)

where $w_v, w_p, w_t, w_d$ are weights to be estimated in order to optimize knowledge creation and achieve sufficient fairness. Suppose the total budget of fiscal spending on rewarding reuse is $FS_R$ following the notation in Eq.4.4, each knowledge object can receive a reuse reward

$$M_{re,k} = FS_R \cdot \frac{R_k \cdot W_k}{\sum_{k=1}^{K} R_k \cdot W_k},$$  \hspace{1cm} (4.8)
where $W_k$ is a window filter function for adjustment. For example, we might not want the bottom knowledge objects to receive reuse rewards, or we want the top performers to receive more rewards. We could use $W_k$ function to do re-balancing.

A redistribution mechanism based on back-tracing is designed and explained in Fig.4-4. The knowledge object $k$ does not keep $M_{re,k}$ in its entirety. There is a back-tracing redistribution rate $r_{bt}$, ($0 < r_{bt} < 1$), so that part of the rewards $M_{re,k}$ go back to its ancestors along the tree, in an exponentially decreasing order.

Such a redistribution mechanism explains why requests for knowledge objects can also generate incomes, and why good questions or remarks that stimulate great further discussions can receive long-term fair rewards. The reuse tracking and redistribution mechanism creates incentives for spending, advertising, or even leaving comments on other knowledge objects, because of the long-term fair return.
4.4 Rewarding Good Behavior

The success and usefulness of an organizational information market platform critically depend on seemingly simple actions by users, such as voting, tagging, tipping, and fraud reporting. In essence, a popular mechanism adopted by many platforms is to outsource knowledge indexing, knowledge validation, knowledge valuation, and maintaining platform integrity to the crowd. The platform works well if users actively engage in these simple activities, and as a result the content provides greater value to the community. These activities are broadly categorized into “Good Behavior” in the following discussion. We visit the list of activities we want to promote in more detail.

4.4.1 Voting (Thumbing)

All users collectively determine the value, quality, and usefulness of a piece of information by providing a binary opinion. With sufficient participation, voting results provide an accurate signal indicating information value to the community. As a result, more valuable information gets promoted to knowledge seekers, and the searching cost is reduced. The measure of information value and re-usage tracking also depend on the voting results.

From a practical perspective, although today’s user interfaces make voting as simple as a mouse click, many users still lack the motivation and interests to perform the simple action. Following the classic 20-80 model, the majority of users are still free-riders who only take away knowledge other users contribute to the platform and enjoy the benefits of other users’ voting actions without contributing back. We wish to establish an ecosystem inside a community with a collaborative culture where every individual’s success on learning and knowledge acquisition depends on each other’s actions, even as simple as clicking on a voting button.

In the context of a knowledge market with economic tools, how can we provide incentives for users to vote on contents following their true assessment of information value? A poorly designed incentive structure can easily encourage irresponsible behaviors of excessive voting.
For instance, putting a fixed price tag on each vote, 1 point per vote, e.g., will tend to collect a lot of garbage voting - users vote on information contents without really assessing its true value to them in order only to collect the point rewards.

The original purpose of encouraging voting is to better assess the value of information and sort contents for easier re-usage to users. Therefore, a vote should be rewarded only if such a vote achieves this purpose. The “central bank” should only award votes that help the platform recognize information value and sort contents by their value. An algorithm needs to be developed to measure the value of a vote, and the “central bank” subsidizes voting based on whether votes add significant value to the platform.

4.4.2 Tipping

Tipping not only serves as a signal for appreciation and gratitude between two individuals, it is also an important activity for the platform to value and sort information contents. Tipping is similar to voting for the purpose of information valuation and sorting. Both tipped amounts and received votes are strong signals as proxies to the re-usage value and quality of a piece of information. Tipped amount is an important attribute used for calculating a re-usage score, similar to voting results.

The “central bank” can subsidize tipping to encourage such behaviors. The challenge is to avoid fix-pricing subsidy and promote tipping as a social norm. Promote tipping as a social norm also alleviates the problem of points getting overly mercenary.

4.4.3 Tagging

For any knowledge platform such as a Q&A exchange, document management, or idea management tools, tagging is always an important feature. Information items usually contain complex textual contents which present significant challenges to knowledge indexing, categorizing, and searching, in terms of both accuracy and speed performance. Therefore, accurate and sufficient tagging of each information item is critical to the success of a large
scalable knowledge market. Re-usage of information will be jeopardized if indexing and searching under-perform, and the value of the platform is not fully explored.

The original information contributor - either as an information seeker or an information provider - can supply tags. However, such a simple but extra activity also suffers from incentive problems. Often the original information contributors do not provide sufficient and accurate tags after they finish the main body of contents. A popular mechanism is to crow-source tagging to all users and let everyone add or remove tags. However, such crowd-sourcing mechanism for tagging also experiences participation and incentive problems.

In the context of an information market, the good behavior of tagging can be encouraged and subsidized by the “central bank”. The subsidizing mechanism is challenging in that a naive fixed-pricing mechanism can introduce excessive garbage tags into the system. For instance, in a scheme where users receive 1 point for each tag provided, users tend to provide low-quality tags just to get the subsidy points.

We develop an algorithm and design a mechanism where only tags that meet certain criteria get rewarded. The criteria has two components

**Accuracy** A keyword accurately represents and summarizes the content;

**Sufficiency** Any information item can usually be sufficiently represented by a limited number of tags. Some tags still represent relevance, but only cover some minor details of the information item. We want to reward tags based on their relative importance and expressive power. For insignificant tags, we want to devise rules to reduce or avoid rewarding.

The challenge of measuring accuracy and sufficiency of tags will be tackled by original information providers and the crowd again. Other users receive subsidized points for providing tags that meet the two criteria.
4.4.4 Fraud Reporting

Fraud prevention is critically important to the success of an information market platform. Market rules and platform technology are imperfect. There are often “smart” users who challenge the platform designer and try to gain unfair advantages. We have covered in detail market fraud and fraud prevention in the previous section. It’s worthwhile to reemphasize fraud in this chapter / section because market fraud prevention is also crowd-sourced to all users and depends on them to report fraud and clean up fraudulent behaviors out of the platform.

Fraud reporting and voting on judging are “good behaviors” that we need to promote and the “central bank” can reward. Users help clean up fraudulent behaviors not only for contributing to establish a honest social culture, but also for receiving points reward if the fraud report is accurate.

The fraud-prevention mechanism needs to avoid fixed-pricing scheme. For instance - receiving 3 points for reporting a fraud, or receiving 2 points for making a judgment on a fraud case will lead to irresponsible behaviors from users. They might randomly report others and make a judgment just to receive the reward points. They should only receive rewards if they successfully convict a fraud case.

4.5 Derivative Market for Information Products

4.5.1 Definition & Overview

The term “Derivative Market” is used in contrast with the “Primary Market” of information products.

Primary Market is where users directly purchase and sell primitive knowledge or information products. For example, a user posts a document for a price, and other users purchase the document after payment. Or, a user asks a question with certain points
as bounty, and allocate points among answerers who provide useful knowledge. These are all direct knowledge / point transactions that happen in the “Primary Market”, which represent the simplest forms of market interactions;

**Derivative Market** is where users purchase and sell securities, whose value is determined or “derived” from the value of the underlying information products. The structure and creation of such securities is much more complex and adds challenges to user understanding of the mechanism and user interface design.

We call the process of structuring and creating securities derived from information products “information securitization”. The exchange for trading such securities is named “Derivative Market” for information.

We first build the basis for information securitization by visiting finance 101. A firm’s valuation can significantly exceed the value of its assets because of its profit-generating capability in future. The valuation is calculated based upon the present value of future income flows. This fact builds the basis for the stock / equity market. An individual prefers to own a stock because a share of stock implies fractional ownership of the company. In addition, the value of a share of stock theoretically depends on the present value of all futuristic possible dividend income, which in turn depends on the profiting capability of the firm. A buy / sell decision is made based upon whether one believes the market price of a stock is lower / higher than its true value.

The root cause of information securitization is based upon the fact that information has spill-over effects - information re-usage creates consistent and long-term value to the community. From our analysis and introduced mechanism design in previous sections, valuable information or knowledge gets reused after its initial creation, which is rewarded by the “central bank” in a continuous fashion. A valuable piece of knowledge thus gets periodic point inflows that are commensurate with its value. This “profit generating” capability of information builds the basis and ground for information securitization.
The Planner

Reuse tracking & long-term rewards mechanism

Knowledge Object

Information securitization process

The sole creator and owner

Knowledge securities

The derivative market

Multiple owners who all have incentives to improve knowledge quality

Figure 4-5: Illustration of the information securitization process and derivative markets
4.5.2 Examples & Use Cases

In the Q&A market and the document market, answers and documents contributed by knowledge providers have long-term reuse value. Based upon our prior discussion on rewarding reuse, these knowledge items can potentially receive periodic income flows based on their reuse during a certain period. The owner of an answer or a document can choose to divide the ownership into \( N \) shares, and sell some or all of the shares to the other users with certain prices for an immediate point return. After this “going public” moment, all further reuse rewards coming from the central bank will be divided based on the number of shares, and distributed among share owners.

4.5.3 Benefits & Caveats

Securitizing information products and designing a secondary market for exchanging securities brings unique strengths to the platform and solves some challenging problems in platform economics.

- Information securitization and derivative market trading adds great gamification and fun components to the platform. Users solve knowledge problems by participating in a fun game.

- Information securitization and exchange helps with knowledge validation, updating and quality assurance. Owners of an information item has incentives to maximize its valuation on the market by improving tagging, knowledge quality, and keeping it up-to-date, because the value of an information item is theoretically determined by its re-usage.

- If the derivative market for securitized information products is effective and efficient, the market price information serves as a stronger and more accurate signal for the value of an information item, compared with other signals such as tipped amounts, votes, or visits. This is useful for knowledge valuation and sorting.
Information securitization and exchange helps with a smooth transfer of ownership of knowledge and innovation, and better tracks credit-sharing.

These benefits come with caveats and challenges on mechanism design:

- Information securitization and a secondary market for exchanging the securities involve complex financial theories and practice that add notable complexity and confusion to the platform and to end users. Confining complexities at the back-end and designing intuitive user interfaces and experiences are critical to its practical usage.

- Market repugnance needs to be managed well. The platform should not look overly mercenary.

- Having such a security market provides an opportunity for market manipulation. Users with excessive currency reserve can influence the price and transaction volumes of such securities, which can mislead other users when doing assessment. Rules and regulations need to be in place to monitor and regulate the marketplace.

- The robustness and correctness of the derivative market critically depend on the the robustness and correctness of the primary market, especially the mechanism design on rewarding the re-usage of information. Deploying the derivative market adds a more stringent requirement on the error-tolerance of the primary market mechanism design.

4.6 Summary

This chapter covers mechanism design issues when we design monetary policies and fiscal policies. We also explain information securitization and derivative markets in more details.

A knowledge economy is a complex system with convoluted network and market interactions among participants and the “Planner”. Managing a knowledge economy striving for
Figure 4-6: Parameter estimation of the knowledge economy

Prosperity relies on outputs from this complex system as key indicators and different economic policy tools as inputs. The "objective functions" to optimize include 1) knowledge creation and sharing (knowledge GDP), 2) sufficient fairness, and 3) users’ activities, shown in Fig.4-6. As shown in the above mechanism design, it is often difficult to model all parameters and system dynamics in a closed form. The relationship between system outputs and inputs is not deterministic nor transparent. Estimating the optimal parameters for policy tools takes tuning and experiences. This is also why established economic theories and proven practice are crucial in running a successful knowledge economy.
Chapter 5

System Deployment & User Studies

5.1 Software Development

Barter is a web-based software platform that realizes the information market design in our research. The software platform is built both as a prototype demonstrating the concepts of knowledge currency, markets, and economic policies, but also used as an experimental testbed to conduct user studies and gain insights from system deployment. At the time of writing this dissertation, the software is still being actively developed and strengthened.

Fig.5-1 shows the front page of Barter when users visit. Fig.5-2 shows the landing homepage after a user logs in. From the landing page, we can have a visual understanding of what functionalities Barter is offering. Users can navigate through different types of knowledge markets such as Q&A, Document, Idea, Product Auction markets. They can also share news items based on the attention module, and report bug fixes or request features on the Design market (named “Fix”). At the center of the homepage, is a news feed where newly created knowledge objects or requests are listed and shared. Users can quickly locate the knowledge objects they need by advanced sorting, filtering and searching. Users can also
Figure 5-1: The entry page of Barter, captured from http://barter.mit.edu/

Figure 5-2: The landing page of Barter after users' login
browse the knowledge base using the tag cloud, starting from which they can identify top experts on each tag and visualize how much value of knowledge has been created on each tag. Users can readily check their account balance, and access transaction history.

5.2 Deployment & Experimental Setup

Barter has been deployed in a few different environments, primarily in university settings as either a teaching tool, or a social knowledge sharing platform. Our user studies and reporting results are mainly based upon the following deployments:

- About 550 students enrolling in a distance-learning program at a French university used an instance of Barter for discussions and knowledge exchanges;
- About 400 students / researchers from three U.S. universities used an instance of Barter as both class tools and daily knowledge sharing tools;
- Entrepreneurship courses used an instance of Barter - primarily the idea market - for students to exchange venture ideas.

In these deployments, users started with certain number of points assigned to their bank accounts. We do not ask users to engage in any particular activity attentively. Barter simply serves as a day-to-day tool for students to exchange knowledge, share documents, contribute ideas, post news, etc., following the underlying market rules.

Incentive design, especially the translation of virtual points to meaningful rewards, i.e. backing up the virtual currency, is important to getting users motivated and engaged. The product auction market provides a mechanism for users to exchange earned points for material rewards they care about. We, as researchers and “managers” of the knowledge economy, employed monetary and fiscal policies. To back up currency value and control currency supply, we posted items in the auction market for sale. Meanwhile, we can use the auction market to measure the dollar value of information created on the platform. For
example, We posted iTunes gift cards, small consumer products, and lunch opportunities with faculty members on the auction market. All user activities, transactions and market statistics have been captured and stored by the system. Through the wide deployment of Barter, we are able to collect a rich dataset on market operations and user behaviors. We mainly aim at obtaining insights for the following research questions.

- Will purely virtual currency suffices in building incentives without being backed up externally with material value?

- Are users sensitive to pricing signals of knowledge objects and requests for knowledge objects?

- Will fixed-pricing lead to oversupply of garbage information?

- Are social interactions effective in driving users to share and contribute?

- What types of market fraud tend to be created in knowledge markets? Are crowdsourcing based fraud prevention mechanism effective in cleaning up the fraud and preventing future fraud from happening?

- Can we measure the value of information created, and how does it compare against \$ value spent on the auction market?

In the following sections, we will answer these questions through quantitative and qualitative analysis of user data collected from software deployment.

5.3 Analysis & Findings

5.3.1 Users are responsive to material incentives

A frequently asked question on the usage of knowledge currency is whether purely virtual currency suffices in building incentives without external backup. We understand that virtual currency can be used to purchase knowledge, build reputation and expertise, and introduce
gamification aspects, but will users be satisfied with these virtual utilities of currency? As introduced in the chapter of system architecture, Barter uses the product auction market to back up currency with material incentives. We aim at understanding the effectiveness and necessity of doing so.

Fig. 5-3 shows several dashboards for monitoring the global economy for the time period 04/2010 - 04/2011 on the U.S. site - the number of questions and answers each day, the “price index” of the Q&A market, and the transaction volume as time series. The “chief economist” of Barter can use it to monitor several key economic indicators of the economy and decide if it is overheated or needs stimulation. For example, he can implement monetary or fiscal policies following our design in the previous chapter.

We tested the effectiveness of backing up currency using material rewards through interventions. We started the platform and deployed it for users with virtual currency only without posting any items on the auction market. We first intervened by adding a significant amount of products and awards, including an iPad, for auction during a certain period. We then suspended the supply of awards on the auction market for another period and examined how user activities responded to these external interventions.

It is evident from these curves that users do respond to material incentives. In mid-June 2010, we posted an iPad on the auction market among many other awards such as mobile devices, gift cards, free lunch opportunities with faculty members. These extrinsic awards greatly stimulated market activities (and market fraud too!). The number of transactions per day increased from 6.9 in April to 22.0 in May, when the iPad auction expired. It dropped back to 9.2 in June as fewer items were left in the auction market. The transaction volume increased from 337.0 points in April to 994.9 in May, and fell back to 160.3 in June. In March 2011, we released the news sharing module to users and posted several valuable rewards on the auction market, which also stimulated the economy significantly. Between these two promotion periods when plenty of awards were on sale in the auction market, user activities remain low.

From the analysis above, we learn that although virtual currency does provide utilities to users such as purchasing other users’ knowledge and building reputation / expertise,
Figure 5-3: Dashboards for monitoring the knowledge economy, which show time series of: 1) the number of questions and answers (top), 2) Price indexes (middle), and 3) frequency and volume of market transactions on each day from 04/20/2010 to 04/16/2011. Jumps in activity and price levels occurred in June 2010 when we offered an iPad prize, and March-April 2011 when we launched the News market with material prizes on the auction market.
users more appreciate currency backed by material value. Backing up virtual currency both “internally” and “externally” provides more incentives for users to earn currency, thus stimulates user activities, especially during the adoption phase of the knowledge platform.

5.3.2 Market forces are significant

A frequently asked question in the context of an information market is whether market forces, especially price signals, are effective. The Q&A market was first implemented and used in the deployment. Thus, we analyze data collected from the Q&A market of the U.S. site to see whether offered points affect the quantity and quality of provided answers.

Fig.5-4 shows the number of questions asked on the U.S. site for each level of offered points - for all, anonymous, non-anonymous questions. Most questions were asked with around 25 points offered, while only a limited number of questions rewarded 100+ points.

Fig.5-5 shows the average number of answers a question received for different levels of offered points. When the number of offered points is below 100, the average number of submitted answers received generally increase as the number of offered points arises. As
the offered points exceed 100, the difficulty of the question increases more significantly, thus the number of submitted answers decreases sharply with offered points. There appears strong linearity for anonymous questions. As in [21], we use the average length of answers as a proxy for answer quality. It is evident from Fig.5-6 that the average length of answers keeps increasing as the offered points arises for a question, and when the offered points exceed 100, the increased difficulty thwarts good quality answers.

Both curves exhibit a reverse-U shape, and the local maximum is reached when the number of offered points are in the 90-110 range, for both the quantity and quality of answers. More interestingly, this is also where the curve in Fig.5-4 reaches a local peak value, which implies that users asked a significant number of questions within this price range.

Therefore, the price effects are prominent. Price Theory properly balances the marginal rates of substitution between using an expert’s time to help others versus having him perform his own work, thus addresses the efficient allocation problem.
Figure 5-6: Average length of answers obtained, categorized by the number of points offered for questions - a) all questions; b) anonymous questions; c) non-anonymous questions.

Figure 5-7: Transactions categorized by 1) markets, 2) transaction types

5.3.3 Fixed-Pricing Results in Oversupply of Low-quality Information

As introduced earlier, we prefer decentralized knowledge markets to a top-down incentive structure where fixed-reward, i.e. fixed-pricing, is used. Fixed pricing leads to oversupply of low-quality information that is less valuable than the given price and under-supply of high-quality information that is more valuable than the given price. The same caveat also applies to fiscal policies for rewarding good behaviors such as voting or tagging.

In order to examine the effects of fixed-pricing, on the French site, we employed the following fixed-pricing rules to encourage voting and commenting: 1) Users receive 2 points when they vote, either up or down, limited by 5 times a day; 2) Users receive 2 points when they leave
a comment, limited by 5 times a day. We observed how users acted to leverage these fixed-pricing rules.

As expected, certain users left trivial garbage comments just to collect the 2 points. Many of such comments contained only 1 or 2 letters. These garbage comments were useless in terms of their knowledge value. Certain users randomly clicked on voting buttons just to collect the 2 points. Such votes did not reflect these voters' true assessment of the quality of answers. Thus, such votes did not provide any value for knowledge sorting and valuation. Conversely, they created huge noise for other users to understand the quality of existing answers. The reuse tracking module does not work properly with such garbage votes.

Fig.5-7 shows transaction volumes categorized by markets and transaction types after the French site was deployed for 3 months with these fixed-pricing rules. It displays the knowledge G.D.P. pie with constituent slices. On the French site, the Q&A market was the primary knowledge exchange tool for students, while the other markets were lightly used. We expected that the “Q&A slice” should be the largest slice contributing a dominant share to the knowledge G.D.P. However, because of the ill-placed fixed-pricing rules, the slice for “Q&A Thumbing” is twice as large as the “Q&A” itself. The slices for “Q&A Comment Answers” is also quite sizable. This clearly indicates a serious problem.

Therefore, fixed-pricing introduces oversupply of low-quality information and unwanted behaviors. We must tackle the adverse effects of fix-pricing when we design fiscal policies or measure information value.

5.3.4 Cultural Differences

Different cultures can be cultivated in different communities. For example, on both the French site and the U.S. site, new users started with 2000 points. However, users on the French site offered much lower bounty for their questions - 27.8 on average. In contrast, users on the U.S. site offered 63.96 on average. Users on the French site make their earnings mostly through the “Planner”’s subsidies, instead of making earnings from other users by sharing knowledge and information. As clearly shown in Fig.5-7, the size of the pie
“Q&A thumbing” is notably larger than “Q&A” itself. On the French site, users used the auction market much more actively, more than 96% of auction items were posted by users themselves, while on the U.S. site, over 90% of auction products were posted by researchers ourselves to back up the currency value.

5.3.5 Exchange Rate & Evaluating Information

The knowledge economy framework provides an effective way of calculating the exchange rate between virtual currency and real U.S. $, and measuring the value of all knowledge created on the platform. In the context of firms making investment on IT platforms, this fact implies that a knowledge economy platform is not merely a “cost / expense” with intangible benefits. Instead, we are able to accurately estimate the $ value created by the knowledge economy, and justify the return on investment. We use data from the U.S. deployment to demonstrate how this is accomplished.

Using virtual currency to exchange knowledge following market rules, and spending virtual currency on material rewards through the auction market provide a mechanism to calculate the exchange rate and measure the value of information created on the platform. Using the U.S. site as an example, we select 11 product items of which we can easily obtain the dollar values, such as a $10 itunes card or the iPad. Virtual rewards such as “Knight of Barter”, or items with undefined $ value such as “A pingpong lesson” are excluded from the calculation. After performing linear regression, we can obtain the approximate exchange rate between U.S. dollar and Barter’s virtual currency is $1 = 6.64(Barter Points).

After obtaining the exchange rate, we next estimate the G.D.P. of knowledge economy denominated in Barter’s currency. As discussed in the previous chapter, G.D.P. is calculated by counting transactions of various types. Here we only count transactions between two users in the Q&A market. This is a subset of all knowledge transactions. During the 1-year period from 04.2010 to 04.2011, the total transaction volume happening in the Q&A market is 7476 Barter Points - the sum of points offered and transacted for solved questions. Using the exchange rate obtained above, the value of information created in the Q&A market is
$1126 denominated in U.S. dollars. This exceeds the value of what we spent to purchase the posted products and stimulate the knowledge economy, which was about $750. This doesn’t include value created in other knowledge markets such as the document and idea markets, and doesn’t count other value created such as users’ voting and tipping for helping sort and index information.

The analysis above also addresses questions on whether it is cost-effective to back up the knowledge currency with material rewards, which incur extra spending in addition to the investment on building and deploying the knowledge economy platform itself. The aforementioned example shows that investment on the product auction market has multiplication effects, which stimulates greater value created on knowledge.

### 5.3.6 Market Fraud & Fraud Prevention

Knowledge markets, or more generally any platforms with currency and certain gamification aspects, are facing the challenge of fraudulent behaviors. Users tend to exploit system loopholes or game ill-designed rules to gain unfair advantage and earn points that are not a result of true contribution. In our deployment, we aimed at observing user behaviors to answer the following questions:

- What fraudulent or gaming behaviors users exhibited?
- Does peer-pressure or social connections help reduce fraudulent behaviors?
- Is a crowd-based fraud prevention mechanism effective in cleaning up market fraud and maintaining the integrity of knowledge markets?

We use data from the U.S. site to answer these questions. Students and teaching staff of a course used Barter as a knowledge exchange tool. It is worth emphasizing that the definition and scope of fraud is relative. Users might exploit ill-designed market rules to gain unfair advantage. However, if such behaviors were not explicitly forbidden and made known to users upfront, such exploitation should not be considered fraudulent. Therefore,
before students started to use Barter, we made it clear that all users should earn points for true knowledge sharing and contribution.

It turned out that users were quite active and creative in exploiting market loopholes, especially after they learned that they can spend the currency for material awards in the auction market. Some examples include

- Users left garbage comments or voted randomly to collect system subsidies, as introduced above when we discussed about fixed-pricing;
- Users uploaded copyright-infringing documents for sale in the document market;
- Users laundered money with each other by tipping each other with unreasonably high amounts, or asking / answering each other trivial questions. The primary goal for such transfers was to convert currency types - after the transfer, currency has longer expiration period, and becomes spendable in the auction market;
- In order to encourage users to allocate points on time after the questions they asked got enough answers, we ran a campaign promotion that askers could receive 1/4 of the bounty back if they allocated points on time. During the promotion period, users colluded with each other actively by asking / answering trivial questions back and forth to earn the “Planner”s subsidy every time.

Students and their teaching staff have social connections among themselves in their real life. Their true identities, such as names and affiliations were also displayed and made known to others by default. Therefore, it does not appear that peer social pressure helps preventing gaming behaviors. Such gaming and fraudulent activities were unfair to other users who earned the points in honest and diligent ways, and harmful to the entire platform.

After one month, we introduced the intervention by opening the “Resolution” space - which was the crowd-based fraud prevention module. Users could flag contents or behaviors as fraudulent, and if enough users concurred, such suspicious items would be moved to the “Resolution” space for further voting. Eventually a verdict would be made on whether the
item was actually fraudulent or not. Users who participate in reporting and voting get rewarded if they stand on the right side. 23 fraud cases were immediately reported after the launch of the fraud prevention mechanism. After that, affected users got warned and penalized, so they started to pay attention to their behaviors. 0 fraud cases got detected or reported afterwards. Therefore, a decentralized fraud-prevention mechanism is proven effective, in our case, to clean up the platform and maintain the integrity of the markets.

As explained in the introductory chapters, the goal of designing a knowledge economy is to establish a solution framework for all knowledge platforms facing similar knowledge-related challenges. In this dissertation, we do focus more on an organizational setting, where such a knowledge economy is deployed within an organizational boundary. The organizational boundary does have practical implications when it comes to market fraud and currency backup - which are more challenging in a public setting. The hierarchical structure of an organization and close social connection among colleagues reduce the risk and likelihood of market fraud. Organizations can back up the currency more freely using creative ways without concerning too much on currency forgery and security. The challenges on currency security and fraud prevention are greatly scaled up in a public knowledge economy with no established structure among users.

5.3.7 Impacts of Social Connections

Users could opt to log onto Barter using a social authentication API. Among those users who used this social authentication API to log in, we could establish a symmetric 0/1 matrix of their social connections. We wish to understand the impacts of users’ social links on their activities within the knowledge economy.

Among 400+ users on the U.S. site, 65 users logged onto Barter using the social authentication API. At a particular time point, each of them had 20 friends on average. There were over 5000 knowledge transactions among all users. 487 transactions had at least one party who logged in using the social authentication API, and 186 transactions happened between two users who logged in using the social authentication API. Only 12 knowledge
transactions took place between two friends, which was less than 7% of the 186 transactions. From the statistics above, we could see that when users decided on knowledge purchases or rewards, impacts of their social connections were not significant.

On the other hand, all fraud cases which were results of collusion involving two users such as money laundering occurred between friends.

5.3.8 Summary

This chapter covers our software development and deployment, and discusses on lessons learned from several deployments. The software developed and deployed was not a complete implementation of the system architecture proposed in previous chapters. Instead, the purpose of developing the software was to illustrate key concepts presented in this dissertation, and obtain several targeted market-related insights through user study and quantitative and qualitative analysis of collected data.

The software provides an experimental testbed for future research deployments and user studies.
Chapter 6

Conclusion

In this dissertation research, we present the design of an information market framework which is able to provide a long-term sustainable incentive structure to organization members to collaboratively share knowledge and create innovation. We design a knowledge economy with three core components: knowledge currency, decentralized knowledge markets, and economic policies to stimulate or moderate user activities.

The management of an organization backs up the value of knowledge currency externally using material rewards through an auction market. Knowledge currency is used to track reputation and expertise on different areas to strengthen social incentives, and cashed out to purchase material goods and services to provide economic incentives. Decentralized knowledge markets replace top-down incentive structure where fixed rewards are usually misused. These peer-to-peer markets are efficient and effective in allocating resource, valuing knowledge objects, and enriching the knowledge base with missed knowledge. The organization management designs and employs economic policies as advanced managerial tools for the platform. Monetary policies manage currency supply and set target currency growth rates. The “Planner” fills the government’s role, and uses fiscal policies to create public services and optimize social welfare. The “Planner” allocates budgets for fiscal spending, which includes rewarding knowledge reuse, encouraging behavioral modification, and running campaign promotions.
There are a few critical modules and architectural design choices made that guard and enhance market safety, efficiency, and fairness. These modules include 1) attention module to recognize the time value of experts and individuals and reduce noise and clutter of information; 2) fraud detection and prevention module that protects markets from gaming and fraudulent behaviors; 3) reuse tracking module that captures and rewards the spillover of knowledge in longterm; 4) optimization of currency expiration to stimulate user activities and maximize knowledge creation; 5) knowledge securitization and derivative markets.

A knowledge economy is a complex system with convoluted network and market interactions among participants and the “Planner”. Managing a knowledge economy striving for prosperity relies on outputs from this complex system as key indicators and different economic policies tools as inputs. The “objective functions” to optimize include 1) knowledge creation and sharing (knowledge GDP), 2) sufficient fairness. When deploying such a knowledge economy inside an organization, impacts on organizational culture and value must also be considered - incentives should be constructed and placed in a pro-social way.

A major contribution of this dissertation research is a thorough treatment of subjects that involve using virtual currency in knowledge-related platforms, and a complete design of a knowledge economy. By applying innovative market mechanism design, we are able to address organizational challenges using a market mechanism efficiently.

We have also introduced software development, deployment, and lessons learned from these user experiments. Our software deployment demonstrates that market forces are effective in incentivizing users to contribute information and engage in a new platform. Fixed-rewards scheme for behavioral modification is a deficient design, which usually leads to oversupply of valueless activities. Users are “creative” and active in exploring market loopholes and gaming the system. A crowd-sourcing based fraud prevention mechanism is effective in cleaning up the system, and cordon the markets from future fraud. Social and economic incentives co-exist in such a marketplace. We could calculate the exchange rate between virtual currency and real U.S. dollars, and measure the value of created knowledge - the knowledge GDP. From the management’s perspective, the value of stimulated knowledge creation is much larger than the value of investment on the production auction market.
The software we have developed provides an ideal experimental testbed for future research deployments and user studies.

Future research questions that can be explored both theoretically and experimentally include:

- Can securitization and a secondary market encourage user participation, increase market liquidity, and enhance the quality and validity of provided information?

- How to rigorously quantify and compare the impacts of social incentives and economic incentives?

- What is the optimal currency expiration and conversion rules for currency acceleration and economy stimulus?

- What are the best rewards-allocation algorithms for rewarding good behaviors such as voting and tagging when employing fiscal policies?

We believe this is an interesting and promising research area that is worth more exploration. There are a rich set of problems to be more thoroughly investigated and addressed. This dissertation lays down some groundwork, and provides a framework for further research and explorations. The learnings from the research will offer great insights into organizational design as well.
Bibliography


