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Measuring virtual wealth in virtual worlds

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Abstract This article presents pioneering research on measuring virtual wealth in an open virtual world for diagnosing the health of virtual worlds. It proved the existence of an open virtual world by proving the existence of a free choice of virtual currencies for virtual goods between distinct virtual worlds. By discussing the features of open virtual world in a circled networked organization, the article devised a virtual wealth measuring scheme, called Gross Virtual Product (*GVP*), for any virtual world. Based on this scheme, it suggested an accountability matrix to account for a changing virtual world regarding its total virtual wealth, profitability, user participation and happiness. To demonstrate the suitability of *GVP* scheme and accountability matrix, the article has conducted a case study on SecondLife.com, which showed the appropriateness of the proposed scheme and matrix. The research made in this article is very important. The proposed measuring scheme and matrix help virtual world participants perceive the possible risks of the participated virtual worlds in advance to make better decisions on virtual business.

Keywords Virtual world · Virtual wealth · Gross Virtual Product · Statistics · Virtual money exchange · Virtual currency · Accountability · Case study · Virtual economy

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1 Introduction

Virtual wealth is an important and interesting topic. It refers to the "power" [18: 28] of acquiring virtual goods and virtual resources created and accumulated in virtual worlds. It can be measured by virtual money of virtual worlds and must be protected for the virtual inhabitants (i.e., virtual world avatars of real-world humans) [5]. *Virtual world* is a virtually-formed common information space [5] and belongs to a subcategory of virtual communities [10]. Technically, it can be defined as a computer-simulated representation allowing avatars to interconnect and communicate in relatively life-like environments [6]. Each virtual world includes a virtual monetary system with particular virtual money (or virtual currency). *Virtual money* is a special type of virtual good and can be used to store, measure and mediate the value of other virtual goods and virtual currencies. It is virtually created for or from virtual activities by virtual inhabitants [2]. When two or more virtual worlds are integrated, they constitute an *integrated virtual world*. When many virtual worlds are significantly integrated worldwide, they become *global virtual world* [5].

Virtual wealth research presents several challenging problems: how to measure the virtual wealth of a virtual world, how to observe its changing amount, and how to diagnose the health of a virtual world. Investigating on these problems is important and necessary. This is because virtual wealth is confined in a virtual world. The worsening or bankruptcy situation of the virtual world will endanger the virtual wealth accumulated in this virtual world [5]. A virtual wealth measuring scheme will be helpful for virtual world participants to perceive the possible risks of the living virtual world and thus to make correct decisions if the virtual world is in worsening.

A successful virtual wealth measuring system shall be accountable, that is, answerable for giving an account as of one's acts and explainable for being accounted for [1, 8]. This requires that measures reflect the key characteristics of relevant virtual worlds, depict their main activities, and be able to interpret the phenomena being occurred. By this measuring system, indicators about virtual world can help perform analysis of the changes of virtual wealth and provide useful analytical results for virtual business decisions.

To obtain measures that are accountable, a reference model of virtual world must be supplied as the measuring target. In this article, we call this reference model as *open virtual world*, which is modeled as an integrated virtual world consisting of many virtual worlds connected by a virtual money exchange system, described in [5].

Motivated by providing measures accountable for virtual world and its virtual wealth, this article aims at conducting a research on the method of virtual wealth measuring. This method will work in an open virtual world accountable for the changes of virtual wealth.

To achieve this goal, the rest of the article is arranged as follows: Sect. 2 discusses the related research on virtual wealth and its measurability, and virtual world and its openness. Section 3 proves the existence of an open virtual world. Section 4 describes the features of an open virtual world and a circled networked organizational method. In Sect. 5, a measuring scheme of Gross Virtual Product (GVP) is devised for measuring the total virtual wealth of a virtual world. Section 6 proposes an accountability matrix for perceiving the health of a changing virtual world. In Sect. 7, a case study on Second Life virtual world is conducted to demonstrate the appropriateness of GVP scheme and accountability matrix. Finally, a conclusion is made together with a summary of contributions, implications and future work.

2 Related research

2.1 Virtual Wealth and its Measurability

Virtual wealth [5] relates to many concepts such as virtual world [6, 14], virtual goods [15], virtual money [2], virtual economy [16] and virtual commerce [7]. Smith refers the wealth as the "power" ([18]:28) of acquiring goods. Similarly, virtual wealth is the purchasing power of acquiring virtual goods that are created, exchanging and used. *Virtual goods* are any virtual-world objects or services [5], including virtual items such as virtual hair and apparels, virtual art performance, and virtually monetized abilities [15] (e.g., access to a restricted area or resources). A virtual good has use value with utility. Utility can be measured in terms of satisfaction, desirability or the usefulness of avatars [5]. When virtual goods are abstractly stored, they become virtual money in general or virtual currency in particular with a measure of amount. *Virtual money* or *virtual currency* is a value carrier of any virtual goods, qualified as a special type of virtual goods. It at least has three properties: store of virtual goods value, media of virtual goods exchange, and measure of virtual goods value [2]. These properties make virtual money/currency eligible for representing virtual wealth that is equivalent to the acquirable virtual goods. Since we have the equivalence relationship in value between virtual wealth, virtual money and virtual goods, the problem of how to measure virtual wealth can be transformed to the problem of how to measure virtual money or virtual goods.

In virtual world practices, the amount of virtual money can be measured by virtual money supply. The source of virtual money supply could be many. Guo et al. [5] found a layered space, where the inner-most layer is a set of virtual worlds, the middle layer is a set of electronic worlds, and the outer-most layer is real world. The first source of virtual money supply of a virtual world comes from the selling of the money (either real or electronic or virtual) of external worlds (either real or electronic or virtual), which is called *extrinsic world-based virtual money supply*. The second source is the *rule-based virtual money supply*, in which virtual money is supplied based on the rules set by the virtual world owners. The third source is the *labor-based virtual money supply*, in which virtual money is supplied based on the labor time consumed. The fourth source is the *credit-based virtual money supply* such that virtual money supply is pegged with one or more credit indicators. For example, the supply of L$ can be managerially pegged with US$.

However, the total virtual money supply of a virtual currency from multiple supply bases does not imply any comparable measure of virtual wealth between virtual worlds. Virtual money supply of a virtual world is only an in-world measure of money valuation intention. In another word, the supplied virtual money of a virtual world is not measurable when other virtual worlds are taken into consideration. This is because any virtual world can arbitrarily increase or decrease the quantity of virtual money supply using its rules without changing the actual use value from the perspective of those living outside of that virtual world. Guo et al. [5] discussed and solved this measurability problem by proposing indicators called intrinsic-world factor and extrinsic-world factor. *Intrinsic factor* refers to the force from internal world to gain more benefit from external worlds. *Extrinsic factor* refers to the force from all external worlds to gain more benefits from the internal world. The former leads to a self-valuation of the virtual money in terms of *money supply volume* (i.e. total intrinsic

value) and the latter leads to a non-self-valuation of the same virtual money in terms of *money demand volume* (i.e. total exchangeable value). Given these two opposite forces on the valuation of a same virtual currency, an equilibrium point between total virtual money supply and total virtual money demand can always be found using a Pareto exchange point, described in [5], to determine the actual valuation of that virtual currency. It is obvious by this measuring approach the virtual wealth measured by any virtual currency is measurable when a virtual money exchange regime [5] is established based on Pareto exchange points between the virtual worlds where the virtual money exchange events happen. These associated virtual worlds form an open virtual world in the sense of their ability of virtual money exchange.

2.2 Virtual world and its openness

When virtual wealth is measured by virtual currency volumes of many virtual worlds and when real value of virtual wealth is determined by mutual valuation of intrinsic value and exchangeable value at a Pareto exchange point of a time, at least two virtual worlds are involved and require open for virtual money exchange. Openness thus becomes a minimal requirement for virtual wealth measuring.

Existing virtual worlds are often not open. Ives and Junglas [6] and Messinger et al. [13, 14] described a virtual world as a computer simulated three-dimensional representation or space metaphored as "a globally shared playground and workspace" [14] for thousands of people to simultaneously interact with each other for gaming, social networking and purpose-focused worlds. Typical examples could be WorldOfWarcraft.com for gaming, Facebook.com for social networking and SecondLife.com for purpose-focused world. Slightly different, Kumar et al. [9] classified virtual worlds into online games and metaverses. A *metaverse* is a fully immersive virtual space with massive, dynamic and user-generated content. For example, SecondLife.com is a metaverse. In these types of virtual worlds, although there are concepts of virtual goods and virtual money, they are not required. In addition, most of them work in an isolated environment without enabling a virtual currency to be compared with the virtual currencies of other virtual worlds. There are only few exceptions, for example, SecondLife.com allows its Linden dollar to be compared with real-world US dollar. Isolation prevents a virtual currency from being mutually valued by multiple virtual worlds to find its real market value for trading virtual goods. This shows that existing virtual worlds, in general, are closed worlds and not opt for virtual trade between virtual worlds. The consequence is the non-transferability of virtual wealth from one virtual world to another and provides no protection on the accumulated virtual wealth [5].

Transferability becomes a concern and is the outcome of the virtual world openness. Table 1 provides some examples on transferability and openness of virtual money that represents virtual wealth. To achieve openness, public measurability of virtual currencies must be accountable for virtual wealth created and accumulated in any associated virtual worlds. Obviously, an open virtual world, designed to integrate many virtual worlds and accountable for virtual wealth, is necessary to achieve public measurability.

3 Open virtual world

Public measurability of virtual wealth requires the existence of an open virtual world that integrates many individual virtual worlds. So, what is an open virtual world and what is the indicator of public measurability? In the rest of this Section, we describe an open virtual world and prove its existence.

3.1 Existence of an open virtual world

An open virtual world will exist if there is a free choice of any virtual currency for measuring a same virtual good between virtual worlds. To prove this, we first define an open virtual world and then prove that there is a free choice based on the Virtual Money Exchange (VMX) regime [5].

Definition 1 (*Open Virtual World*): An open virtual world is an integrated virtual word satisfying the following assumptions:

- (*Virtual World*). There is a finite set of virtual worlds W such that each $W_k \in W$.
- (*Avatar*). There is a finite set of avatars A such that each $A_k \in A$ is an avatar, which is a virtual computer simulated image of a real-world person or organization in virtual world.
- (*Virtual Good*). There is a finite set of virtual goods G such that any $G_k \in G \subset W$.
- (*Virtual Currency*). There is a finite set of virtual currencies C such that each $C_k \in C$ is from a distinct virtual world W_k.
- (*Quantity*). A quantity is a set Q with a partial order $\leq_Q$. If the quantity is clear from the context, we denote the order just by $\leq$.

If $\leq_Q$ is total, the quantity is called *basic*. Smaller quantities are preferred over larger quantities. The price level of virtual products is, for instance, characterized by the price:

$$\text{PriceSpace} = \{\text{PS\_low}, \text{PS\_med}, \text{PS\_high}\},$$
$$\text{PS\_low} \leq \text{PS\_med} \leq \text{PS\_high}.$$

Table 1 Transferability and openness of virtual money as virtual wealth representation

Virtual currency	Virtual world	Transferability	Openness
QB (QQ Coin Form 1)	Parts of QQ.com as a virtual marketplace and an online game	RMB ⇒ QB and QB ⇒ QG, but not reversed	One-way open from real-world money to virtual money and no reverse, stipulated by China's law and the corporate regulations. Not open between QQ and other virtual worlds
QG (QQ Coin Form 2)			
WoW Gold	WorldOfWarcraft.com as an online game	US$, etc. ⇒ WoW Gold, but not reversed	One-way open from real-world money to virtual money, stipulated by the corporate regulations. Not open with other virtual worlds
Acebucks (Abs)	Facebook.com as a social network	Abs is not transferable	Created and used inside of Facebook.com and not open. Not open to other virtual worlds
Linden Dollar (L$)	SecondLife.com as a metaverse	US$, etc. ⇔ L$	Reversible and open to real-world US dollar, stipulated by SecondLife.com. Indirectly open to other virtual worlds in certain extent through some marketplaces L$ ⇔ real money, such as LindeX (in SecondLife), dxexchange.net, virvox.com, yolto.com, etc. Not directly open to other virtual worlds through virtual-to-virtual money exchange

- (*Choice Space*). A choice space S is a Cartesian product $Q_1^{g,c,w} \times Q_1^{g,c,w} \times \cdots \times Q_1^{g,c,w}$ of a finite number of quantities that choose all virtual goods in all virtual currencies of all virtual worlds by all virtual inhabitants. To simplify the notion, we replace it by $Q_1 \times Q_1 \times \cdots \times Q_n$.
- (*Choice*). A choice of operation set by all inhabitants at a time is $o^* = (o_1, o_2, \ldots, o_n)$, which is an element of $Q_1 \times Q_1 \times \cdots \times Q_n$. We use $o^*(Q_k)$ or $o^*(k)$ to denote o_k.

Sets $O \subseteq \{o_1^*, o_2^* \ldots o_n^*\} \subseteq S$ of choices represent the different alternatives on choosing virtual goods from relevant virtual worlds. For example, given a choice *product* × *price* × *currency* × *quantity*, the choice combination could be: {(hat, 500, AceBucks, 2), (hat, 100, Linden Dollar, 2), (jacket, 2, QB, 3)}.

- (*Free Choice*). A free choice f is a capability of selecting any virtual good from the total alternatives of the choice space such that $f = o_i \vee o_j$, $f \in F$, where $o_i = o_j$.

For example, given $\{o_1 =$ (hat, 500, AceBucks, 2), $o_2 =$ (hat, 100, Linden Dollar, 2)$\}$, the free choice enables us to select either o_1 or o_2, such that 2 hats of the same quality can be bought or sold either in 500 Acebucks of Facebook.com or in 100 Linden Dollars of SecondLife.com. A free choice of selling and buying same goods in different virtual worlds implies the value equivalence of different virtual currency amounts between the choices such that $o_1 = o_2$.

By observation, virtual worlds, such as SecondLife.com, QQ.com and FaceBook.com, obviously hold the first 7 assumptions. However, the last assumption of Free Choice does not exist because there are no direct public measures among different virtual currencies (except for Second Life having a virtual-real exchange rate), enabling $o_1 = o_2$. To prove the existence of an open virtual world, we must first prove that the assumption of Free Choice exists.

3.2 Proof of free choice assumption

To prove the Free Choice assumption, we need to prove that any two virtual currencies are freely convertible between the two virtual worlds at a fair market rate.

Definition 2 (*Convertible Virtual Currency*): Any virtual currency c_1 is said to be convertible to another virtual currency c_2, such that the quantity q_1 of c_1 equals to the quantity q_2 of c_2, denoted by $q_1c_1 = q_2c_2$ or $c_1 = (q_2/q_1)c_2$ or $c_2 = (q_1/q_2)c_1$.

Theorem 1 *Given any virtual good g valued by any virtual currency of either c_1 or c_2, and given any two choices o_1 and o_2 respectively at (@) virtual worlds w_1 and w_2, the free choice $f = o_1 \vee o_2 = o_1(q_1c_1/g)@w_1 \vee o_2(q_2c_2/g)@w_2$ exists if c_1 and c_2 are convertible.*

Proof To prove the Theorem 1, we only need to prove that c_1 and c_2 are convertible between w_1 and w_2, that is, $q_1c_1@w_1 = q_2c_2@w_2$.

1. For virtual-to-virtual money exchange, according to the Virtual Money Exchange (VMX) regime described

in [5], an equivalence formula of $\sum_{y=c_1}^{c_n} S_{XY} = \sum_{y=c_1}^{c_n} d_{xy}$ is always existent at a Pareto Exchange Point, where s_{xy} is the supply of virtual currency x to all y and d_{xy} is the demand of virtual currency of all y for x. Applying this formula, we have the same situation such that: q_1 is the supply of c_1 to c_2 and is also the demand of c_2 by c_1 in w_1, and the same is for q_2 in w_2. This makes $q_1c_1 = q_2c_2$, and c_1 and c_2 are convertible between w_1 and w_2 on $c_1 = (q_2/q_1)c_2$ or $c_2 = (q_1/q_2)c_1$. Thus, $q_1c_1/g@w_1 = q_2c_2/g@w_2$ in virtual wealth value and the choice operation o_1 on $q_1c_1/g@w_1$ is equivalent to choice operation o_2 on $q_2c_2/g@w_2$. Thus, there is a free choice $f = o_1 \vee o_2 = o_1(q_1c_1/g)@w_1 \vee o_2(q_2c_2/g)@w_2$.

2. For virtual-to-real money exchange, according to the practice of SecondLife.com, we can always find a virtual currency to be convertible to another virtual currency indirectly through a real-world currency. Take Linden dollar and WoW Gold as an example, we can find L$ $\Rightarrow$ US$ $\Rightarrow$ WoW Gold.

Combining (1) and (2) together, different virtual currencies can always be convertible. Thus, proof of Theorem 1 finishes.

Lemma 1 *There is an open virtual market if there is open virtual world.*

The proof is straight-forward. Since Theorem 1 enables the free choice of $f = o_1 \vee o_2$, we can always find $(q_1c_1/g_1)@w_1 = (q_2c_2/g_1)@w_2$. When we also have $(q_2c_2/g_1)@w_2 = (q_2c_2/g_2)@w_2$, we have $(q_1c_1/g_1)@w_1 = (q_2c_2/g_2)@w_2$. Thus, g_1 and g_2 are tradable between w_1 and w_2. Thus, an open virtual market exists between w_1 and w_2. The existence of an open virtual market provides a means of free virtual wealth transfer between virtual worlds. It also provides a valuation system for measuring virtual wealth based on fair market value recognized by all virtual worlds.

4 Features of open virtual world

Open virtual world presents some peculiar features that outline its framework. These features can be summarized as the methods of structuration, roles of representation, handling of differences, and rules of conducts. Understanding these features could help design a better measuring system for virtual wealth. *Methods of structuration* define how to deconstruct many existing virtual worlds into controllable parts and how to reconstruct them into a manageable open virtual world. *Roles of representation* define who reconstruct an open virtual world with what responsibility. *Handling of differences* refers to the differences of virtual worlds and the ways of their alignment. *Rules of conduct* define approaches of behaving in an open virtual world. In this Section, relevant to virtual wealth measuring, we focus on describing methods of structuration and roles of representation.

4.1 Methods of structuration

Virtual world presenting to us is many things such as avatars, symbols, indications and actions [2, 5–7, 14–16]. It is an abstraction, transformation and image of the real world on a simulated computer-supported environment. Like language and speech in Saussure's semiotics [17], the structuration of a virtual world is dichotomic, clearly divided into a systematized set of patterns necessary to human interaction and indifferent to materials composing it. There is a duality of structuring an open virtual world, which is construction and inhabitation.

Construction is an ongoing process of composing a constitution for an open virtual world. The process consists of two steps of deconstruction and reconstruction. Deconstruction includes the analyses and studies on the aspects such as types, purposes, places, populations, technical platforms, performances, and profit models. By deconstruction, insights of the associated virtual worlds can be gained, for instance, those investigated in [9, 14]. The result is used to reconstruct a manageable open virtual world in a new framework consisting of a set of regimes or schemes such as the new specifications of technical platform and the new institutions of virtual economy, virtual money, security and privacy, specialized contents, formality, etc. In general, construction works out a systematic plan of world representations designed in patterns, satisfying the requirements of avatars that will use the open virtual world in future.

As opposed to construction, *inhabitation* covers purely individual part of construction, appearing to be avatars' behavioral outcomes that express personal ideas. It provides numerous use instances of patterned schemes that are constructed. Inhabitation is dynamic and is a force of requiring deconstruction for reconstructing a better open virtual world.

Construction and inhabitation is dialectic. The construction of virtual world needs bricks and mortars common for all avatars to build their virtual homes and requires unified language for every avatar to communicate and interact. This commonality does not reject the individual or group life but encourages individual avatars to bring about more colorful life to all to improve the process of further reconstruction of virtual world. Construction and inhabitation also suggest the corresponding concepts of production and consumption for measuring virtual world wealth such that construction implies production and inhabitation

implies consumption, trade and capital movement. These correspondences are existent and will be validated in Sect. 5.

4.2 Roles of representation

An open virtual world is a computer simulated three-dimensional representation [14]. However, how it is really represented? By observation, at least several levels of representations could be found. They are: virtual world systems (e.g. Second Life and Facebook world platforms), added components (e.g. new features later added by world operators), resources and materials (e.g. land provided by Second Life), plug-in programs and services (e.g. applications by developers in Facebook, gadgets, scripts and services provided by residents in Second Life), the finished virtual goods (e.g. apparels made by Second Life residents). These representations match with object-oriented design and implementation method. They can be classified into a set of virtual objects in modules and layers. Modular design allows representations reusable by avatars to express their ideas and behaviors. Layered design enables representations to be divided into levels, permitting avatars to be grouped for analysis.

While virtual objects are useful to explain virtual world representations in a monolithic perspective, Guo [3] provided more insight into a representation. He defined a representation as a *sign* composed of structure and concept. *Structure* expresses the form and shape of a representation while *concept* denotes the mean of the structured form and shape. The former provides the schemes and languages describing various representations while the latter defines representations that constitute the knowledge of virtual worlds. For example, 3D images and codes of scripts are structures, and their annotations like the notions of avatar, world map, sofa, land, prim, pants and shirt are concepts.

Technically, a virtual representation is a meaningfully named object. It is created and used by avatars in defined circumstances. Guo [4] further described this relationship in a *sign relationship* between sign, context and interpretant, where avatars as interpretants interpret real-world objects to create virtual-world objects as signs in their personal situations of contexts. This sign relationship is pervasive. Avatars could further interpret virtual objects to create and use more other virtual objects in their use cases. For example, some avatars could further use land, bricks, wood, steel, etc. to make windows, doors, walls and roofs to build a house. Other avatars can use virtual money to buy the house for re-sales.

Sign and sign relationship present a powerful representation method for various types of roles to stringently describe and express an open virtual world in their contextual use cases. These roles and their work can be defined and explained to account for the virtual wealth that is produced in an open virtual world. Table 2 provides a classification of the key roles and their work content, useful for further study on measuring virtual wealth.

As shown in Table 2, open virtual world implies a lot in its representation. First, its representation can be divided into technically constructing virtual worlds in real world and virtually inhabiting in virtual worlds, following division of labor and specialization of production [18]. Responsibilities are allocated to different worlds. In real world, system owners are responsible for commercial running of all associated worlds, systems creators for technically building the worlds, systems operators for technically managing the worlds, and application providers for adding new features to the worlds. In virtual world, virtual producers are responsible for goods production, virtual traders for goods re-selling, virtual consumers and virtual walker for goods consumption, and virtual financier for virtual capital movement. By this specialization, the gross production of an open virtual world is divided into *real world production* (from systems owners, systems creators, systems operators, and application providers), *real world investment* (from systems owners), *virtual world production* (from virtual producers), *virtual world consumption* (from virtual consumers), *virtual world trade* (from virtual traders), and *virtual world investment* (from virtual world financiers). This division provides a precondition for measuring virtual wealth in an open virtual world.

Second, an organizational method suggests how an open virtual world is complexly organized for wealth measuring between roles. In this article, we depict the roles of open virtual world in a *multi-circled networked organization*, shown in Fig. 1 with the following definitions:

Definition 3 (*Outer-most circle*): The role of systems owner is the out-most circle.

Definition 4 (*Mandatory condition of openness*): There is at least one virtual-to-virtual money exchange system within an outer-most circle, connectible to all other virtual-to-virtual money exchange systems in other outer-most circles.

Definition 5 (*Optional condition of openness*): There are optionally one or more virtual-to-real money exchange systems within an outer-most circle.

Definition 6 (*Inner circle*): Any circle except for the outer-most circle is an inner circle and has an outer circle.

Multi-circled networked organization is a representation of an open virtual world, in which there are many sets of individually owned virtual worlds. Each owner owns some virtual worlds. All virtual worlds are open for virtual

Table 2 Classification of key roles in open virtual world

Def. no	Role (*in Structuration*)	Work content definition	Examples	Virtual wealth outcome
1	Systems owner (*Construction*)	Refers to the owner of open virtual world. It is a legal representative of open virtual world in real world and must obey real-world legal systems for the owned systems	Linden Research Inc. includes LindenLab.com, XStreetSL.com, SecondLifeGrid.ne, SecondLife.com	Make investment; Earn real money by selling real and virtual goods and services incl. virtual money
2	Systems creator (*Construction*)	Refers to the party that design and implement virtual worlds and establishes the virtual world constitutions on social, economic, and legal regimes for the created virtual worlds	Creators of LindenLab.com and Blizzard.com	Spend real money to obtain real goods of virtual world systems
3	Systems operator (*Construction*)	Refers to the party providing the maintenance, support and further development of virtual worlds	Technicians and governors in SecondLife.com	Spend real money to earn real and virtual money
4	Application provider (*Construction*)	Refers to the party providing virtual world solutions and applications, e.g., virtual money exchange, virtual business solution, virtual education solution, APIs, etc	Solutions given by SecondLifeGrid.net and dxexchange.net	Spend real money to earn real or virtual money
5	Virtual producer (*Inhabitation*)	Refers to the party that produces virtual goods and services such as apparels, scripted codes, arts, etc	Virtual enterprises in SecondLife.com	Spend real and virtual money for virtual money convertible back.
6	Virtual trader (*Inhabitation*)	Refers to the party that resells the virtual goods and services	Virtual traders in various virtual worlds	Spend real and virtual money to virtual money convertible back.
7	Virtual financier (*Inhabitation*)	Refers to the party that makes investments on and re-sells virtual monies	Virtual money exchangers	Spend real and virtual money to earn virtual and real money.
8	Virtual consumer (*Inhabitation*)	Refers to the party that uses virtual goods and services	Virtual consumers in SecondLife.com	Spend real and virtual money for fun.
9	Virtual walker (*Inhabitation*)	Refers to the free users of virtual world with non-monetary participations in virtual world	Onlookers of all types of virtual worlds	Increase virtual resources; Increase impact of virtual world

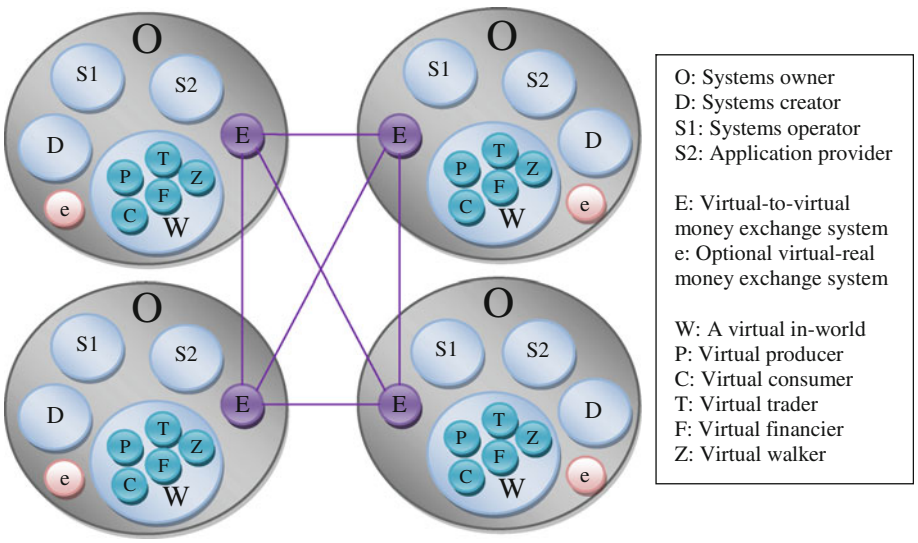

Fig. 1 A multi-circled networked organization representing an open virtual world

trading through virtual-to-virtual or virtual-to-real money exchanges. The rules, described above, constitute the basic organizational requirements that organize an open virtual world in an open, integrated and measurable framework.

In this organization, the financial performance can be measured. In general, there is an important aliveness indicator for this organization, which is the signal of bankruptcy:

Theorem 2 (*Signal of bankruptcy*): *The outer-most circle including its inside circles, as a real-world business organization, has a signal of bankruptcy if its total real money inflow is less than its total real money outflow.*

The proof is pretty straight-forward. A virtual world is actually is real-world legal person. It must obey the economic laws of real world. While total real-world cash inflow (e.g., investments from investors, loans from financial institutions, sales of virtual money, sales of virtual goods and virtual services, earnings of subscription fees, and revenues of online advertising) is less than real-world total cash outflow (e.g., expenses of virtual world systems research and development, payments of dividends, payments of loans, virtual money sales, salaries, advertising fees, and operation expenses), the changes of cash inflow are negative, the organization (i.e., the out-most circle) running the virtual world cannot operate further. This is a signal of bankruptcy.

Theorem 2 provides an extremely important risk measure for all virtual world participants to indicate the health status of a virtual world, which could suggest further virtual world decisions.

5 Measuring virtual wealth in open virtual world

The features of open virtual world and its organization method, described previously, help understand where virtual wealth is created, how it should be measured, and how the measurable virtual wealth can be utilized to diagnose the health of existing virtual worlds.

5.1 Classification of virtual wealth

Based on the open virtual world organization and the roles involved in it, virtual wealth can be classified into three levels: entity virtual wealth, world virtual wealth and global virtual wealth.

Entity virtual wealth is the wealth that a *virtual entity* (often defined in the form of an avatar registered as a virtually legal person) has obtained. This entity could be any circle in the multi-circled networked organization, shown in Fig. 1. It is analogous to a legal person in real-world. The sources of entity virtual wealth can be: (1) earnings from real world, (2) earnings from real-to-virtual money exchanges, (3) earnings from between-world trade and investment, and (4) earnings from in-world business activities. *World virtual wealth* is the aggregation of all entities' virtual wealth of a world. The scope of the world here is defined by the outer-most circle, including all of its inside circles, in the multi-circled networked organization, shown in Fig. 1. It is analogous to a real-world country. *Global virtual wealth* is the aggregation of all worlds' virtual wealth, that is, the total virtual wealth of an open virtual world, given by all circles in Fig. 1. Particularly, virtual world activities can be categorized in Table 3 in three aspects of activities of real-world, cross-world and in-world based on the roles of virtual worlds, which belong to different entity types.

By categorizing virtual activities for virtual entity types, we can clearly measure their revenues and expenditures and thus to measure their virtual business performance. If virtual consumers have more consumption, they have

Table 3 Categorization of virtual world activities

World activity category	Key world activity	Virtual entity type	Role type
Real world investments	Real world investment and related matters	Virtual government	Systems owner
Real world production	Real world R&D and related matters	Virtual government	Systems creator
Cross-world services	Virtual world operation and services	Virtual government	Systems operator
			Systems owner
Cross-world services	Provision of virtual world applications, solutions and services	Virtual enterprise	Application provider
In-world services	Provision of virtual world applications, solutions and services	Virtual enterprise	Application provider
In-world production	Virtual goods production	Virtual enterprise	Virtual producer
			Virtual onlooker
Cross-world trade	Imports and exports virtual services and goods	Virtual enterprise	Virtual trader
In-world trade	Re-selling within a virtual world	Virtual enterprise	Virtual trader
Cross-world investment	Make investments across virtual worlds	Virtual enterprise	Virtual financier
In-world investment	Make investments within a virtual world	Virtual enterprise	Virtual financier
In-world consumption	Consume virtual goods and services	Virtual consumer	Virtual consumer
			Virtual onlooker

more fun. If virtual enterprises have more net income, they are more profitable. If a virtual government has more revenues, it is a potentially promising virtual world. If a virtual government has more net cash inflow, it presents less risk to virtual world participants. These indicators are important. In the rest of the article, we will build a measuring scheme, called *Gross Virtual Product* (*GVP*), to measure the total virtual wealth of a virtual world based on a combined expenditure and income approach, explaining all spending on total virtual world goods.

5.2 Measuring gross virtual product

GVP can be defined as the increased or decreased amount of total virtual world goods of a period, calculated by total quantity multiplies goods price level. Its needed virtual money amount of the year is called *virtual money supply* (*V*) of the year, such that:

$$GVP = \text{Quantity} \times \text{Price} = \text{V increased of the year} = VW. \quad (1)$$

Formula (1) reflects the total amount of virtual money V created in a year and equivalent to the amount of virtual wealth *VW*.

Since virtual wealth relates to both virtual world and real world, it involves both real money and virtual money. To unify the measure, we adopt a series of real-to-virtual and virtual-to-virtual exchanges rates to convert virtual wealth value. Our practice is to use a dual currency system for *GVP* measuring: when we measure *GVP* in virtual sense, we use virtual money (*V*); when we measure *GVP* in real sense, we use real money (*R*).

Given these definitions and based on the virtual activities that are involved in a year, we define Gross Virtual Product (*GVP*) as follows:

$$GVP = V = V_1 + V_2 + V_3 = GVP_1 + GVP_2 + GVP_3 \quad (2)$$

where V is the total spending of investment, consumption, production, services and trade, in which V_1 of GVP_1 is the in-world spending amount within a virtual world, V_2 of GVP_2 is the cross-world spending amount between virtual worlds, and V_3 of GVP_3 is the real-world earning amount between virtual worlds and real world.

5.3 Measuring changes of in-world virtual activities

In a *closed virtual world* where virtual entities only interact within a virtual world (called in-world), the virtual wealth increases as GVP_1 increases. It is measured by the in-world consumption (*IC*), in-world production (*IP*), in-world trade (*IT*), in-world investments (*II*), in-world services (*IS*), and the in-in-world virtual government spending (*IG*), such that:

$$GVP_1 = IX + IP + IS + IT + II + IG \quad (3)$$

where:

- *IX* is the net in-world consumption deducting fees paid to virtual government K_{ix};
- *IP* is the net in-world production deducting fees paid to virtual government K_{ip};
- *IT* is the net in-world trade deducting fees paid to virtual government K_{it};
- *IS* is the net in-world service deducting fees paid to virtual government K_{is};
- *II* is the net in-world investment deducting fees paid to virtual government K_{ii};
- *IG* is the net in-world government spending deducting revenues ($K_{ix} + K_{ip} + K_{it} + K_{is} + K_{ii}$).

The deduction of *K* (e.g., VAT to virtual government) is to avoid double accounting of the world expenditures. Formula (3) indicates an in-world's economic scale of a year, which is the total in-world virtual wealth produced in the year.

Analysis of in-world production. To analyze the in-world production, we can divide *IP* into production levels of IP_1, IP_2, …, IP_{n-1}, IP_n such that there is a supply chain IP_n is sold to IP_{n-1}, IP_{n-1} to IP_{n-2}, …, IP_2 to IP_1 and each selling has gained added value. So, IP_1 is the virtual finished products and IP_n is the virtual materials and resources. As we know, the virtual resources (e.g. land) and virtual materials (e.g. textures) are provided by virtual government (often sold directly in real money, for example, the case of Second Life). Thus, by virtual production, virtual government gain more real money amount by selling resources.

Analysis of in-world consumption, service, trade and investment. Activities of increasing the net consumption, services, trade and investments do not increase the volume of total goods of a virtual world. Yet, they increase the demand of virtual money by virtual consumers and virtual enterprises and ask to increase virtual money supply to match the GVP_1 scale of in-world. The benefit will not reflect in real money increase for virtual government but require it to add virtual money supply. GVP_1 is a most important index of in-world business activities. It reflects the vigor of an in-world.

5.4 Measuring changes of cross-world virtual activities

In an open virtual world that virtual entities have virtual business interactions with other virtual worlds, the virtual wealth of a period for cross-world activities is measured as follows:

$$GVP_2 = CX + CS + CT + CI + CG \quad (4)$$

where:

- CX is the cross-world net consumption deducting fees paid to virtual government K_{cx};
- CS is the cross-world net outgoing services deducting fees paid to virtual government K_{cs};
- CT is the cross-world net export deducting fees paid to virtual government K_{ct};
- CI is the cross-world net incoming investment deducting fees paid to virtual government;
- CG is the net cross-world government spending deducting revenues ($K_{cx} + K_{cs} + K_{ct} + K_{ci}$).

In Formula (4), the net outgoing services CS reflect that difference between the sold services to other virtual worlds and the bought services to the virtual world. If the sold service amount is larger than the bought services, the virtual world has a service provision surplus. The same applies to trade and investments. The positive net amounts reflect a favorable situation.

It is intricate when the virtual-to-virtual virtual business of CX, CS, CT and CI adopts other virtual currencies as payment and settlement means. If the net increase adopts other currencies, it will reduce the demand of the local virtual currency supply, and thus reduce the selling of local virtual currencies in real-to-virtual world market. The local virtual world obtains foreign virtual currency reserves. Contrarily, it gains more local currency sales for GVP_3 and asks for more local virtual currency supply. GVP_2 is a most important index of cross-world business activities. It reflects the expansion ability of a virtual world and shows whether a virtual world can become a dominant virtual world among others.

5.5 Measuring changes of real-world virtual activities

In an open virtual world, a virtual world does not only in-world and cross-world business but also real-world business related to the virtual world. This reflects in the changes of GVP_3, which can be defined in Formula (5).

$$GVP_3 = RX + RS + RT + RI - -RG \tag{5}$$

where:

- RX is the net real-world consumption of virtual world goods, which deducts fees paid to the real-world government K_{rx}.
- RS is the net real-world services serving virtual worlds, which deducts fees paid to the real-world government K_{rs}.
- RT is the net real-world trade between real and virtual world, which deducts fees paid to the real-world government K_{rt};
- RI is the net real-world investment in all real and virtual worlds, which deducts fees paid to the real-world government K_{ri}.
- RG is the net real-world business revenues from real world.

In Formula (5) of GVP_3, a large amount of real-world consumption by virtual consumers is the purchase of virtual money, virtual materials and resources using real money. Real-world consumption is a key financial source of virtual government. Also, the important service sales by both virtual governments are virtual world solution packages and APIs deliveries. GVP3 is a most important measure for virtual government. It is also an important measure of the added values that virtual world industry makes contribution to the real world gross domestic product (GDP).

5.6 Measuring changes of a whole virtual world

It is important to understand in which condition a virtual world can be alive. Combining GVP_1, GVP_2 and GVP_3 together, the total GVP can be re-written as follows to diagnose the health of a virtual world:

$$GVP = X + P + S + T + I + G \tag{6}$$

where $X = (IX + CX + RX)$ is the total virtual consumption, $P = IP$ is the total virtual production, $S = (IS + CS + RS)$ is the total virtual service, $T = (IT + CT + RT)$ is the total virtual trade, $I = (II + CI + RI)$ is the total virtual investment, and $G = (IG + CG + RG)$ is the total virtual government spending. Between these indices, relationships can be diagrammed in Fig. 2.

Figure 2 illustrates the cash inflow that virtual government can possibly obtain from the real world (e.g., others' investments and loans from banks), subscription fees, advertising fees, virtual services fees, and sales virtual money from in-world and other third-party worlds. Accordingly, virtual government has cash outflow, for example, various expenses

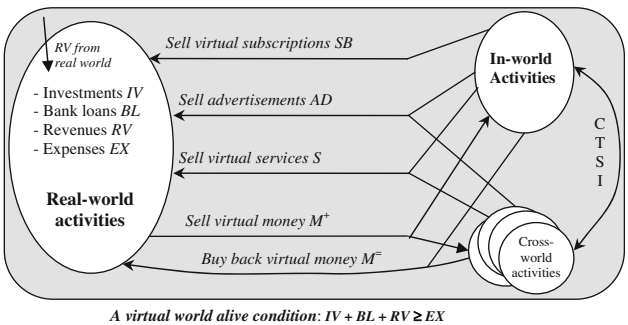

Fig. 2 Financial relationships between real-world, in-world and cross-world activities

and the buy-back of virtual money. It is obvious that if the total of these cash inflow is less than the total cash outflow (i.e., $IV + BL + RV < EX$), the virtual world government (i.e., the owner) can be in danger of financial situation according to Theorem 2. Here, an important factor is the buy-back virtual money that is converted back by virtual consumers and enterprises for real money. This virtual-to-real money exchange implies a lemma such that virtual government must keep enough real money reserve.

Lemma 2 (*Real money reserve*): *Real-world money reserve of virtual government shall always be larger than the estimated amount of real money for conversion back from virtual money.*

This lemma is important. In a fixed exchange rate system that is used to peg the virtual currency to a certain real currency (e.g. Linden dollar), if the reserve amount is less than the actual conversion amount, the virtual money will be depreciated and the virtual world goods will be inflated. This will greatly strike the confidence of virtual enterprises and virtual consumers and make them to quickly leave the virtual world.

GVP is an indicator of a whole virtual world. It reflects the scale of a virtual world.

6 Accountability of virtual world

An open virtual world can protect the virtual wealth of virtual world inhabitants by allowing virtual money movement through a virtual money exchange system [5]. However, how shall a virtual inhabitant know that its situated virtual world is worsening in business performance? Apparently, we need some measures that can evaluate a virtual world. In most commercial and legal governance, the ability to hold individuals or organizations accountable for actions is important for such measure [8]. *Accountable* is often defined as responsible for giving an account as of one's acts (i.e. answerable) or, alternative, capable of being accounted for (i.e. explainable) [1]. To maintain a sustainable virtual community where virtual wealth can be formed, measured and realized, this article views the accountability of virtual wealth as an explicit match of an accountability matrix performed by a virtual government.

Particularly in this article, our goal is to provide a set of answerable and explainable indicators that can assess whether a virtual world is sustainable for its virtual wealth to be realizable. To achieve this goal, we build an accountability matrix in Table 4, which measures whether a virtual world is sustainable in four aspects of finance, growth, participation and wealth security.

In Table 4, the *profit rate* is a key account for a virtual world, measuring whether the virtual world is financially well-performed as a sustainable virtual world. The *growth rate* measures whether a virtual world has sustainable growth. Specifically, detailed check is required on its balanced growth between each sector such as the total spending of virtual government, virtual enterprises and virtual consumers. The *user rate* accounts for a virtual world in the aspect of the sustainable user (U) participation. The *happiness rate* checks whether a virtual world provides wealth security to its users against the wealth gain (VW_G) or wealth loss (VW_L) of the existing virtual wealth (VW) caused by virtual world system failure, avatar fraud, virtual money inflation/deflation, virtual money exchange rate changes, etc.

7 Second life example

In this section, we make a case analysis on (1) investigating whether the open virtual world representation method applies to Second Life virtual world, and (2) examining whether Second Life virtual world is sustainable according to the accountability matrix.

7.1 Representation of second life

Second Life (secondlife.com) is an open 3D virtual world inhabited by its Residents (i.e. virtual inhabitants) for entertainment, experiences, and opportunity. Second Life world, in general, can be represented as a virtual world in an open virtual world, discussed in Sects. 3 and 4. It can be illustrated in Fig. 3.

Second Life, shown in Fig. 3, has the following features:

- *Organization*. Applying the multi-circled networked organizational method, described in Fig. 1, the Linden Research, Inc. can be regarded as an outer-most circle (a virtual government of Second Life virtual world) of an open virtual world. It includes a system creator and operator (LindenLab.com), an application provider and systems operator (SecondLifeGrid.net), an in-world for virtual enterprises and virtual consumers (SecondLife.com), a cross-world as a virtual marketplace (XStreetSL.com), and a virtual money exchange service provider LindeX (secondlife.com/currency). It allows virtual consumers and virtual enterprises to connect to the real world and other virtual worlds through the use of Linden dollars.
- *Pegged exchange rate*. Second Life issues its own virtual money, called Linden Dollar or L$. It adopts a pegged exchange rate with United States dollar with an exchange rate ranging around L$254–266/US$. It maintains the pegged rate using a sink mechanism such that Linden dollars paid to Linden Lab from

Table 4 Accountability matrix for virtual wealth

Indicator	Account	Measure
Sustainable finance	Profit rate (PR)	$PR = \frac{REV-EXP}{EXP} \times 100\%$ (7)
Sustainable growth	Growth rate (GR)	$GR = \frac{GVP_2-GVP_1}{GVP_1} \times 100\%$ (8)
Sustainable participation	User rate (UR)	$UR = \frac{U_2-U_1}{U_1} \times 100\%$ (9)
Wealth security [12]	Happiness rate (HR)	$HR = \frac{VW_G \mid VW_L}{VW} \times 100\%$ (10)

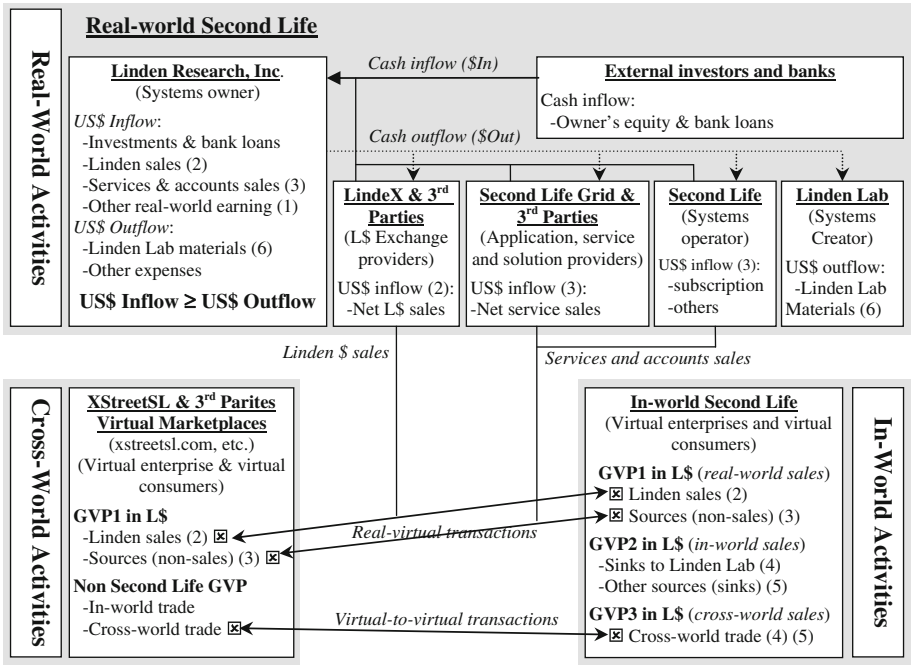

Fig. 3 Second life virtual world as of the 2008 Year End

Residents do not generate Linden dollar supply and are simply removed circulation. Thus, the circulated Linden dollars reflect the sales of Linden dollars and in-world resources (e.g. land) in actual US$ revenues of Linden Research. In another word, the exchange rate is based on the US$ earnings. In this sense, we can regard the paid US dollars as a type of deposit to Linden Research, from which the Residents obtain receipts of Linden dollar amounts equivalent to US$ amount in the pegged exchange rate.

- *GVP representation*. Linden Research contributes to GVP_3 as the part of real-world *GVP*. It consists of net earnings from real world and net earnings from Second Life and Linden dollar sales. With L$, the Residents can play various types of roles to consume, produce, trade and invest in Linden dollars. When the activities happen within SecondLife.com and the transactions are settled in Linden dollars, they are the in-world activities virtual goods. The value added here is the in-world part of GVP_1. When the Residents of Second Life make transactions with other virtual worlds, they add values of cross-world activities, which can be denoted by the cross-world part of GVP_2. In general, GVP_1 and GVP_2 cannot be accurately measured if Second Life operator provides no such statistics. However, the sinks of Linden dollars to Linden Lab can be seen as a type of money supply of a period, which offset the GVP_1 and GVP_2.

Second Life world can regarded as an instance of implementing a particular outer-most circle of an open virtual world. Its study helps improve the measures of virtual wealth.

7.2 Accountability of second life

Checking Second Life virtual world using the accountability matrix listed in Table 4, we found that Second Life is a part of open virtual world and it was generally healthy in virtual wealth changes based on our data analysis, as shown in Fig. 4. Its GVP can be calculated based on the formula (11) as follows:

$$\begin{aligned}\text{GVP} =& \text{Earning from real - world}(1) + \text{Linden Sales}(2)\\ &+ \text{Non - Linden sales of sources}(3)\\ &+ \text{Sinks to Linden Lab}(4)\\ &+ \text{Sinks of others sources}(5)\\ &- \text{Linden Lab materials}(6) \qquad (11)\end{aligned}$$

where item (2), (3), (4) and (5) are available by analyzing L$ supply data from the Linden Lab publicly published in real-time [11]. The item (2) and (3) could reflect GVP_3 while item (4) and (5) reflects GVP_1 and GVP_2. The changes of data from 2005 to 2008 for (2) + (3) + (4) + (5) can be shown in Fig. 4.

It is difficult to find the item (1) of accurate earnings and the item (6) materials (i.e., equipment etc. for systems) (6) in Second Life. Thus, Fig. 4 can only be a rough reference for GVP_3 of Linden Research. Thus, it is also difficult to forecast net US$ cash inflow. If the net US$ inflow has a problem, the US$ reserve for converting L$ back may encounter a problem.

In Formula (11), the "sinks" refers to L$ paid to Linden Lab by Residents for those such as classified ads, which can be regarded as a part of added values from GVP_1 and GVP_2. The non-Linden sales are US$ payment by Residents for those such as subscriptions and land (GVP_3).

The *user rate of Second Life* is much positive in terms of the data of Total Hours Used by all Residents compiled by the data of different years from Linden Lab [11], which represents the sustainable user participation (Fig. 5).

The *happiness rate of Second Life* can be computed based on the Formula (11) as follows:

$$\begin{aligned}\text{HR} = &\ \% \text{ of wealth change due to loss or gain from}\\ &\text{exchange rate (WLGE)} + \% \text{ of total user hours lost}\\ &\text{due to downtime (WLT) according to Linden Lab data}\\ &\qquad (12)\end{aligned}$$

Based on the data presented Second Life, Fig. 6 shows the growing changes of the happiness rate computed from

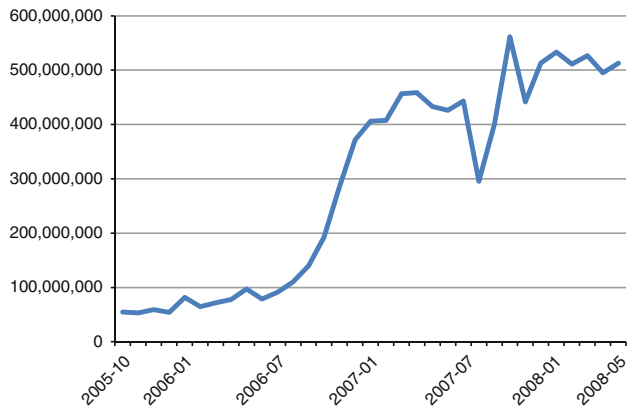

Fig. 4 Linden lab cash inflow (L$) (monthly)

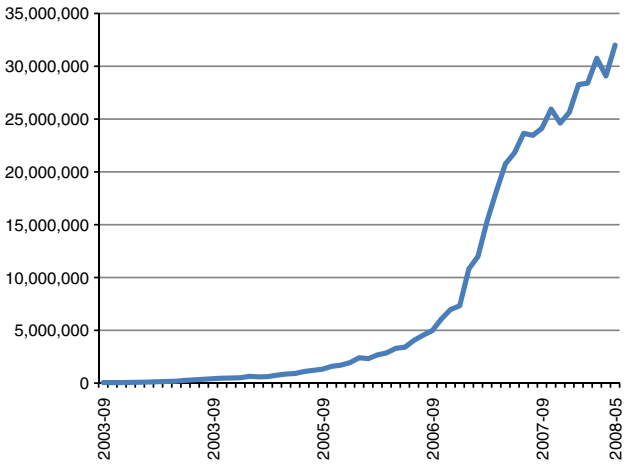

Fig. 5 Total hours used by all residents

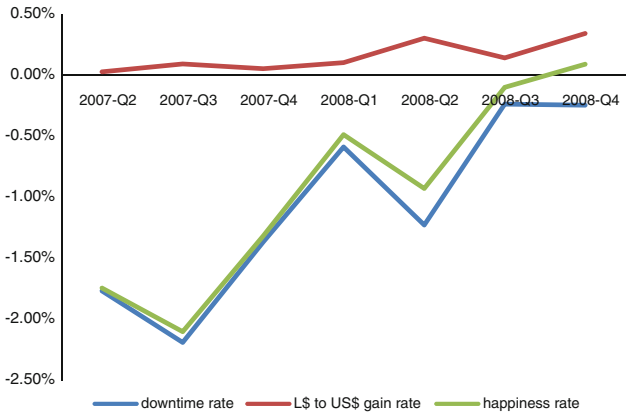

Fig. 6 Happiness rate

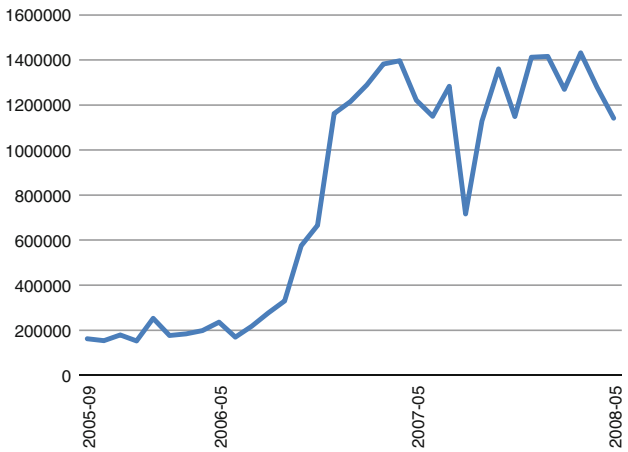

Fig. 7 Linden lab real revenue in US$ (monthly)

the loss of downtime and the gain of Linden dollar exchange rate. By this measure, we can check the wealth security in Second Life world.

For the profit rate of Linden Lab, the revenue can be roughly computed from Linden Sales and Non-sales

sources, shown in Fig. 7. While non-sales sources and L$ sales can be a guess of real-world sales of services and subscriptions for US$, the difficulty is obtain the expenditure data from Linden Lab. This affects the evaluation of Second Life on its operation.

Second Life, in general, is healthy, but to strengthen the users' confidence, its financial data must be available to public for users' assessment.

8 Conclusion

Virtual wealth measurement is extremely important in virtual world business. It helps identify the health of a virtual world, thus allow virtual world participants to make correct decisions for averting the possible risks of virtual wealth. This article conducted an investigation on this issue and suggested that the better measurement of virtual wealth only exists in an open virtual world that has a fair market value of virtual wealth. It proved that if there is a free choice of virtual currencies for denominating virtual goods between virtual worlds then we can always have an open virtual world. The open virtual world is a multi-circled networked organization in which virtual world roles are orderly organized for distinct activities of real-world, in-world and cross-world. In this organization of virtual worlds, we can devise a novel virtual wealth measuring scheme to measure total virtual wealth as gross virtual product (*GVP*). *GVP* can be further divided into three parts of in-world GVP_1, cross-world GVP_2 and real-world GVP_3 for virtual world roles of virtual government, virtual enterprises and virtual consumers. *GVP* reflects the virtual wealth changes of a virtual world in an open virtual world and is accountable for analyzing and explaining the virtual world on its health. Particularly, these changes can be measured through a newly proposed accountability matrix. To demonstrate the suitability of the accountability matrix and the measures of *GVP*, we conducted a case study of SecondLife.com virtual world. The result showed that Second Life is a virtual world fit in the multi-circled networked organization of open virtual world. The business performance analysis based on accountability matrix showed that Second Life virtual world is generally healthy with steady growth in *GVP*, user participation and happiness.

In summary, this article has provided a new understanding of virtual world and its virtual wealth measuring. It opens a door in which readers can see how virtual wealth can be correctly measured to diagnose the health of a virtual world in an open virtual world. Particularly, the article has made contributions as follows:

- It has proved there is an open virtual world where virtual wealth can be correctly measured;
- It has abstracted a novel circled networked organizational method for organizing open virtual world in an open context;
- It has devised a feasible gross virtual product (*GVP*) measuring scheme to measure the changes of virtual wealth in an open virtual world;
- It has proposed an accountability matrix for measuring the health of a changing virtual world;
- It has conducted a case study on SecondLife.com virtual world to demonstrate the appropriateness of the *GVP* measuring scheme and the accountability matrix.

This article has several implications: First, it is necessary for existing virtual worlds to be connected with each other as an open virtual world through virtual-to-virtual or virtual-to-real money exchange systems. This will provide a suitable mechanism for measuring and protecting virtual wealth. Second, any virtual world is owned by a real-world business owner. The net cash inflow is essential to maintain a secured virtual world and is a key index to the health of the virtual world. Third, technology study on virtual world should more focus on how to construct an open virtual world where virtual money, virtual goods, virtual services and virtual investments can be easier to move between virtual worlds.

Virtual wealth measurement is a new topic of virtual world. More research is still needed to optimize and enhance the measuring schemes.

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